



# IEA Wind Technology Collaboration Programme

2018  
Annual Report

# MESSAGE FROM THE CHAIR

Wind power's installed capacity grew by 9% in 2018, while maintaining the trend toward lower cost of energy both onshore and offshore. With almost 600 GW of installed capacity worldwide, wind power continues to be the largest non-hydropower source of renewable energy. Corporate funding for wind energy through PPAs has seen a clear increase, with more subsidy-free projects in the pipeline. A growing number of wind farms provide grid services, contributing to a stable and resilient electricity grid.

Although new plans and targets for wind energy have been announced by many (mainly European) countries, the speed of deployment slowed in 2018 due to changes in support mechanisms in different countries. Long-term stability and predictability of market rules and grid access continue to be crucial to enabling large-scale deployment of wind energy.

Upscaling wind turbines continues as a key trend to reduce offshore costs, with units larger than 8 MW installed in 2018—and we are not yet close to the limit. Larger rotors and taller towers are driving land-based wind power costs down and enabling deployment in areas with lower available resources. IEA Wind research activities have reduced uncertainty in the design of large offshore wind turbines and more effective blades needed to operate in a broader range of conditions.

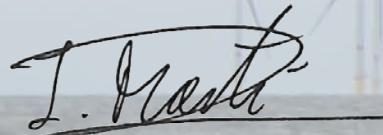
From a grid perspective, new International Energy Agency Wind Technology Collaboration Programme (IEA Wind TCP) research activities are focusing on a 100% renewables-based grid where wind energy will have a fundamental role. The environmental and social research conducted under IEA Wind contributes to the removal of barriers that can affect large scale deployment.

After more than 40 years, the collaborative model of the IEA Wind TCP is still successful and growing. New Research Tasks focus on challenges like digitalization or life extension, adding to the extensive list of topics that IEA Wind is addressing.

To increase the relevance and impact of our Annual Report and to get an industry perspective on the value of IEA Wind TCP activities, we have taken the initiative to invite industry stakeholders globally to provide a foreword; this year WindEurope has been invited to provide it.

It has been an honor and a pleasure to serve as IEA Wind Chair during the last three years and to be part of this unique international Technology Collaboration Program. IEA Wind TCP is based on a collaborative approach, not only in research but also in management. A long list of Operating Agents, Executive Committee (ExCo) members, Vice Chairs and Chairs have worked to ensure a constant evolution of IEA Wind. Their efforts have nurtured the spirit of knowledge-sharing while maintaining an effective and lean management structure. Now it is time for the next Chair, John McCann, to take the lead and bring IEA Wind to the next level.

*In memoriam of Giacomo Arsuffi and Cheolwan Kim, whose commitment, positivity, enthusiasm, and teamwork will be a source of inspiration for years to come.*



Ignacio Martí  
Chair of the Executive Committee, 2016-2018





# IEA Wind TCP

## 2018 Annual Report

December 2019



## FOREWORD

Dear reader,

We are at a pivotal point in the history of the planet. Never before has the demand for climate action been more urgent. Never before has there been such a groundswell of global support for the decarbonization of the world's economy.

Achieving the ambitions of the Paris Agreement requires nothing less than a transformation of the global energy system. Wind energy is uniquely positioned to play a large role in making this happen. Thanks to R&D, wind energy will continue to be the cheapest source of new power generation in many parts of the world.

But the demands on R&D reach far beyond cost. We must decarbonize our economies by integrating heating and transport into a renewable electricity sector. The global share of wind energy will continue to grow massively, raising the question of how to integrate large amounts of renewables into the energy system. Today's R&D efforts will help define the role of technologies like demand response and energy storage to meet these challenges.

The wind energy supply chain must become more circular, too. New materials and turbine concepts will play a key role in the recycling of rotor blades and other components. Meanwhile, radical new technologies, like floating offshore wind, have moved beyond the lab and are ready to unlock expansive new wind resources.

Research is not just a technological affair. Transparent and transversal engagement with the broader public is essential to a successful energy transition. Research into social acceptance will ensure that we know how to best get everyone on board with this mission. Continued research into the environmental benefits and impacts of wind energy bolsters these efforts.

Policy is crucial to enabling science and research in all the above areas. Governments must continue their support of research and innovation in wind energy. Only government-led initiatives can sustain the incremental innovation and long-term research required to transition the global energy system. We owe a debt of gratitude to the IEA for its role in advising governments worldwide. The IEA TCPs work tirelessly to facilitate the international and industry-wide cooperative work that is crucial to mitigating climate change.

Working together, R&D and policy improve the performance and reduce the cost of utility-scale wind energy. They bring new concepts to market faster, enhance sustainability, and promote circularity within industries. They also accelerate renewables-based electrification in an inclusive and just way, involving communities and all sectors of the economy. You can explore all of these efforts in the following pages.

I wish you an enjoyable read.



A handwritten signature in blue ink that reads "Giles Dickson".

Giles Dickson  
CEO WindEurope

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# IEA WIND TCP

## 2018 OVERVIEW



### WIND ENERGY RESEARCH, DEVELOPMENT, & DEPLOYMENT SUCCESS

Wind energy saw steady growth in installed capacity in 2018, completing a fifth consecutive year with more than 50 GW of new installed capacity. Global wind power capacity is approaching 600 GW, with China surpassing 200 GW, Europe at 180 GW, and North America at 115 GW installed. Auction prices reported in 2018 continued to hit record low costs.

Subsidy-free projects were announced in several countries in 2018, confirming successes in cost reduction. Meanwhile, new targets beyond 2020 are being drafted in many countries, ensuring continued market growth in years to come.

Globally, 51 GW of wind power capacity was added in 2018, reaching a total of 591 GW (Table 1). This growth represents a 9% increase in worldwide installed capacity [1]. A record 4.6 GW of new offshore capacity was installed, increasing the cumulative capacity by 25% to 23.4 GW.

Wind power continues to be the largest non-hydropower source of renewable electricity by installed capacity, providing nearly 50% of all non-hydropower renewable energy sources [2]. The trend of moving from old subsidy schemes to auctions, which were in many cases electricity market-based and in some cases technology-neutral, continued in 2018.

A record number of countries reported a first tender for land-based wind power (China, Denmark, and Finland) in 2018 or published plans for tenders in 2019 (Ireland, Italy, and the United Kingdom). Auctions for both land-based and offshore capacity continued the cost reduction trend in 2018, with record low prices reported in Canada, Denmark, Finland, and México.

Corporate funding via PPAs (Power Purchase Agreements) continued increasing in Norway, Sweden, the Netherlands, the United Kingdom, and the United States. PPAs are also emerging outside of subsidy schemes: Spain saw the first "merchant based" wind power plant in operation in 2018, while subsidy-free wind energy PPA projects were reported in Denmark and Finland. This indicates that subsidy-free operation is becoming a reality. Norway and the United States are expected to move to full market operation for wind plants after their current subsidy schemes end in 2021. China is discussing moving to a wind power tariff, similar to the tariff for coal.

**Table 1. Wind Energy Key Statistics 2018**

	IEA Wind TCP Member Countries	Global Statistics
Total installed power capacity (land-based and offshore)	497.9 GW	591.5 GW
Total offshore wind power capacity	23.4 GW	23.7 GW
Total new wind power capacity installed	40.8 GW	51.3 GW
Total annual output from wind power	1,048.1 TWh	1,468.5 TWh
Wind-generated electricity as a percent of national electricity demand	6.4%	5.5%

*Global capacity [1]; share of electricity [2]*

Within the IEA Wind TCP member countries, 498 GW of operational wind power capacity generated 1,048 TWh of electricity in 2018, meeting 6.4% of the total electricity demand. Nearly 84% of the world's wind generating capacity—and all offshore capacity—resides in countries participating in the IEA Wind TCP. These countries added about 41 GW of capacity in 2018, accounting for 80% of worldwide market growth.

Members of the IEA Wind Technology Collaboration Programme (IEA Wind TCP) share information and engage in research activities (Tasks) to advance wind energy deployment.

This Executive Summary of the Annual Report 2018 presents highlights and trends from 22 countries and Europe. The annual report also presents the latest research results and plans for the 16 co-operative Tasks, which address specific issues related to wind energy development. Data reported in previous IEA Wind TCP documents (1995–2017) are included as background for the evolution of trends. The annual report is freely downloadable at [community.ieawind.org](http://community.ieawind.org).

## PROGRESS TOWARD POLICY TARGETS

IEA Wind TCP member countries reported a 79% fulfillment of their 2020 wind deployment targets. Most countries are setting new renewable energy and wind power goals to meet their energy and climate targets for 2030 and beyond.

Wind energy deployment is a key contributor to creating an energy mix capable of fulfilling climate targets, transforming the energy system, and reducing CO<sub>2</sub> emissions to limit the global temperature increase.

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 7. Many member countries are continuing their work to update the targets post-2020.

### Sustained Growth Amid Policy Transitions

New wind power capacity installed in 2018 represented almost 10% of the global cumulative installed wind capacity [1]. Although total capacity is increasing, the annual rate of growth is not increasing—the newly installed capacity in 2018 was at the same level as in 2017, and remained below the peak annual installation rate of 2015–16 (Figure 1).

China, the United States, and Germany continue to lead in cumulative wind power capacity. China installed more than 40% of the installed capacity of the global wind energy market in 2018, followed by the United States (15%) and Germany

(5.5%). The United Kingdom, India, Brazil, and France each installed more than 1 GW [1]. Norway and México increased their cumulative capacity by 20% or more in 2018.

### Increasing Momentum for Offshore Wind

Offshore wind power installations continued to increase in 2018. Globally, a record of 4.6 GW of new capacity was added, reaching a total of 23.4 GW of cumulative capacity (Figure 2). Offshore wind deployment rates increased by 20% in 2018 and now stand in excess of 20 GW. Upscaling wind turbines continues as a key trend to reduce offshore costs, with units larger than 8 MW installed in 2018.

New records were set in offshore power plant size (657 MW) and turbine size (8.8 MW). China became the leader of new installed offshore wind power in 2018. China, the United Kingdom, and Germany installed 88% of all new offshore capacity (1.7 GW, 1.2 GW, and 0.1 GW, respectively). New capacity was also built in Denmark and Belgium.



Figure 1. Net and cumulative wind power capacity and electricity production for member countries as a share of global capacity [2]

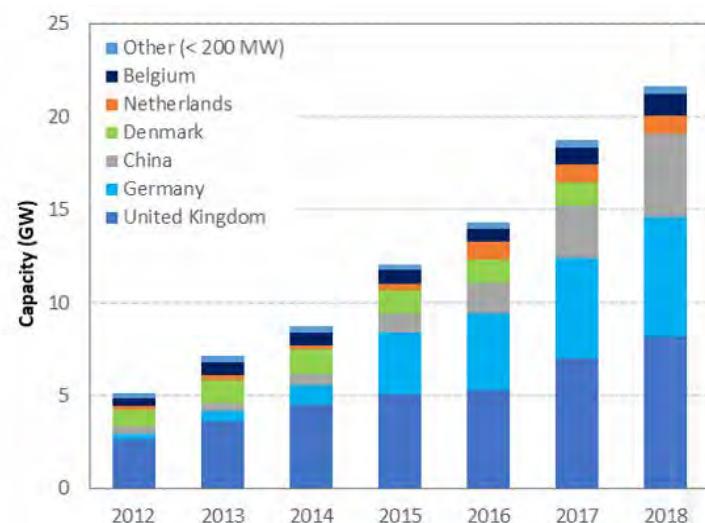


Figure 2. Cumulative Installed offshore wind power in member countries

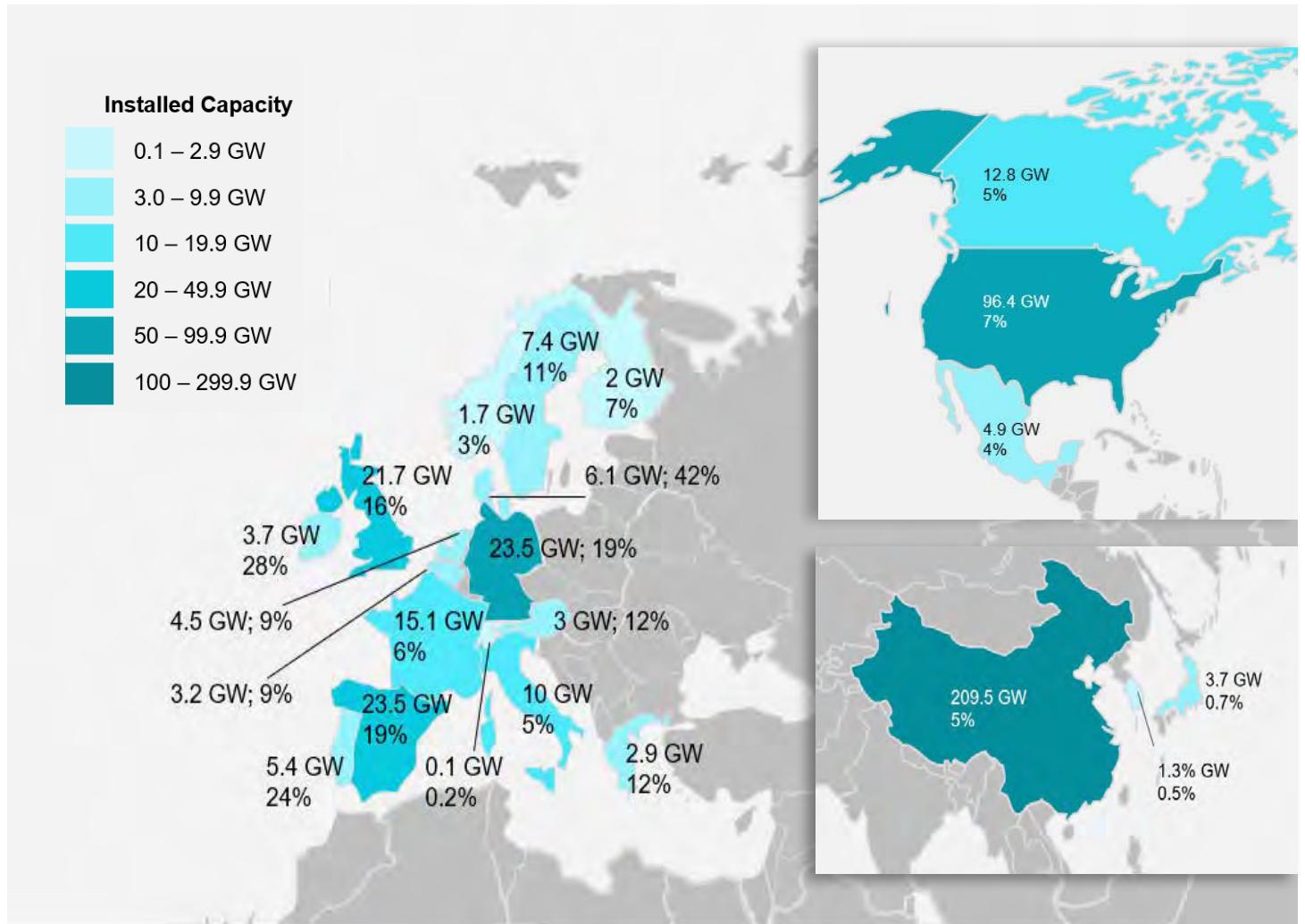


Figure 3. Total installed wind power capacity and wind generated electricity as a percent of national electric demand at the end of 2018

## Wind Continues to Grow in the Energy Mix

Wind power continues to steadily increase its share of the energy mix. In 2018, wind power produced an average of 6.4% of the electricity supply in member countries—up from 6.1% in 2017 (Figure 4). Wind-generated electricity met almost 5.6% of the world's demand in 2018 [2].

Key deployment milestones in 2018 were:

- Eight countries now meet more than 10% of electricity demand with wind power, including Denmark at 41%, Ireland at 28%, and Portugal at 24%.
- Annual offshore installations increased to 4.6 GW, representing 9% of the annual global market. Six countries have more than 1 GW of offshore wind power capacity.
- Ten countries have 10 GW or more of installed wind power capacity. Globally, 31 countries have more than 1 GW of grid-connected capacity, and 21 of these participate in the IEA Wind TCP [1].

Additionally, wind-generated electricity within participating countries surpassed 1,000 TWh in 2018 (up 11% from 2017). In 2018, China produced 366 TWh of wind-generated electricity, an increase of 20% over the previous year, with a decrease in curtailments. The United States generated 275 TWh. Germany generated more than 110 TWh, reaching a new record of wind power supplying about half of all renewable energy. In Spain, wind-based electricity generation approached 50 TWh and became the second largest source of electricity generation.

Denmark and Portugal have experienced periods with more than 100% of demand supplied from wind generated electricity. Ireland, a small system, has increased the instantaneous share of wind in the system operation to 65%, and Spain reached a 61% instantaneous wind-power share of total electricity demand.

## Opportunities for Repowering

An increasing proportion of installed capacity will reach its end of life between 2020 and 2030. Therefore, a regulatory framework to speed the permitting of repowering projects is needed in many countries. 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 old in 2030, according to IHS Markit. More than 30% of Denmark's installed capacity will be more than 20 years old in 2020, and both Italy and Portugal report repowering as a way to meet future targets for wind energy.

In 2018, Spain repowered a 23-year-old, 30-MW wind farm on the coast of Andalusia, replacing 90 330-kW Kenetech KVS33 turbines with eight 3-MW Nordex/Acciona N100/3000 turbines and four 1.5-MW Nordex/Acciona AW70/1500 turbines; this change will increase the farm's total energy production by 16%.

## 2020 Policy Targets & Beyond

Governments continue to establish targets for renewable energy sources and wind energy, and to design market mechanisms, enact energy policies, and fund research to reach these targets.

Some new policies have resulted in lower than expected new installation rates due to investment uncertainty and gaps in regulatory programs. This is occurring in many European countries, as reported by the European Commission. For example, changes in the German offshore auction system are expected to reduce that country's new offshore wind power installations in 2020.

Most member countries are progressing toward their 2020 wind deployment targets as expected—on average, they report a 79% fulfillment of those targets (Figure 5).

In Europe, most IEA Wind TCP member countries have drafted National Energy and Climate Plans (NECP) for the period from 2021 to 2030. These plans are required to meet the EU's new energy and climate targets for 2030, which include providing 32% of total energy consumption from renewable energy sources (RES). Denmark, France, Ireland, Italy, Portugal, and Spain announced new target policies in 2018, some of which are pending approval in 2019.

Targets for 100% RES electricity production are emerging in several countries and some states in the United States. Sweden set a 100% RES electricity target by 2040, followed by a 2045 target of zero net greenhouse gas emissions; thereafter, the country should achieve negative emissions. In 2018, the EU published a long-term vision of climate neutrality by 2050.

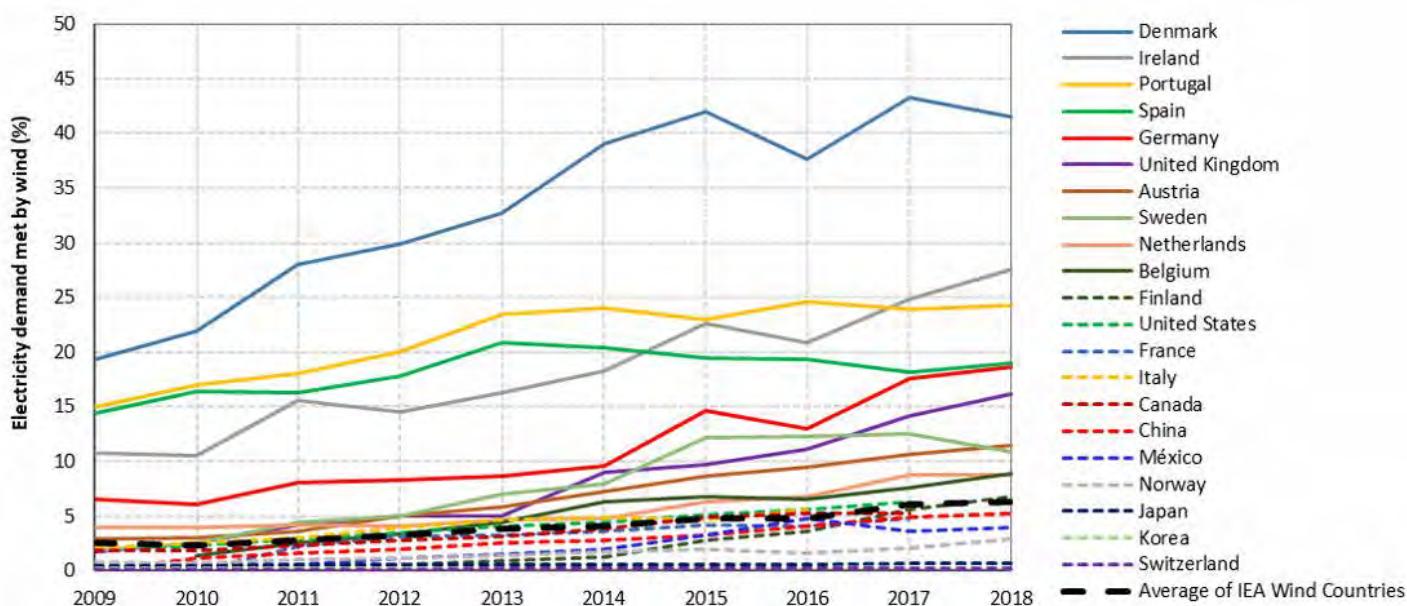


Figure 4. National electricity demand met by wind-generated electricity

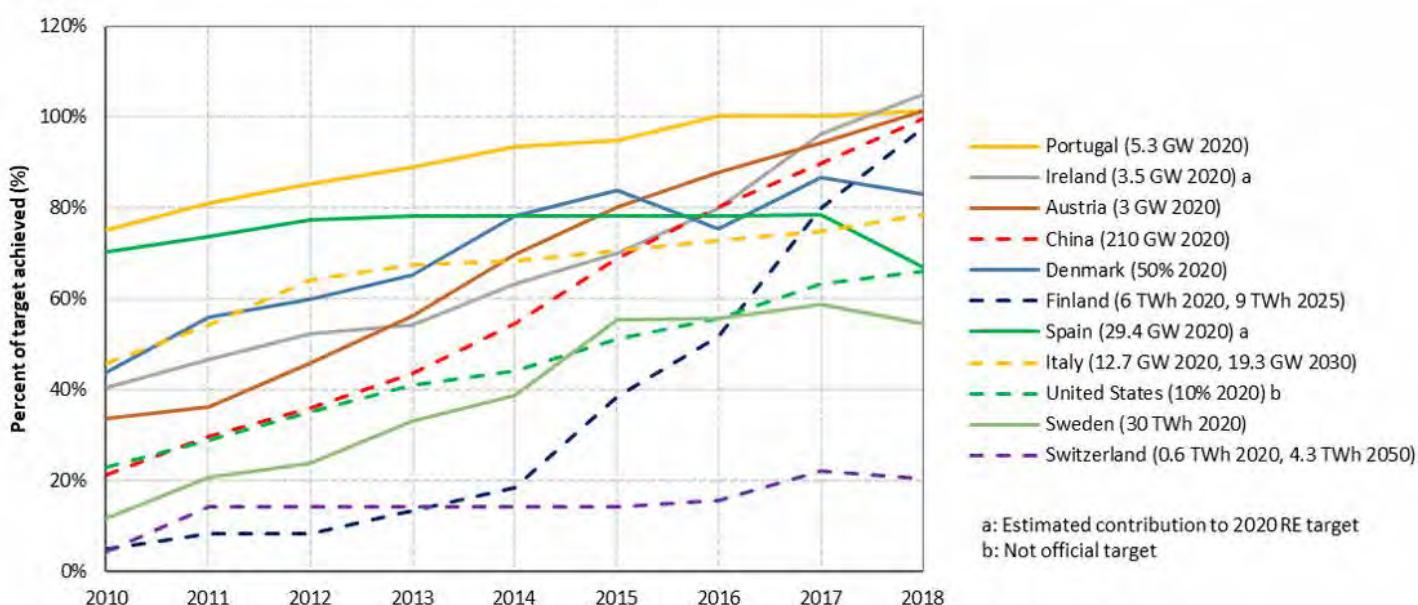


Figure 5. Progress in reaching 2020 wind energy targets and percent of target reached (expressed in GW, TWh, or share of electricity)

# PERFORMANCE GAINS FROM WIND TECHNOLOGY IMPROVEMENTS

The trend toward larger turbines continued in 2018, with the average installed capacity of new turbines in member countries reaching 2.9 MW, up from 2.7 MW in 2017. Capacity factors also increased in many countries and the cost of wind power has become even more competitive.

## Turbines Continue to Increase in Size

Over the last ten years, the rated capacity of new turbines in member countries has increased by an average of 4% annually (Figure 6). Table 2 shows the top ten wind power capacity rankings for net and cumulative capacity, as well as the percent increase for 2018 and capacity relative to country size.

The size of wind turbines, in particular, has grown rapidly in the past two years. In 2017, blade manufacturer LM-GE tested an 88.4-m blade. The next size milestone for offshore turbines is the 107-m blade, which is designed to fit the 12-MW, 220-m GE Haliade-X turbine. It is expected to become commercially available in 2021.

Floating offshore wind power farms continue to advance toward commercial maturity. Japan's Fukushima FORWARD

II-Hitachi project, which began operation in March 2017, features a 5-MW wind turbine built on an advanced spar-type floater. In 2018, a new floating offshore wind farm, Hywind, started operations off the coast of Scotland.

## Capacity Factors Continue to Increase

Technology advancements drives long-term improvement trends, but fluctuations result from annual wind resource variations, fleet age, curtailments, and the wind climate at new sites. The wind power index decreased from 2017 to 2018 in all reporting European countries due to below average wind resources and wind climate (Figure 7).

On average, land-based wind power capacity factors show a slowly increasing trend, whereas offshore wind power factors have been more stable (Figure 8).

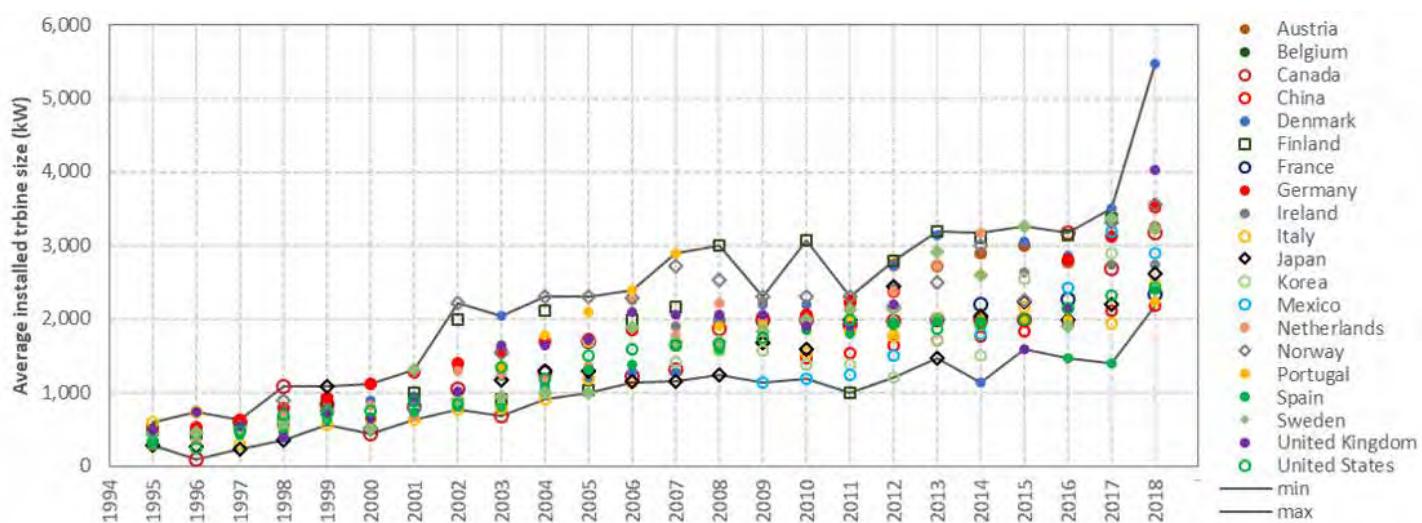


Figure 6. Average size of newly installed wind turbines (Note: excludes turbines under 25 kW)

Table 2. Top Ten Wind Power Capacity Rankings

	Cumulative Capacity (end of 2018)		Net Capacity Additions (2018)		Increase in Cumulative Capacity (2018)		Capacity Relative to Country Size	
	Country	GW	Country	GW	Country	%	Country	kW/km <sup>2</sup>
1	China	209.53	China	21.14	Norway	43%	Germany	165
2	United States	96.43	United States	7.46	México	23%	Denmark	141
3	Germany	58.98	Germany	3.07	Korea	14%	Belgium	105
4	Spain	23.48	United Kingdom	1.96	Belgium	13%	Netherlands	103
5	United Kingdom	21.74	France	1.51	Denmark	12%	United Kingdom	90
6	France	15.12	México	0.93	China	11%	Portugal	58
7	Canada	12.82	Sweden	0.70	France	11%	Ireland	51
8	Italy	9.96	Denmark	0.64	Sweden	11%	Spain	47
9	Sweden	7.41	Canada	0.57	United Kingdom	10%	Austria	37
10	Denmark	6.12	Norway	0.51	Greece	9%	Italy	33

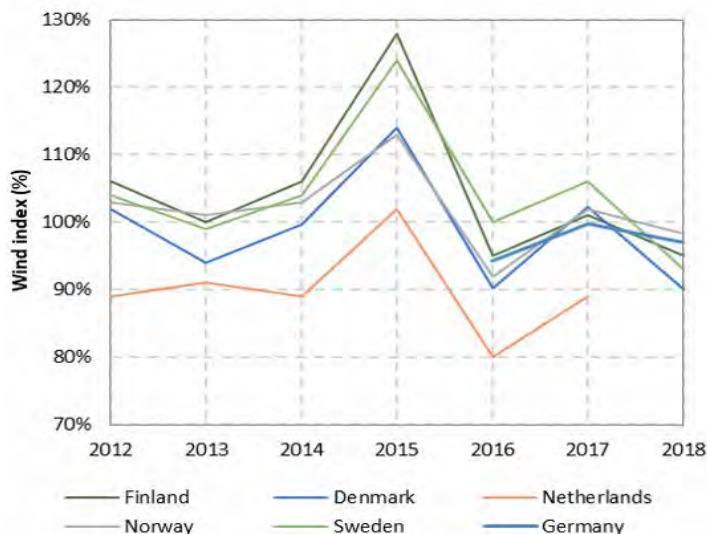


Figure 7. Wind resources reported as wind (production) index, which is a measure of how much the wind has blown more or less than expected over a given period

## Progress Toward Cost Reduction Targets

The wind power industry continues to become more competitive. Decreasing auction prices were 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 (16.3 USD/MWh) and Canada reported a price of 23 EUR/MWh (26 USD/MWh).

In Spain, bids were as low as 33 EUR/MWh (38 USD/MWh), the minimum allowed under the Spanish system. In 2018, land-based wind power auctions were performed in Canada, France, Germany, the Netherlands, Greece, Denmark, and Finland, and planned for 2019 in Ireland and Spain. The latest onshore wind power auctions in Germany and France were undersubscribed, while Danish, Finnish and Greek auctions recorded extremely low prices due to a healthy pipeline of permitted projects.

In Germany, the lowest onshore bid was 38 EUR/MWh (44 USD/MWh) and the weighted average of four land-based auction rounds in 2018 was 47.3 EUR/MWh (54.2 USD/MWh). In France, the average land-based auction winning price of

65 EUR/MWh (74 USD/MWh) represents a 21% price drop compared to previously awarded feed-in tariffs. The average cost of land-based projects in member countries was 1,293 EUR/kW (1,481 USD/kW) in 2018 (Figure 9).

In Germany and the Netherlands, offshore bids were awarded at zero premium (over and above the wholesale electricity price, excluding grid connection). In Germany, in addition to zero premium awards for the lowest bids, the weighted average of the offshore auction round in 2018 was 46.6 EUR/MWh (53.4 USD/MWh).

In the United Kingdom, a Contract for Differences (CfD) auction round had two offshore wind farms with record strike prices as low as 58 GBP/MWh (65 EUR/MWh, 74 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 (99 USD/MWh). In France, the Dunkirk tender resulted in a record-low price of 44 EUR/MWh (50 USD/MWh).

A growing share of new wind energy capacity is now being developed outside of support schemes. In Europe, the majority of signed corporate wind-PPA capacity is found in Norway, Sweden, the Netherlands, and the United Kingdom. The high-tech sector is the main buyer at this time. In total, 4.8 GW of wind-PPAs have been signed since 2000, with deals above 1 GW annually for the last three years. In the United States, a record volume of PPAs were signed in 2018, driven by brand-name corporations and non-utilities such as AT&T, Facebook, Royal Caribbean, T-Mobile, and Walmart. Investment in U.S. wind energy has totaled more than 142 billion USD since 2006, demonstrating wind energy's increasing role in the U.S. electricity generation portfolio [1].

IEA Wind TCP Task 26 focuses on analyzing the cost of wind energy; Task members developed a web-based data viewer for researchers to visualize and download data related to wind energy project statistics. Ongoing work efforts are expected to provide new insights into technology trends, innovation drivers, and characterization of the levelized revenue of energy for land-based and offshore wind energy projects among the participating countries.

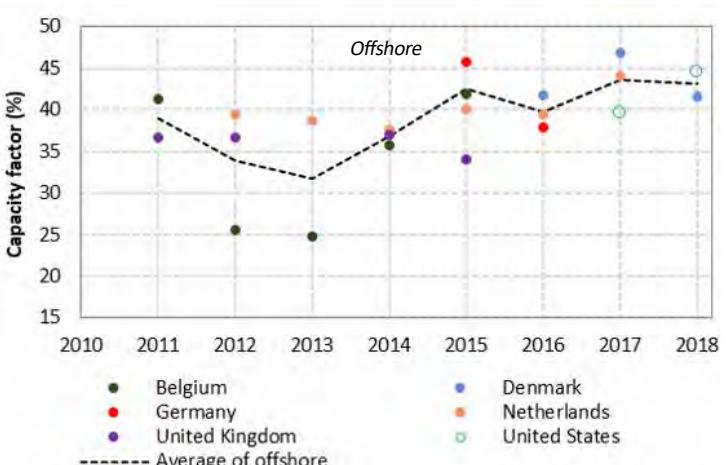
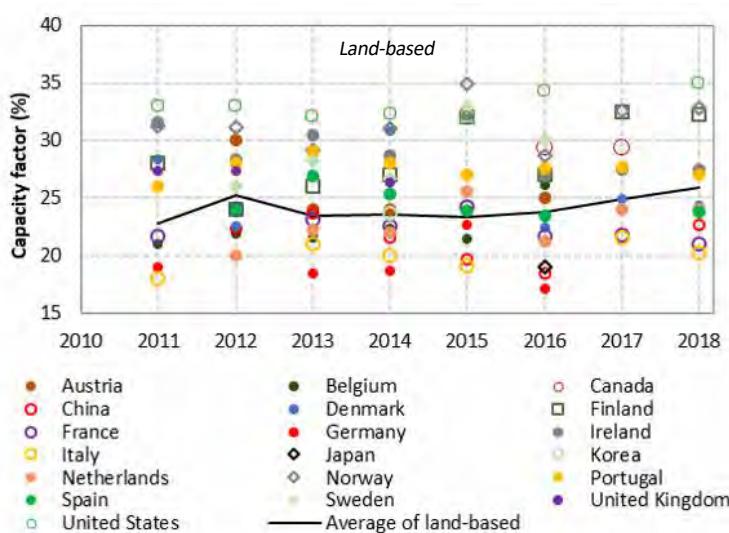


Figure 8. Reported capacity factors (average wind power output) by country for land-based and offshore wind power generation

# MITIGATING DEPLOYMENT CONSTRAINTS

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

## Becoming Competitive in Electricity Markets

Considerable reductions in levelized cost of energy (LCOE) have made wind power 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 low electricity market prices and low green certificate prices resulted in very low income for wind power producers. Lower prices have increased demands for financial support mechanisms. Incentivizing wind power investment has been a major instrument used to increase deployment.

One way to mitigate electricity market risks is to sell the energy directly through power purchase agreements (PPAs), ensuring a predictable income flow. Increasingly competitive renewable electricity prices are stimulating industrial consumers to procure their energy directly through renewable power producers, particularly with wind energy producers.

However, in 2018, some investors still considered wind energy to be risky. To address this, the National Renewable Energy Laboratory (NREL) led an effort called Performance, Risk, Uncertainty, and Finance (PRUF), which focused on the mitigation of risk related to investment and financing of wind energy projects. The intention is to expand the potential pool of industry investors and drive down the cost of capital for the wind power industry.

## Reducing Wind Power Curtailment

Research from IEA Wind TCP Task 25 on grid integration shows that high rates of curtailment are a signal of integration challenges. These limitations on transmitting wind-generated electricity can be related to operational practices caused by inflexible power-generation, with inflexible tariffs, or with a lack of transmission to transport all available wind energy to where electricity is consumed.

Integration and consumption are still significant problems limiting wind power development in China, where wind power curtailment continues to be the main restriction on wind power development. The Chinese government has issued a series of policies and regulations to reduce wind curtailment and promote the development of distributed wind power. In 2018, China reported 27.7 TWh of curtailed wind-generated electricity, with four provinces experiencing wind curtailment rates between 15% and 33% of production. The average wind curtailment rate was 7%, a decline of 5% compared to 2017.

However, system operators in several countries have achieved high instantaneous shares of wind without facing technical problems such as curtailment. For example, in Portugal, where wind contributed to 24% of electricity demand during 2018, the Portuguese TSO reported no occurrences of wind energy curtailment. In Germany and Ireland, some curtailment was reported, but it remained below 5% of their total wind-generated electricity for the year. In Denmark and Spain, wind power plants offer curtailment as down-regulation reserve in the electricity markets.

## Wind Power Providing System Support

IEA Wind TCP Task 25 reports ways to enable grid support from wind power plants. Examples reported are:

- In Quebec (Canada), wind power plants supported the power system when recovering from a frequency event.
- In Texas (U.S.), fast responses from wind power plants contributed to a decreasing trend in the need for fast frequency reserves. This is a very interesting trend and highlights the value of fast, accurate wind power plant responses to overall power system operation.
- Evidence from Canada, Denmark, Ireland, Spain, and the United States shows that wind power can participate in frequency support services.

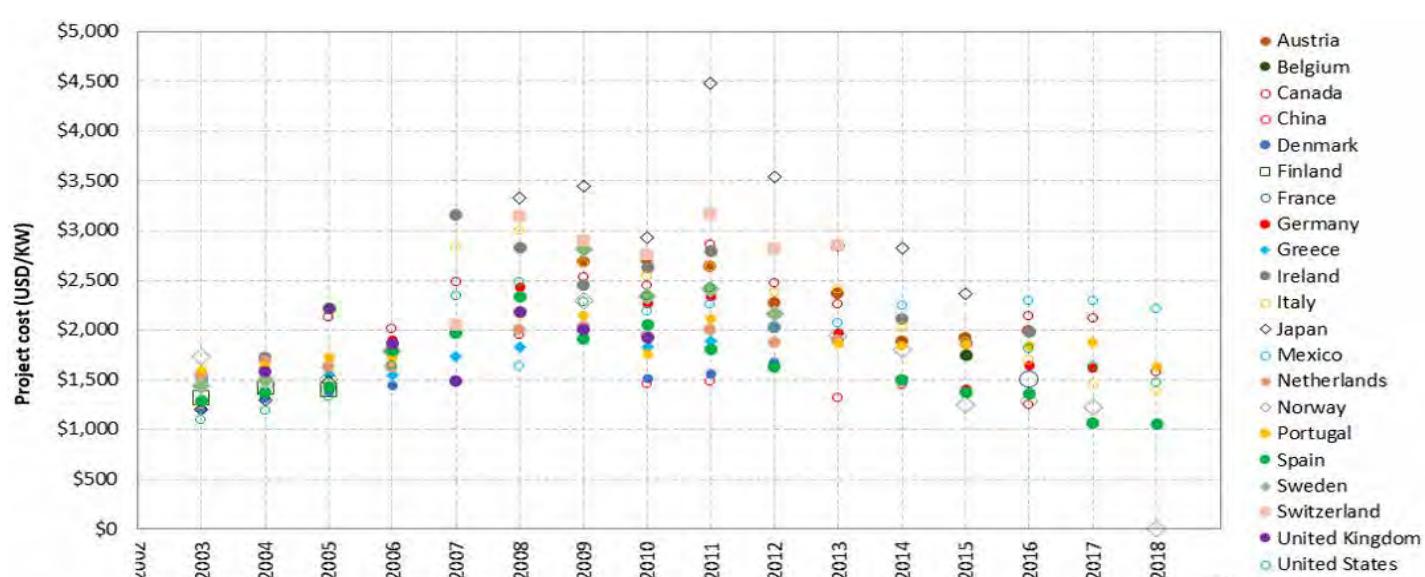


Figure 9. Land-based wind power project cost history from reporting IEA Wind TCP countries



Figure 10. The E2i Energie Speciali Monteferrante Wind Farm in Italy consisting of 41 600-kW turbines

## Seeking Ways to Improve Public Acceptance

IEA Wind TCP Task 28 focuses on social acceptance of wind energy. Because social acceptance continues to be a key constraint on the development of wind energy projects, increasing social acceptance will help member countries meet their renewable energy obligations.

Several factors relevant to wind power project acceptance include high-density populations (Italy, Korea, Netherlands), tourism and landscape impacts (Italy), and noise (Finland). Improving acceptance has become a high priority in countries such as Finland, Ireland, and Switzerland, each of which have dedicated funding toward the effort.

In Switzerland, the government has worked to support public acceptance of wind power by accelerating permitting procedures and funding research between wind power and other fields, such as ornithology or noise research. These efforts have led to stronger cooperation between federal offices and institutes.

Other methods of improving social acceptance reported by member countries include using early stakeholder engagement and incentivizing local communities, including community ownership or participation in wind power projects. Industry, government, and research institutions appear to be increasingly interested in these topics, particularly in terms of quantification and monitoring.

## Legal & Regulatory Matters

Wind energy deployment can be hindered by lengthy permitting procedures and appeal processes, often due to factors such as the interaction of wind projects with aviation, environmental constraints, and administrative procedures at the national and regional levels.

Regulations on setback distances, noise limits, or interference with civil aviation and military radars are tightening in several countries; however, many are also taking steps to simplify or streamline the permitting and approval processes.

In Belgium, the main issue affecting land-based wind energy growth is the number of judicial appeals filed in the Flemish and Wallonia state councils. Work to remove barriers to new

wind energy projects continues, including mitigating spatial planning limitations (i.e., military, aeronautical, or traffic-related restrictions). The federal administration has also created a “one-stop-shop” aimed at simplifying and speeding up licensing procedures.

France is seeing the results of several measures adopted in 2017 which aimed to reduce the regulatory timeframe for wind energy deployment. These efforts included developing a single environmental authorization process for the full territory, reducing deadlines for appeals within this single authorization process, and providing incentives for residents to acquire shareholdings in limited companies involved in local renewable energy projects.

In Japan, new rules allowing installation of power generation facilities in general common sea areas will become effective April 2019. This change is expected to contribute to the deployment of offshore wind farms. Total planned installations of offshore wind power generation were estimated to be about 5 GW as of 2018. This estimate is achieved by aggregating port and harbor area capacities (546 MW) and general common sea area capacities (4,817 MW), according to environmental impact assessment data.

## Transition Toward New Tender Mechanisms

Long-term visibility and stable regulatory frameworks will continue to be crucial for wind energy deployment in the near future. Several countries’ post-2020 wind power targets are very ambitious (including Denmark, Italy, Korea, and Sweden’s targets) due to national implementation of similarly ambitious climate targets for reduction of greenhouse gas emissions. In Japan, wind power is still seen as a limited resource, largely due to unsolved power system integration issues.

The shift from feed-in tariffs to tender-based support schemes promoted by the European Commission’s state aid guidelines have prompted increasingly competitive prices for wind energy. In particular, more than 3.1 GW of offshore wind power capacity has been allocated under zero-subsidy bids in Germany and the Netherlands, while bid prices have decreased by 65% in tenders held in Denmark from 2010 to 2016 and in the United Kingdom from 2013 to 2017.

Figure 11. The ELISA-ELICAN Project, a 5-MW offshore wind turbine installed in Gran Canaria Island (Spain). The project features a self-installing precast concrete telescopic tower and foundation. This was the first bottom offshore wind turbine installed without using a heavy-lift vessel. (Photo credit: ESTEYCO)



## 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, while providing energy to communities with limited access to electricity.

### Industry Revenues & Jobs

Wind energy can be a major economic driver that creates sustained employment, tax revenues, and investment opportunities. It can also improve trade balances between countries by displacing fossil fuel imports.

Employment is generated throughout a wind plant's lifetime, most intensively during design and construction, but also during the operation, maintenance, and the decommissioning stages. Notably, countries also report ongoing employment related to manufacturing wind turbines and other components further up the supply chain (Belgium, Canada, France, Norway, Spain, and the United Kingdom). In Canada, total employment attributable to new wind energy projects provided approximately 2,576 job-years of employment in 2018 (including construction, operations, and maintenance). It was also estimated that approximately 4.55 job-years of employment are created per megawatt.

In China, total employment in the wind power industry was estimated to reach more than 800,000 jobs through 2020. During the Chinese government's current five-year planning period, the total investment in wind energy is expected to be more than 600 billion CNY (76.1 billion EUR; 87.2 billion USD). It was estimated that about 15 jobs are produced for every megawatt of installed wind power capacity.

The United States estimated that the wind industry employs approximately 114,000 people. The U.S. wind industry invested 12 billion USD (10.5 billion EUR) in new wind projects, which contributed more than 1 billion USD (0.87 billion EUR) in tax and lease payments to state and local governments and landowners in 2018.

In Europe, the European Commission reports that the total wind energy industry employment reached about 260,000 jobs in 2016 (including direct and indirect employment). As an example, the Belgium offshore wind industry supports about 15,000 jobs (including export activities, construction, and operations and maintenance). In France, 10,000 to 11,000 direct jobs and nearly 8,000 indirect jobs are attributable to wind power installations, with an additional 6,700 employees involved in the manufacturing of wind turbines and components. In Italy and Spain, the wind sector employs 26,000 and 22,500 people annually, respectively.

The European Commission also reported that the wind industry contributed 36.1 billion EUR (41.4 billion USD) to the EU's GDP and had net exports of products and services totaling 2.4 billion EUR (2.7 billion USD) in 2018. European wind energy companies have a commercial presence (including manufacturing sites) in more than 80 countries outside Europe.

In Spain, for example, there are more than 207 Spanish companies focusing on exports due to limited national deployment. The sector accounts for 1% of the country's total exports, around 2.4 billion EUR (2.7 billion USD) in 2018. In Italy, the economic impact of wind energy in 2018 was estimated to be approximately 3.3 billion EUR (3.8 billion USD). This value represents the overall contribution of three different business areas: new installations, operation and maintenance of online plants, and energy production and commercialization.

## **Smaller Emissions Footprint**

Several member countries calculated the avoided CO<sub>2</sub> 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).

An Irish Wind Energy Association report in 2018 identified that wind energy will displace 33 million tonnes of CO<sub>2</sub> emissions from the power sector from 2000 to 2020. Avoiding 137 TWh of fossil fuel consumption in this same timeframe would save an estimated 2.7 billion EUR. In 2018, Japanese wind-generated electricity contributed to a reduction of about 3.4 million tons of CO<sub>2</sub> equivalent to 0.26% of Japan's total CO<sub>2</sub> emissions. Japan aims to reduce its CO<sub>2</sub> emissions from energy generation by 25% from 2013 to 2030; wind energy generation will be a portion of this reduction.

In México, development of 8,000 MW of wind power by 2020 is estimated to reduce emissions by more than 13 million tons of CO<sub>2</sub>, approximately 10% of the national mitigation target. In addition to the environmental benefits of reducing CO<sub>2</sub> emissions, wind generated electricity supplies energy to areas that have limited access to service and encourages development in locations where large resources are located.

The United Kingdom estimated there was a 3% reduction in the total CO<sub>2</sub> emissions in 2018, including a 10% reduction due to the gradual closing of coal-fired plants. CO<sub>2</sub> emissions were 38% lower in the United Kingdom compared to 1990 levels. The annual CO<sub>2</sub> emissions savings attributed to wind energy are approximately 24.6 million tonnes.

In addition to CO<sub>2</sub> reductions, setting targets for air quality and reducing other emissions is becoming more prominent in countries like China and Korea. In China in 2018, wind-generated electricity totaled 366 billion kWh, which saved about 130.5 million tons of standard coal per year. This led to a reduction of 277 million tons of CO<sub>2</sub>, 0.95 million tons of SO<sub>2</sub>, and 0.8 million tons of NO<sub>x</sub>. Based on predictions for 2020, wind power will save 150 million tons of standard coal per year and play an important role in reducing air pollution and controlling greenhouse gas emissions in China.

## **Environmental Impacts & Benefits**

Wind energy development's impact on wildlife can present challenges to deployment. Many countries have invested in research and strategies to understand potential environmental impacts and benefits so they can make more informed decisions that balance the need for renewable energy with the need to sustain and protect local wildlife. Some example studies are presented here.

In Belgium, offshore wind energy developments have been found to also increase biodiversity, specifically organisms such as corals and marine flora. 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 aquaculture and fishing industries in the Belgian North Sea.

Figure 12. Wind turbine supplying electricity to Sweden (Credit: Lars Johansson, Mostphotos)

The Canadian Wind Energy Association (CanWEA) released a Wind Energy and Bat Conservation Review that provides industry and regulators with science-backed strategies for avoiding, minimizing, and mitigating the impact of wind turbines on bats. The review summarizes the scientific and practical knowledge gained over decades of relevant research.

The Danish Health Study sought to find possible connections between wind turbine noise and health effects on humans by comparing health data for cardiovascular disease, diabetes, negative birth outcomes, and use of certain medications to the average nocturnal outdoor and indoor noise from wind turbines. The study failed to find any conclusive evidence of a correlation between exposure to wind turbine noise and the triggering of blood clots in the heart or strokes.

In Germany, the Helbird project examined the possible impacts of a wind park cluster (north of Helgoland) on seabirds and marine mammals. Using visual observation and GPS data, researchers investigated the behavior of seabirds and marine mammals with respect to the impacts of offshore wind farms, including ship movements.

The U.S. Department of Energy's National Laboratories have partnered with industry to research the impact of wind energy. In 2018, Pacific Northwest National Laboratory (PNNL) researchers devised a novel way to integrate stereo vision into software to better "see" the flight patterns of birds and bats in real time. This new 3D flight tracking capability (called ThermalTracker) enables scientists to better identify animal species and their flight patterns near offshore wind turbines

IEA Wind TCP Task 34, also known as WREN (Working Together to Resolve Environmental Effects of Wind Energy), serves as the leading international forum for facilitating the deployment of wind energy technology around the globe. The Task works to provide a better understanding of environmental issues and demonstrated solutions to wildlife challenges for its participating members.



# 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

Wind energy R&D funding increased slightly in 2018 at the country level. Of the twelve countries reporting R&D budgets in 2018, seven reported increased funding (China, Denmark, Finland, Japan, the Netherlands, Spain, and the United States). 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. National budgets for public wind power R&D from 2010–2018 are shown in Table 3.

In Europe, many national R&D priorities are reflected at the European level through the European Technology and Innovation Platform for Wind Energy (ETIPWIND) and the Joint Programme for Wind Energy under the European Energy Research Alliance (EERA JP WIND). 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. Horizon 2020 (H2020) is the main funding instrument for energy research and innovation at the European Union level, with a budget of about 6 billion EUR (6.9 billion USD) for the period 2014–2020.

In 2018, 65 million EUR (74.5 million USD) were allocated to projects specifically focused on wind energy, but this figure increases to 72.4 million EUR (82.9 million USD) when other projects in which wind is a significant component are included.

## Research Initiatives & Results

Member countries highlighted key topics driving ongoing and future R&D activities, many of which have been identified as national priorities. Here are some highlights of national and cooperative projects that show the breadth of R&D priorities.

### Cold climates

- In Austria, the “R.Ice” project aims to elaborate 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, and project “N.Ice” investigates the reduction of ice formation by nanostructuring of surfaces with an ultrashort pulse laser.
- China’s Center of Aeromechanical Research and Development, GoldWind, Hunan University and Shantou University finished a refrigeration experiment with the GoldWind HQ63-17 airfoil in tunnel to test an electric de-icing protection system.
- In Finland, VTT performed a test campaign in the Icing Wind Tunnel (IWT) facility to compare the particle size distributions measured by different droplet sensors. The test campaign was performed as a collaborative effort undertaken by the Finnish Meteorological institute (FMI), Oulu University, Danish technical University (DTU) and VTT.

**Table 3. National Wind R&D Budgets for Reporting Countries, 2010–2018**

Country	Budget (million USD)								
	2010 <sup>a</sup>	2011 <sup>a</sup>	2012 <sup>a</sup>	2013 <sup>a</sup>	2014	2015	2016	2017	2018
Canada		7.8	5.8	5.0	4.7*	2.3	3.4	3.3	2.9
China	---	---	---	---	---	11.7	1.4	---	8.8
Denmark	24.2	26.6	9.9	31.5	20.9	23.1	17.0	8.1	26.1
European Commission	47.0	36.7	80.9	90.5	29.9	315.0	68.5	40.0	81.1
Finland	5.2	12.9	2.8	4.3	1.2	1.9	1.9	0.0	1.7
Germany	81.1	120.6	122.97	51.4	44.1	97.8	98.8	109.9	103.8
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	69.6
Korea	38.1	37.7	44.7	49.1	---	---	30.0	---	40.0
México	---	---	---	---	1.4	3.5	2.3	1.5	---
Netherlands	51.1	9.2	11.6	7.0	4.5	---	---	14.7	33.8
Norway	16.7	19.7	22.7	18.2	15.0	10.2	10.8	7.3	6.4
Spain	115.9	115.9	158.2	117.8	---	94.0	85.5	13.2	17.2
Sweden	14.5	14.5	14.2	14.9	7.8	7.7	7.7	7.3	6.6
Switzerland	0.5	0.5	0.5	0.5	0.5	0.6	0.7	0.8	0.8
United States	79.0	78.8	91.8	86.1	87.0	105.9	95.45	90.0	92.0

--- No data available

\* Estimates

<sup>a</sup> Currency expressed in year of budget (not adjusted to present value)

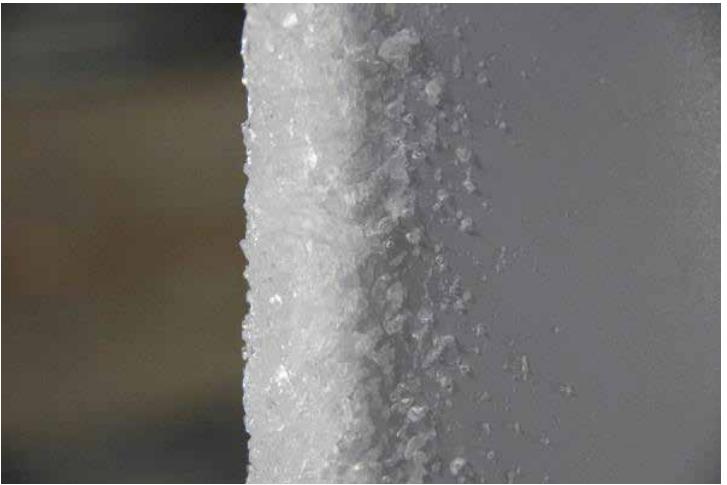


Figure 13. Refrigeration experiment of the Goldwind HQ63-17 airfoil in tunnel in China

### Wind farm control

- The EU's TotalControl project aims to develop and validate advanced integrated wind power plant and wind turbine control schemes, including all essential interactions between the wind turbines (e.g., production and load aspects).
- France's SmartEole project focuses on wind turbine control at the blade, turbine, and farm levels with several highly instrumented test campaigns at a land-based wind farm, using nacelle-based, bottom and scanning lidars as well as plasma and air jet actuators on the blades.
- In the United States, DOE's National Renewable Energy Laboratory conducted successful field trials that suggested annual energy production gains of 1–2% are achievable for facilities implementing wind plant control methods.
- In Japan, the Hokkaido Electric Power Co., Inc. and TEPCO Power Grid, Inc. started a demonstration project on electric power grid system control for expanding the introduction of wind-generated electricity.
- The Netherlands' Sensor Assisted Wind farm Optimization (SAWOP) project focuses on spinner sensor and nacelle lidar technology needed for individual wind turbine power performance assessment and implementation in standards.
- In Sweden, the Vindforsk project was organized around three topics: wind resource assessment and installation, operation and maintenance and grid integration.

### Life extension and decommissioning

- Denmark's LifeWind project aimed to demonstrate procedures that can quantify the risk of failure, the remaining structural reliability, and the maintenance costs when extending the operations of wind turbines nearing their end of certified life.
- 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.
- In Germany, the SeeOff project aimed to support stakeholders to develop and assess efficient, project-specific decommissioning strategies that are cost-minimizing, comply with legal requirements, ensure safety at work and environmental protection, and are publicly accepted.

### Grid integration

- In Belgium, GREDOR 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 North American Renewable Integration Study (NARIS) is examining the interconnected power systems of Canada, México, and the United States, from planning through operation, and balancing at 5-minute resolution, to assess strategies and technologies to enable high penetration of renewables.
- In the United Kingdom, the eGrid facility was installed at ORE Catapult and is one of the world's most advanced grid emulation systems, allowing researchers to simultaneously test mechanical and electrical systems to evaluate electrical performance, gain critical performance data and achieve grid-compliant assurance.

### Wind resource assessment and forecasting

- Canada's CanmetENERGY-Ottawa lab is collaborating with the University of New Brunswick and Nergica to refine and validate wind plant production forecasting models using inputs from Environment and Climate Change Canada (ECCC) weather forecasts.
- The U.S. Department of Energy's second Wind Forecast Improvement Project generated comprehensive meteorological data sets collected in complex terrain and developed physical modeling methods and atmospheric theories to improve forecasts in areas of complex terrain.

### Offshore wind

- In Europe, the X1 Wind project is developing a self-orientated platform with a single point mooring system and a downwind structural design that removes the active yaw system, the ballast system and the tower. The WTSS project is creating a floating support structure with no mooring lines and a single point anchoring system to optimize assembly, installation and decommissioning. The i4Offshore proposes a full-scale demonstration of a highly innovative offshore system solution at a challenging deep-water site featuring a next-generation direct drive wind turbine, a hybrid-material gravity jacket foundation optimized for low-cost manufacturing, and new very-low-cost array cable-in-pipe solution.

- In Germany, the SilentHammer project is working to reduce the underwater noise produced during installation of offshore wind energy plants with the goal of protecting marine mammals.
- Spain's ISOBATA Project is working on standardization of floating structures for offshore wind applicable at low and high depths.
- In the United Kingdom, GE Renewable Energy and ORE Catapult will test and develop next generation offshore wind technologies. Haliade-X 12-MW offshore wind turbine manufactured in France, and existing Haliade 150 6-MW turbines will undergo advanced test and demonstration programs that accurately replicate real-world operational conditions to enhance performance and reliability.

## Components

- In Germany, the BladeFactory project aims to further reduce rotor blade costs through a differential structural design, new manufacturing technologies, parallelized and shortened production steps, and an extended and experimentally validated understanding of the influence of process parameters on component quality.
- The German-Danish project ReliaBlade aims to predict actual structural blade reliability, making blades more cost efficient through optimized material usage and more appropriate maintenance concepts. The prediction requires an accurate knowledge about the structural condition of each individual blade during its lifetime.

## Wind turbine upscaling

- In the Netherlands, the GE Haliade-X 12-MW offshore wind turbine with a 220-m rotor is the first prototype to validate aerodynamic models, to enable a stable and verified power curve, and to validate design and load models, components functionality, O&M and installation procedures.
- Also in the Netherlands, a 14-MW wind turbine, based on a 2-bladed downwind turbine on a full-jacket support structure, with an integrated helicopter landing platform, is being developed and demonstrated. The design is predicted to increase the performance of wind turbines and significantly lower the leveled cost of energy.
- In the United States, university and laboratory researchers completed and began testing the Segmented Ultralight Morphing Rotor (SUMR) 50-MW offshore wind turbine design. The turbine's segmented blades fold together in strong winds, much as the fronds of palm trees bend and yield to the direction of the wind to withstand hurricanes.
- Also in the United States, the Big Adaptive Rotor initiative is working to develop rotors with larger swept area and improved energy capture for tall wind applications.

## Environmental impact and social acceptance

- In the Netherlands, the Win-Wind project is researching multiple uses for offshore wind farms by studying lobster and brown crab fisheries in offshore wind farms. The JIP ECO-FRIEND project is investigating how to restore the almost extinct flat oysters in the North Sea, with a research site at the Gemini Wind Farm.
- The Swedish Vindval research program focused on studying the environmental effects of wind power; the project's fourth phase focuses on wind power and spatial planning.

## Innovative concepts

- In December 2018, Vestas dismantled its multi-rotor concept after a two-and-a-half-year testing and validation campaign. The Danish manufacturer observed many technical benefits from the four-turbine prototype, including a 1.5% power gain.
- In France, the DGE (drone génératrice éolien) project to develop an airborne wind energy device obtained initial results; several 20-kW prototypes were built and tested in flight conditions.
- Also in Europe, the Skypull is demonstrating a 100-kW airborne wind energy system; Ventura Habitat is creating a novel blade maintenance system; and YURAKAN created a high power rated, novel, cyclone converter generator for onshore wind turbines.

## New Test Facilities & Demonstration Projects

A major component of continued innovation in the wind industry is the ability to conduct demonstration projects and utilize test facilities, which are now located in countries around the world. IEA Wind TCP member countries support projects that test advanced design and construction methods as well as grid integration and components. Some projects are not wind energy specific, but indirectly support the wind industry by seeking to further integrate renewable energy sources into the bulk electricity system, such as the Smart Grid demonstration and deployment projects in Canada.

Several new projects have commenced operations which reflect the industry's appetite for offshore wind, particularly floating concepts and the novel installation and balance of plant solutions. Table 4 highlights several of the test and demonstration facilities in IEA Wind TCP member countries.

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## References

- Opening photo: The A2Sea wind turbine installation vessel "Sea Installer" at the Port of Ostend, Belgium (Source: PWT Communications Inc)
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  - [4] IRENA (2019). Renewable Power generation costs in 2018
  - [5] IEA (2019). Global electricity demand. Download from [www.iea.org/geco/electricity/](http://www.iea.org/geco/electricity/)
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**Table 4. Examples of Test and Demonstration Facilities in IEA Wind TCP Member Countries**

Country	Facility Description
<b>Offshore wind test and demonstrations sites</b>	
Belgium	OCAS fatigue testing facility for welding seams in offshore substructures
Denmark	Test sites added at Høvsøre and Østerild, with Østerild able to test turbines as high as 330 m
Finland	A 42-MW demonstration offshore wind farm at a Baltic Sea site with winter ice
France	Floatgen: a floating offshore demonstrator featuring an innovative “damping pool” concrete floating substructure and a 2-MW Vestas turbine; Faraman: three Siemens 8-MW turbines 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 include testing of full size floating offshore turbines in the scope of the Atlantic Marine Energy Test Site (AMETS). It will test BluWind, a floating wind 1:6 scale prototype demonstrator
Japan	Floating offshore demonstrator commenced operations in the Fukushima FORWARD offshore wind farm, featuring 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	30-MW Hywind, the first floating grid-connected offshore wind park, achieved 65% capacity factor from November 2017 through January 2018; a demonstration wind farm commissioned by EDF features five MHI Vestas V164 8.3-MW turbines mounted on float-and-sink gravity-based foundations at the Blyth Offshore Demonstration site
United States	Two offshore wind demonstration projects are under development: the Icebreaker project with six 3.45-MW, direct-drive turbines on mono bucket foundations in Lake Erie; the Aqua Ventus I project is planning a pilot floating offshore wind farm of up to 12 MW using a concrete, semisubmersible foundation design in deep waters off Monhegan Island, Maine
<b>Land-based test and demonstration sites</b>	
Canada	WEICan 10-MW test site including energy storage demonstrated secondary frequency regulation
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
Ireland	Eirgrid, the Irish TSO, tested the capabilities of power-generation and other technologies. The wind power plant qualified to provide the following system 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)
México	A blade manufacturing laboratory and a test facility for small blades (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 commissioned by ORE Catapult
<b>Climatic testing facilities</b>	
Belgium	Climatic test chamber (OWI-lab); cold climate wind tunnel (VKI)
Finland	An Icing Wind Tunnel for testing of instruments and materials in representative icing conditions
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
<b>Wind tunnels and wave tanks</b>	
Denmark	A new wind tunnel is under construction at DTU
Italy	CNR-INSEAN hosts a wave tank and circulating water channel to test model-scale offshore wind turbines installed on a floating platform in a controlled environment; POLI-Wind tunnel tunnel includes actively controlled and aero-elastically scaled wind turbine models for studying wake interactions
<b>Resource assessment</b>	
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 U.S. DOE’s Wind Energy Facilities Book and in Catalogue of Facilities Available, published by EU FP7-project IRPWIND ([www.irpwind.eu/publications/deliverables](http://www.irpwind.eu/publications/deliverables))

**Table 5. National Statistics of the IEA Wind Member Countries 2018**

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	3.0	201	7.0	63	11.5%
Belgium	3.2	363	7.5	84	8.9%
Canada	12.8	566	31.9	595	5.4%
China	209.5	21,143	366.0	6,995	5.2%
Denmark	6.1	635	13.9	34	41.5%
Finland	2.0	-3.0	5.9	87	6.7%
France	15.1	1,511	27.8	489	5.7%
Germany	59.0	3,070	111.6	598	18.7%
Greece	2.9	237	6.3	52	12.2%
Ireland	3.7	355	8.5	31	27.6%
Italy	10.0	452	17.3	320	5.4%
Japan	3.7	261	6.5	908	0.7%
Korea	1.3	157	2.5	537	0.5 %
México	4.9	927	12.4	318	3.9%
Netherlands	4.5	58	9.9	120	8.8%
Norway	1.7	506	3.9	135	2.9%
Portugal	5.4	67	12.7	52	24.2%
Spain	23.5	392	48.9	257	19.0%
Sweden	7.4	704	16.4	150	10.9%
Switzerland	0.1	0	0.1	58	0.2%
United Kingdom	21.7	1,957	57.1	354	16.1%
United States	96.4	7,461	275.0	4,207	6.6%
<b>Totals</b>	<b>497.9</b>	<b>41,060</b>	<b>1048.1</b>	<b>16,466</b>	<b>6.4%</b>
Non-IEA Wind TCP countries	93.6*	13,940*	420.4*	10,234*	4.1%*
<b>World Total</b>	<b>591.5 [1]</b>	<b>55,000</b>	<b>1,468.5*</b>	<b>26,700*</b>	<b>5.5% [2]</b>

\* Estimates      [1] World total capacity [2] Wind share [5] Global electricity demand

**Table 6. Potential Capacity Increases Beyond 2018 in Reporting Member Countries**

Country	Planning Approval <sup>a</sup> (MW)		Under Construction <sup>b</sup> (MW)		Total (MW)
	Land-based	Offshore	Land-based	Offshore	
Austria	570	---	---	---	570
Canada	1,000	---	---	---	1,000
Denmark	138	---	---	1,006	1,144
Finland	3,849	820	378	---	5,047
France	1,819	---	---	---	1,819
Germany	1,477	---	---	1,000	2,477
Ireland	678	---	---	---	678
Italy	---	30	---	---	30
México	---	---	19	---	19
Netherlands	2,600	3,500	---	---	6,100
Norway	5,041	---	2,036	---	7,077
Spain	13,138	---	3,154	---	16,292
Sweden	8,382	2,267	3,395	---	14,044
Switzerland	12	---	---	---	12
United Kingdom	---	---	---	5,575	5,576
United States	---	19,968	35,135	2,068	57,171

--- No data available

<sup>a</sup> Projects have been approved by all planning bodies<sup>b</sup> Physical work has begun on the projects

**Table 7. Targets Reported for IEA Wind TCP Member Countries**

<b>Country</b>	<b>Official Target Renewable Energy Sources (RES)</b>	<b>Official Target Wind Energy</b>	<b>2018 Total Wind Power Capacity (MW), Annual Contribution to Demand (%), or Annual Production (TWh)</b>
Austria	34% RES share in final gross energy demand by 2020	3,000 MW by 2020 (from year 2012)	3,045 MW
Belgium	13% RES share in final gross energy demand by 2020	2,741 MW offshore and 3,000 MW land-based by 2020	3,169 MW (1,186 MW offshore and 1,983 MW land-based)
China	680 GW by 2020	210 GW by 2020	209.5 GW (grid connected 184 GW)
Denmark	30% by 2020, 50% by 2030; independent of fossil fuels by 2050	50% by 2020	41.7%
European Union	20% RES share in final gross energy demand by 2020; 1,206 TWh of renewable energy electricity by 2020; 32% RES in 2030	486 TWh by 2020	363 TWh
Finland	39% RES share in final gross energy demand by 2020	6-6.5 TWh/yr by 2020, 9 TWh/yr by 2025	5.9 TWh
France	74 GW by 2023	Land-based: 15 GW by 2018. Proposed new target: 24.5 GW by 2023 Offshore: 0.5 GW by 2018. Proposed new target: 2.4 GW by 2023	15.12 GW land-based, 0.002 GW offshore
Germany	Gross electricity demand: 40-45% by 2025, 55-60% by 2035, >80% by 2050	Land-based: regular auctions for 2.8 GW in 2018; 2.675 GW in 2019; 2.7 GW in 2020; 2.65 in 2021; 2.9 GW/yr from 2022 on; plus 1.0 GW in 2019; 1.4 GW in 2020; 1.6 GW in 2021 Offshore: 15 GW by 2030	58.9 GW, 18.6%, 111 TWh
Ireland	16% RES share in final gross energy demand by 2020, projected 40% of electricity demand	3.5 GW by 2020. Eirgrid estimated in 2018 that 3.9-4.4 GW of land-based wind capacity is required to meet 2020 RES-E targets, with 4,200 MW being the most likely figure	3.7 GW
Italy	17% RES share in final gross energy demand by 2020	12 GW land-based and 0.68 GW offshore by 2020. 18.4 GW land based and 0.9 GW offshore by 2030	10 GW land-based
Japan	22-24% by 2030 (54th Strategic Energy Plan, METI 2014)	10 GW by 2030	3.7 GW
Korea	20% RES share in total electricity demand by 2030	6.8% in total electricity demand by 2030	1.3 GW
México	25% of electricity by 2018, 30% by 2021 and 35% by 2024	5.5 GW by 2031. Industry target 8 GW by 2020	4.9 GW
Netherlands	14% RES share in final gross energy demand by 2020	---	---
Norway	28.4 TWh/yr by 2020 (shared target with Sweden)	---	---
Portugal	31% RES share in final gross energy demand by 2020	5.3 GW land-based, and 0.027 GW offshore by 2020	5.4 GW
Spain	20% RES share in final gross energy demand by 2020	35 GW by 2020, 2018 proposal, 22.3 GW of new wind capacity by 2030	23.5 GW
Sweden	50% RES share in final gross energy demand by 2020. 100% renewable electricity in 2040. By 2045, no net emissions of greenhouse gases	30 TWh by 2020 (20 TWh onshore, 10 TWh offshore)	16.4 TWh
Switzerland	Increase generation by 22.6 TWh by 2050	0.6 TWh by 2020, 4 TWh by 2050	0.12 TWh
United Kingdom	30% of electricity from renewable sources by 2020	No specific target, forecast 20 GW by 2020	21.7 GW
United States	Increase generation of electric power from renewables through cost reductions	Reduce the cost of land-based wind power to \$0.06/kWh (0.057 EUR/kWh) without incentives by 2020 and reduce the modeled cost of offshore to \$0.20/kWh (0.095 EUR/kWh) by 2030	---

# ACTIVITIES OF THE IEA WIND TCP



Figure 1. Participants at IEA Wind TCP ExCo 81, Oostende Belgium

## RESEARCH TASKS & STRATEGIC PRIORITIES

The 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.

The IEA Wind TCP supported 16 Tasks working on wind energy research, development, and deployment (R,D&D) in 2018. 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.

### Task Participation

The IEA Wind TCP Executive Committee (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 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.

Each active task had between 4 to 18 participating countries working on issues related to wind energy technology and deployment 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.

In 2018, Task 41, a new task on distributed wind was approved, and will begin work in 2019. Task 27 Small Wind Turbines in High Turbulent Sites concluded at the end of 2018. 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.

### Strategic Plan

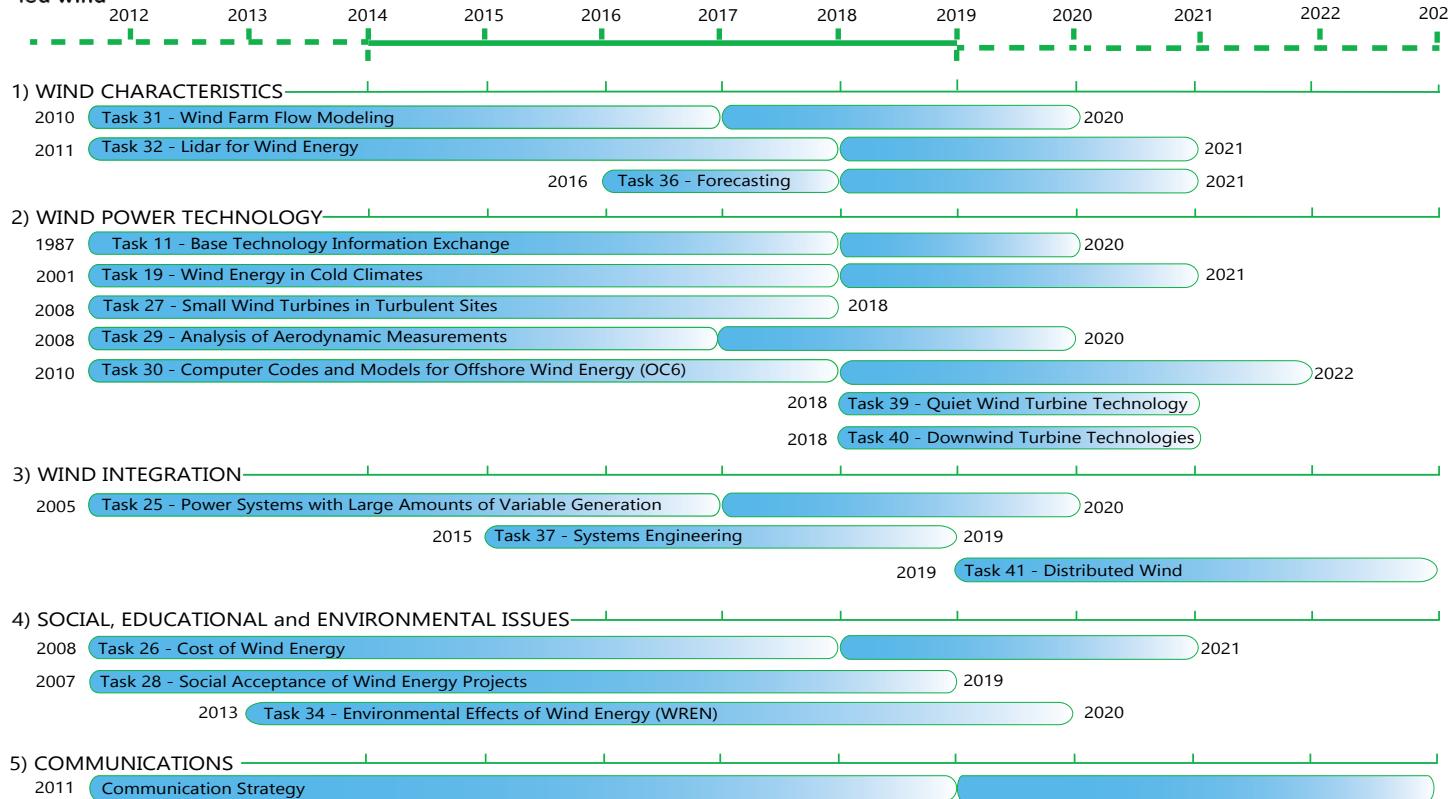
IEA Wind TCP research tasks focus on sharing the latest technologies and best practices to advance wind power deployment and help meet renewable energy goals. The TCP's activities in 2018 aligned with the TCP's 2014-2019 Strategic Plan, which aimed to reduce wind energy costs by conducting R&D in five 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.

In 2018, the IEA Wind TCP published the *2019–2024 Strategic Work Plan* to help guide the TCP's activities for the next five-year term. The new plan is presented on pages 22 and 23.



## 2014-2019 Strategic Priority Areas



**Table 1. Member Participation in Research Tasks During 2018**

Participant	Research Task Number															
	11	19	25	26	27	28	29	30	31	32	34	36	37	39	40	41
Austria		x			x					x		x				x
Belgium		x			x							x				x
Canada		x	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		OA	x	OA		x
European Commission				x												
Finland	x	OA	OA			x							x			
France			x				x	x	x	x	x	x	x			
Germany	x	x	x	x		x	x	x	x	OA		x	x			x
Greece																
Ireland	x		x	x	x	OA					x	x				x
Italy	x		x						x							
Japan	x		x		x	x		x	x	x				OA	x	
Korea					x			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	OA			x	x	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	OA		x	OA
WindEurope			x													
<b>Totals</b>	<b>15</b>	<b>11</b>	<b>18</b>	<b>9</b>	<b>8</b>	<b>8</b>	<b>7</b>	<b>13</b>	<b>10</b>	<b>12</b>	<b>12</b>	<b>13</b>	<b>8</b>	-	<b>4</b>	<b>10</b>

OA indicates Operating Agent that manages the task; check task websites for the latest participation data.

## IEA WIND TCP STRATEGIC WORK PLAN

This 2019–2024 Strategic Work Plan presents the strategic objectives and priority research areas proposed for the next five-year term of the IEA Technology Collaboration Programme on Wind Energy Systems (Wind TCP). For forty years, the Wind TCP has been multiplying national technology R,D&D efforts through information exchange and joint research projects. Wind TCP has 16 active Tasks and 24 member countries and sponsor organizations, with membership expanding.

Wind energy has achieved impressive milestones in the past few years, with auction prices falling below 40 EUR/MWh for land-based projects and recent subsidy-free auctions for offshore wind projects. In Denmark, which has achieved a 40% share of annual electricity demand. In 2017, over 52 GW of wind generation capacity was installed worldwide, bringing the global capacity to about 598 GW. Nearly 85% of this global capacity is deployed in IEA Wind TCP member countries.

Still, there are significant opportunities for technological innovation and cost-competitiveness improvements in order to maximize the value and contribution of wind in the energy system—aiming toward wind energy being a major pillar of the transition to a renewable-energy-powered energy system.

### 2019–2024 Strategic Objectives

The following strategic objectives have been developed to define the scope and strategic direction of the Wind TCP:

#### 1. Maximize the value of wind energy in energy systems and markets

Focus R,D&D advances and sharing of best practices on the integration of wind power into energy systems and markets to improve the economic, technological, and societal value of wind energy, while enhancing security of supply.

#### 2. Lower the cost of land-based and offshore wind energy

Support innovative research at all scales and for all technology types (including disruptive technologies) to continue to improve the economic performance of wind energy projects in both mature and emerging markets. Address technology, market, and information needs to maximize the potential for wind energy to become the most cost-competitive energy by 2050.

#### 3. Facilitate wind energy deployment through social support and environmental compatibility

Refine communication and technological tools to enhance the social support for, and environmental compatibility of, wind energy projects and to reduce barriers to wind energy deployment. Support sociological and environmental research to inform the sustainable deployment of wind energy in both distributed and utility-scale wind energy systems.

#### 4. Foster collaborative research and the exchange of best practices and data

Support international collaboration among experts in all aspects of wind energy to promote standardization and accelerate the pace of technology development and deployment. Engage with a global cohort of stakeholder groups and organizations to disseminate Wind TCP outputs.

### Wind TCP Alignment with the IEA's Mission

The Wind TCP's Strategic Plan aligns with the IEA Medium Term Strategic Plan for Research and Technology 2019–2022.

**Energy Security** – Wind energy provides a reliable, affordable, and domestic energy source that may add to the diversity of a country's energy supply and provide grid support. Wind TCP activities directly support energy security by improving the value of wind energy in the energy system, improving its cost-competitiveness, and by addressing wind energy deployment challenges.

**Economic Development** – Cost-competitive renewable energy is a critical component of the growth of the world's developed and developing nations. Wind TCP fosters economic development by lowering the cost and increasing the value of wind energy in the system through collaborative R&D. This work also enables the most difficult R&D challenges to be approached and solved collaboratively.

**Environmental Awareness** – Wind TCP provides research, analysis, information, and data on technology development and deployment issues, including resource efficiency and environmental externalities. Information generated by the Wind TCP is used by policy makers and regulatory authorities to identify and evaluate the sustainability of energy options.

**Engagement Worldwide** – The Wind TCP actively engages the energy sector and other experts worldwide through Task research activities and communications (e.g., publications, presentations, and workshops) and outreach activities on the TCP level (e.g., new website and networking platform in 2017; collaboration with IEA, IRENA, and other organizations; efforts to expand membership in mature and emerging markets).

**Table 1. IEA Wind TCP 2019–2024 Research Priority Areas**

Research Priority Areas	High-Level Actions	Current and Ongoing Activities
<b>1. Resource and Site Characterization</b>		
Better understand, measure, and predict the physics of wind energy systems (including the atmosphere, land, and ocean) to assess wind resources, wake behavior, local climate, and extreme conditions.  Impact: Improve site resource assessment accuracy, aerodynamic performance, and energy forecasts	<ul style="list-style-type: none"> <li>Characterize normal and extreme environmental conditions for both onshore and offshore wind plants</li> <li>Improve design and analysis tools through formal verification, validation, and uncertainty quantification</li> <li>Develop low-cost, high-resolution site assessment techniques to inform siting and plant design</li> </ul>	<ul style="list-style-type: none"> <li>Topical Expert Meetings (TEMs) (Task 11)</li> <li>Cold Climates (Task 19)</li> <li>Small Wind (Task 27)</li> <li>Aerodynamics (Task 29)</li> <li>Offshore (Task 30)</li> <li>Flow Modeling (Task 31)</li> <li>Lidar (Task 32)</li> <li>Forecasting (Task 36)</li> <li>Quiet Wind (Task 39)</li> </ul>
<b>2. Advanced Technology</b>		
Support pre-competitive and incremental technological development to overcome design, manufacturing, and operational challenges (including upscaling and disruptive innovations).  Impact: Reduce the costs of design, installation, and maintenance; increase production; and expand market to new locations	<ul style="list-style-type: none"> <li>Advance and establish best practices for design, digitalization, and optimization techniques for wind turbines and plants</li> <li>Investigate advanced technologies to address specific site conditions (taller towers, logistics, offshore support structure design, advanced airfoils and strategies to increase flexibility, reliability, etc.)</li> <li>Advance best practices and technologies for repowering and end-of-life processes</li> </ul>	<ul style="list-style-type: none"> <li>TEMs (Task 11)</li> <li>Cold Climates (Task 19)</li> <li>Cost of Wind (Task 26)</li> <li>Small Wind (Task 27)</li> <li>Aerodynamics (Task 29)</li> <li>Offshore (Task 30)</li> <li>Lidar (Task 32)</li> <li>Systems Engineering (Task 37)</li> <li>Quiet Wind (Task 39)</li> <li>Downwind (Task 40)</li> </ul>
<b>3. Energy Systems with High Amounts of Wind</b>		
Research power system operations, forecasting, and grid and market integration of high amounts of wind generation.  Impact: Develop the 21st century electrical system to support high levels of wind energy and to maximize the system value of wind energy in a broad range of applications	<ul style="list-style-type: none"> <li>Study flexibility in both production and demand to achieve 100% renewable energy systems in the future</li> <li>Identify best practices to increase the system value of wind, which includes capacity value, grid support (e.g., ancillary services value), and opportunities for flexible demand and sector coupling</li> <li>Investigate improved wind power forecasts and increase the value of existing forecasts for users</li> </ul>	<ul style="list-style-type: none"> <li>TEMs (Task 11)</li> <li>System Integration (Task 25)</li> <li>Forecasting (Task 36)</li> </ul>
<b>4. Social, Environmental, and Economic Impacts</b>		
Identify acceptance needs and develop solutions for social, environmental, and economic impacts over the plant's lifecycle to increase the social support for and environmental compatibility of wind energy projects; maximize socio-economic benefits; and enable large-scale deployment of wind power.  Impact: Directly inform regulatory authorities, helping to make informed decisions on wind deployment, permitting, and safety	<ul style="list-style-type: none"> <li>Document, develop, and advance best practices, planning approaches, and other tools to build social support for wind energy projects and mitigate social acceptance issues</li> <li>Better understand and address wildlife conflicts and develop sensing, deterrent, mitigation, and minimization technology</li> <li>Expand technical knowledge and best practices for aeroacoustic design of wind turbine components</li> </ul>	<ul style="list-style-type: none"> <li>TEMs (Task 11)</li> <li>Cost of Wind (Task 26)</li> <li>Social Acceptance (Task 28)</li> <li>Aerodynamics (Task 29)</li> <li>Environmental Assessment and Monitoring for Wind Energy Systems (Task 34)</li> <li>Quiet Wind (Task 39)</li> </ul>
<b>5. Communication, Education, and Engagement</b>		
Establish the Wind TCP as the definitive source for wind R&D expertise, best practices, and data (including deployment statistics and national R&D programs).  Impact: Affect the cost, performance, and deployment of wind energy systems by distributing key results and information	<ul style="list-style-type: none"> <li>Develop and distribute an easy access platform to promote discussion and information sharing with wind energy and other experts on key results and information from Wind TCP</li> <li>Expand network of experts and researchers and communicate findings between IEA and TCPs to increase synergy</li> <li>Promote a new integrated discipline of wind energy science and engineering to achieve the full potential of low cost/high value wind energy</li> </ul>	<ul style="list-style-type: none"> <li>The IEA Wind TCP Secretariat and all research Tasks support this priority area</li> </ul>

# TASK 11

## BASE TECHNOLOGY INFORMATION EXCHANGE

### Task 11 Contact and Information

Phase: 2017-2018; 2019-2020  
Contact: Lionel Perret,  
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## ABOUT TASK 11

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 have served as the basis for both national and international standards.

Nearly every country in the consortium 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 offers 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. Meeting proceedings are made available to Task 11 participating countries immediately and to the public one year later. Four TEMs were held in 2018:

### TEM 90 Strategic Dialog for Community and Distributed Wind

**TEM 90 Strategic Dialog for Community and Distributed Wind:** Developing a common understanding of future technology and market innovations for the expansion of the global distributed wind market. It took place on March 26-28 at the Technical University of Denmark (DTU). NREL's Ian Baring-Gould took the technical lead in the organization of the meeting. TEM 90, which was organized jointly with a Task 28 meeting, was attended by 25 participants from 12 countries.

Following the meeting, a task proposal was prepared for the IEA Wind TCP Executive Committee's (ExCo) approval.

### TEM 91 Durability and Damage Tolerant Design of Wind Turbine Blades

The meeting was held June 12-14 at Montana State University (MSU) in Bozeman. Joshua Paquette from Sandia National Laboratories (SNL) and Douglas Cairns from MSU were technical leads in the organization process. The meeting was attended by 21 participants from six countries, which included many industry representatives. It aimed to define a framework for the DADT (durability and damage tolerant) design process for wind blades, to come up with recommendations for changes to blade standards, and to identify the needed research activities to support standards updates.

### TEM on Digitalization – Record Attendance

The buzz word "digitalization" managed to gather close to 50 experts for TEM 92 in October in Dublin, Ireland. Eighteen presentations, interspersed with Q&A, group discussions, and structured brainstorming sessions, were facilitated. In general, presentations ranged from the strategic implications of digitalization to specific implementations and practices already deployed. The first day was dedicated to exploring what digitalization means to the different players in the wind energy sector and presenting and discussing the current challenges.

On the second day, the participants discussed opportunities to mitigate barriers and to exploit the advantages of digitalization. Attendees collected and prioritized digitalization ideas arising from the TEM presentations and discussions as well as their professional experience. Three highly engaged groups generated and classified over 70 ideas according to implementation effort and industry impact. The findings from the session will inform follow-up actions, including the scoping of a new IEA Wind TCP task on digitalization.



Figure 1. Participants at TEM 92, Wind Energy & Digitalization in Dublin, Ireland (Photo credit: Task 11 OA)

**TEM 92 on Wind Energy & Digitalization:** This TEM took place on October 4-5 at the Sustainable Energy Authority of Ireland (SEAI). John McCann (SEAI, Ireland), Jason Fields (NREL, USA), Des Farren (Servusnet, Ireland), and Berthold Hahn (Fraunhofer, Germany) were technical leads for TEM 92. A record 45 experts from 11 countries came together to discuss the challenges and opportunities of digitalization for the wind energy sector. The participants showed a high interest in collaboration throughout the course of the meeting, which motivated Task 11 to start the process of creating a new IEA Wind TCP task focusing on digitalization, and a proposal will be presented at the ExCo's 83rd meeting.

**TEM 93 on Life Extension:** DTU Wind Energy hosted the meeting on December 2018 at their Risø campus in Roskilde, Denmark. More than 37 participants representing 12 countries attended. Presentations centered on available and needed data to determine remaining life, regulatory matters for specific implementation, and practices already deployed. The group agreed that, while elements of lifetime assessment already exist, developing a framework for collaborating will significantly benefit the sector. Consequently, a core team volunteered to collaboratively prepare a work proposal for a new IEA Wind TCP research task. DTU is leading the process and a task proposal will be presented to the ExCo.

### 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. Two Recommended Practices (RP) were reviewed and published in 2018:

- RP 16, Ed. 2: *Wind/PV Integration Studies* (Task 25 in collaboration with IEA PVPS)
- RP 19: *Micro-siting Small Wind Turbines* (Task 27)

## OUTCOMES & SIGNIFICANCE

Task 11 can be seen as the backbone of the IEA Wind TCP's activities. 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.

If a TEM attracts sufficient interest, it can serve as a kick-off for the process of organizing a new research task within the IEA Wind TCP. In 2018, three of the four TEMs organized are leading to new tasks. The workplan for the new tasks dedicated to "Enabling Distributed Wind" and "Life Extension" will be presented and seek approval from the ExCo. The task workplan on digitalization is under development.

**Table 1. Task 11 Participants in 2018**

Member/Sponsor	Participating Organizations
CWEA	Chinese Wind Energy Association (CWEA)
Denmark	Danish Technical University (DTU)
Finland	Technical Research Centre of Finland (VTT)
Germany	Federal Ministry for Economic Affairs and Energy (BMWi)
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)

## NEXT STEPS

The TEM topics selected for 2019 are:

- TEM 94: Large component testing in ultra-large WT blades, hosted by NREL in February 2019
- TEM 95: Improving the availability and reliability of electrical infrastructure components, hosted by OREC in April 2019
- TEM 96: Decommissioning, repowering and recycling, hosted by RES in November 2019

In 2019, Task 11 participants will hold a dedicated meeting in conjunction with the spring ExCo meeting. It will be a great opportunity to discuss the strategic orientation of the task. Also, the Task 11 operating agent will work closely with the new Secretariat to define a new communication strategy, including Recommended Practices and TEMs.

## 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

Phase: 2016-2018; 2019-2021

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## ABOUT TASK 19

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, these wind energy projects still face challenges caused by turbine icing and low ambient temperatures, which 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 deploy cold climate wind power at a large scale in a safe and economically feasible manner.

Expected results for 2018 were:

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

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

## PROGRESS & ACHIEVEMENTS

In 2018, Task 19 published three important reports:

*Performance Warranty Guidelines, Ice Throw Recommendations and Available Technologies for Wind Turbines in Cold Climates.*

*Performance Warranty Guidelines*, published in May 2018, sets out possible options for defining and testing wind turbine ice protection system (IPS) warranties. This baseline can be used in combination with field-testing experience from industry to

develop further standardization. The document also defines alternative methods for full-scale testing and warranty validation of the IPS-equipped wind turbine.

*International Recommendations for Ice Fall and Ice Throw Risk Assessments* came out in October 2018. The guidelines were created by an international expert group lead by Task 19. The purpose of the report was to provide the best available recommendations for assessing the risk of ice fall and ice throw from wind turbines with the aim of reducing the uncertainties involved in such assessments. The report presents recommendations for the selecting and defining the essential methodology and input parameters for ice throw/ice fall simulations and risk assessment. The findings presented in the report will pave the way for more transparency and increase the quality of ice-risk assessments internationally.

*Available Technologies, 2nd Edition* was published in October 2018. This report consists of a unique and massive collection of more than 500 references. Easy access summary tables allow the reader to quickly and easily find potential solutions to some of the most demanding challenges in cold climate wind energy. The target audience for this report is R&D design engineers, analysts, researchers, or similar professionals with a technical background and basic knowledge about wind energy.

## International Recommendations for Ice Fall and Ice Throw Risk Assessments

*International Recommendations for Ice Fall and Ice Throw Risk Assessments* was finalized after two years of work by an industry group lead by Task 19. As the risk of ice fall and ice throw from wind turbines becomes more recognized, there was a clear requirement from the industry to harmonize the methods for risk assessment.

The report produced by Task 19 collects recommendations and best practices from throughout the industry to create a baseline for a unified, international approach to assess the risk of ice fragments falling from a wind turbine and causing harm to a person under or near the turbine.

The guidelines define the following recommendations for ice risk assessment:

- Compute the spatial distribution of ice fragments falling or being thrown from the turbine from a statistical model.
- Include gravity, aerodynamic drag, turbine parameters, operational mode, and site topography as points of consideration in the model for calculating the trajectories of ice fragments.
- Use site-specific wind data in at least 10-minute intervals.
- Determine the total amount of ice and the number of ice pieces from either the scaling of site observations, ice load distribution formula, or ice accretion simulations.
- Consider the size and mass distributions of the ice pieces.
- Ensure long-term representativeness of icing conditions.
- Take into account societal and individual risks when defining measures.
- Consider the exposure of people and road traffic to ice fall.
- Clearly discuss the treatment of uncertainties in the assessment.
- The selection and adoption of risk reduction measures shall be decided on a site-specific basis.

In addition to these recommendations, there are national laws and standards that need to be taken into account. Knowing the local laws and requirements remains the responsibility of the risk assessment author. The findings presented in the recommendations will hopefully lead to greater transparency and quality in ice risk assessments worldwide.

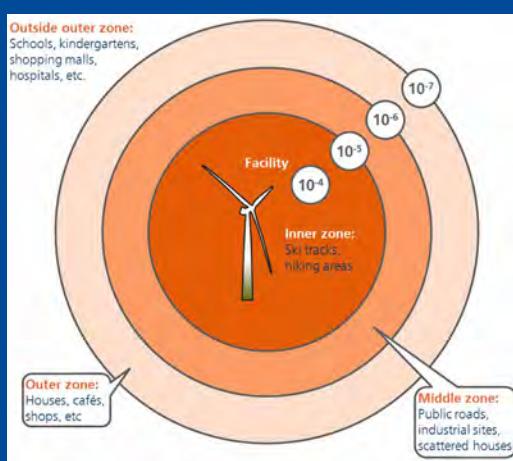


Figure 1. Suggested safety zones around installation that may cause risk of ice throw or ice fall [1].

## OUTCOMES & SIGNIFICANCE

The cold climate wind industry and research communities are united in the need 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 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 was granted a three-year extension for the period 2019-2021. The extremely ambitious work plan for the new period includes the following long-list deliverables:

- T19IceLossMethod IPS: update the existing open source icing loss assessment tool to be able to handle turbines equipped with blade heating systems
- IPS and retrofits presentation: summarize commercially available IPS and retrofit systems
- Market study update 2020-2025: estimate the current cold climate market size and its growth over the next five years
- Performance evaluation guidelines for ice detection systems: define methods to assess the accuracy and reliability of wind turbine ice detection systems
- Fact sheet on icing forecasts: work together with industry group to identify the existing icing forecast models and products for long and short term
- New cold climate inputs to IEC 61400-15, ed. 1 "Site Energy Yield Assessment": denoted as the most important standard for wind energy to-date, Task 19 has the important task to develop and propose icing loss uncertainty definitions and quantification categories
- Performance warranty guidelines for IPS update: outline improvements to testing methods in the 2018 report, based on industry input
- Available technologies wikipage: transform the current *Available Technologies* report to a website to make it easier to access and make more frequent updates possible
- Recommended practices report: update the latest recommended practices, which is considered to be one of the most important cold climate reports globally
- Fact sheet of recommended practices: create an easy format summary of the recommended practices reports
- Ice throw guidelines update: update the 2018 report based on industry feedback; main updates are uncertainty quantification and turbine control effects on ice throw risk
- Best practice for assessment of icephobic coatings report: establish a working group of international experts to define evaluation methods for icephobic materials
- Iced turbine sound emission summary presentation: release a summary of available research to-date

In addition to these deliverables, a new dissemination plan (website, Twitter, LinkedIn, email newsletter) was created to increase the visibility of the Task 19 work.

## References

- Opening photo: Cold climate scenery. (C 2016 Mikko Tiilinen, VTT)  
[1] Source: courtesy of Lloyds Register / Kjeller Vindteknikk  
Authors: Timo Karlsson, VTT Technical Research Centre of Finland; and Ville Lehtomäki, Kjeller Vindteknikk, Finland.

# TASK 25

## DESIGN & OPERATION OF ENERGY SYSTEMS W/LARGE AMOUNTS OF VARIABLE GENERATION

### Task 25 Contact and Information

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## ABOUT TASK 25

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

IEA Wind TCP Task 25 analyzes and develops methodologies to assess the impact of wind and solar energy—variable generation—on power systems. This information helps to make wind energy shares more economically feasible in

electricity systems worldwide. Task 25 formulates best practice recommendations for system impact and integration studies.

Task 25 started in 2006 and in its fifth term has evolved from focusing on wind integration studies to covering wind and solar energy, as well as both electricity and energy systems. Task work focuses heavily on power system operators, with operators for Denmark, France, and Italy directly participating in 2018, as well as the Energy System Integration Group (ESIG, formerly known as UVIG) from the United States. The European body for Transmission System Operators (ENTSO-E) also presented during task meetings.

## PROGRESS & ACHIEVEMENTS

Task 25 has established an international forum for member countries and Transmission System Operators (TSOs) to exchange knowledge and experience about electricity and energy systems that operate with large amounts of wind power, as well as variable generation. Task 25 collaborates with IEA (GIVAR project) and IRENA. In 2018, this resulted in a collaborative paper on integration costs of wind energy [1].

Laboratório Nacional de Energia e Geologia (LNEG) hosted the 2018 spring Task meeting in Lisbon, Portugal. KTH Royal Institute of Technology hosted the autumn meeting in Stockholm, Sweden, in conjunction with the annual Wind Integration Workshop. A joint meeting was held with PVPS TCP Task 14 and both tasks hosted a common session in the Wind Integration Workshop. In collaboration with IEA PVPS Task 14, a thorough update of *Recommended Practices for Wind/PV Integration Studies Ed 2* was published in August 2018 [2]. In December, the two tasks held a webinar to disseminate the report. The webinar drew nearly 100 attendees and is posted on the website. A summary report for the task's 2015-2017 phase was published in April 2018 [3].

The following collaborative articles were published in 2018:

- Integration cost estimations [1]
- Summary of wind and solar integration study results [4]
- Dynamic line rating [5]
- Wind in capacity markets [6]
- Wind power within European grid codes [7]

Wiley *WIREs* launched a call for abstracts for a special wind/PV integration studies collection with guest editors from Task 25. Altogether, nine papers were published in 2018.

### Summary Report Highlights Advancements in Wind Power Plants Providing Grid Support [9]

Wind power plants providing grid support is increasing:

- Denmark has operated their system with more than 100% wind share without any large power plants online, relying on HVDC links and smaller power plants for frequency and voltage control.
- In Texas, the benefits of fast and accurate responses from wind power plants contribute to a decreasing trend in the need for fast frequency reserves.
- Experience is growing also from Colorado, California, Denmark, Ireland, Quebec, and Spain to show that wind power can participate in frequency support services. Market operation of wind power plants is still evolving.
- There is some recorded experience of actual balancing costs decreasing despite growing shares of wind power. In Germany, this was due to the benefits of shared balancing between system operators, and in Texas it was caused by moving closer to real-time dispatch.

Presentations disseminating the work of Task 25 included:

- WindEurope workshop on integration costs, February 2018, Brussels, (H. Holttinen)
- Grid meets Renewables, fair poster and stand, March 2018, Brussels (H. Holttinen)
- Presentation and paper at Grand RE2018 International Conference Yokohama, Japan June 2018 (H. Holttinen) [8]
- Task 25 presentation on IEA flexibility side event, Yokohama, Japan, June 2018 (P. Børre Eriksen)
- WindEurope conference presentation on the future of grid support services, and poster on recommended practices, Hamburg, September 2018 (H. Holttinen)
- IRENA workshop for South East Europe system operators and regulators, October 2018 (H. Holttinen)

## OUTCOMES & SIGNIFICANCE

Task 25 brings best practice wind integration experience, study methods, and results to member countries and a wider audience through IEA, IRENA, ESIG, IEEE, and various task publications. The collaboration with IEA PVPS Task 14 resulted in a new Recommended Practices report (Figure 1).

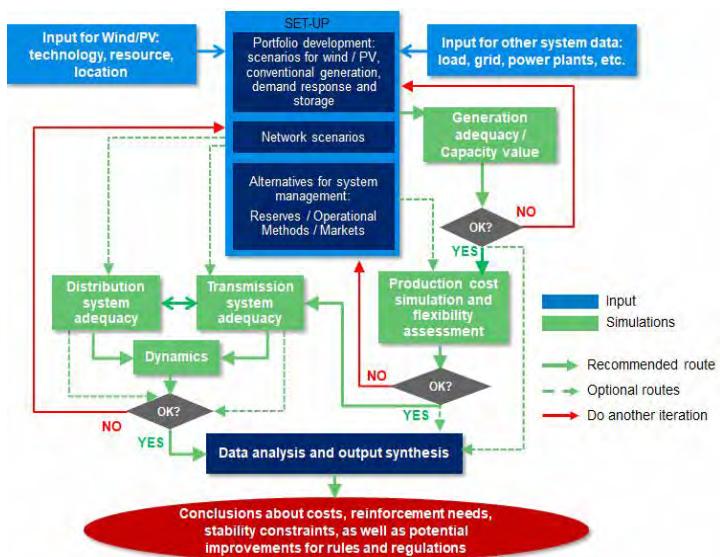


Figure 1. Recommended Practices for wind/solar integration studies follow a flow chart, including parts of an integration study [2]

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- Opening figure: Windfarm in Oaxaca, México (Photo: INEEL, México)
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- Authors: Hannele Holttinen, Recognis, Finland; Juha Kiviluoma VTT, Finland.

## NEXT STEPS

In 2019, the task will focus on studies tending toward 100% renewables, which require new methodology and recommendations. The task's Wind Integration fact sheets and the integration study hourly time series database will be updated. Meetings will be held in Spain, hosted by the Spanish system operator REE, and Romania.

**Table 1. Task 25 Participants in 2018**

Member/Sponsor	Participating Organizations
Canada	Natural Resources Canada, Hydro Quebec Research Institute (IREQ)
CWEA	State Grid Energy Research Institute (SGERI)
Denmark	Technical University of Denmark (DTU), TSO Energinet.dk
Finland	VTT Technical Research Centre of Finland
France	EdF R&D (Electricite de France), TSO RTE, Mines Paris Tech
Germany	FfE, Fraunhofer IWES, TSO Ampriion
Ireland	University College Dublin (UCD), Sustainable Energy Authority of Ireland, EnergyReform
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	Delft University of Technology
Norway	Norwegian University of Science and Technology (NTNU), SINTEF Energy Research
Portugal	Laboratorio Nacional de Energia e Geologia (LNEG), Institute for Systems and Computer Engineering, Technology and Science (InseTec)
Spain	University of Castilla-La Mancha
Sweden	Royal Institute of Technology (KTH)
United Kingdom	Imperial College, Strathclyde University
United States	National Renewable Energy Laboratory (NREL), ESIG, U.S. Department of Energy
WindEurope	WindEurope

Note: IEA Secretariat and IRENA have observed meetings  
TSO - Transmission System Operator

# TASK 26

## COST OF WIND ENERGY



### Task 26 Contact and Information

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## ABOUT TASK 26

Wind power serves as a key source of low cost, clean energy in markets around the world. However, the wind industry's future depends on a sophisticated understanding of cost reduction opportunities, as well as a robust understanding of the means by which society can maximize the value of wind energy in the electricity and energy sectors, which are the focus of Task 26.

The three principal work areas covered by Task 26 include:

- Analyzing trends in wind power costs
- Identifying opportunities and intelligence on the future cost reduction potential of wind power technologies
- Exploring the value that wind power technologies can offer to energy systems.

The work of the task considers the full array of land-based and offshore wind power applications but focuses primarily on utility scale technologies and plants. Phase four of the task began in October 2018 and will continue through September 2021.

Task 26 generates data and insights that inform the potential role for wind power in the future energy system. Industry stakeholders regularly collaborate on work products and participate in the task's in-person meetings. Ten IEA Wind TCP Members, representing 13 distinct organizations with participation from 18 individuals, contributed to the task in 2018 (Table 1).

## PROGRESS & ACHIEVEMENTS

In 2018, Task 26 concluded its third research phase and was approved for an additional 3-year task extension. During this third phase, Task 26 continued collecting land-based wind project-level statistics to assess the cost and value of energy among participating countries. This data includes wind power plant and turbine technology trends, investment and operating costs, and capacity factors. The data from this activity is available in an interactive online data viewer, which is intended to help analysts understand differences in technology trends for land-based wind projects over time [1].

In addition, the task published two technical reports:

- Trends affecting the cost and value of land-based wind energy in Denmark, Germany, Ireland, Norway, Sweden, the European Union, and the United States from 2008 through 2016 (Figure 2) [2]
- Characterizing the physical site characteristics, technology choices, and regulatory context driving offshore wind levelized cost of energy (LCOE) in participating countries [3]

Three manuscripts were submitted to peer-reviewed journals:

- The Task 26 LCOE methodology and land-based wind energy cost trends in Germany, Denmark, Ireland, Norway, Sweden and the United States (submitted to *Applied Energy*) [4]
- An analysis of technology substitution in re-powered wind farms (submitted to *Wind Energy*) [5]

- Results from a survey of wind industry experts to benchmark wind power operating costs in the United States (accepted by *Renewable Energy Focus*) [6]

Ongoing work efforts are expected to provide new insights around technology trends, innovation drivers, and characterization of the levelized revenue of energy for land-based and offshore wind power projects among the participating countries.

**Table 1. Task 26 Participants in 2018**

Member/Sponsor	Participating Organizations
Denmark	Denmark Technical University (DTU), Ea Energy Analyses
European Commission	Joint Research Centre (JRC)
Germany	Deutsche WindGuard, Fraunhofer IEE
Ireland	Dublin Institute of Technology
Netherlands	TKI Wind-op-zee
Norway	Norwegian Water Resources and Energy Directorate (NVE)
Sweden	Swedish Energy Agency (SEA)
United Kingdom	Offshore Renewable Energy (ORE) Catapult
United States	Lawrence Berkeley National Laboratory (LBNL), National Renewable Energy Laboratory (NREL)



Figure 1. Experts Participating in IEA Wind Task 26 (Photo Credit: Eric Lantz, NREL)

## OUTCOMES & SIGNIFICANCE

Task 26's work aims to inform the analysis, policy, and regulatory communities of the current and future cost of wind energy for land-based and offshore wind technologies, as well as the technology's value proposition within an evolving power system. By providing high-quality data that support analyses related to cost of wind energy, the task enhances the broader energy community's efforts to plan for the future.

The task also develops novel models that are often applied by key stakeholder groups and industry. Organizations such as IEA and the International Renewable Energy Agency have used Task 26 wind project cost and performance statistics, and participants regularly use this data for internal and external purposes.

## NEXT STEPS

Work activities in the task are ongoing across multiple fronts. A particularly noteworthy activity from Task 26 in 2019 will be the continued exploration of the cost and value of wind energy. This will be accomplished by:

- Updating the land-based wind power project statistics through 2018 in the interactive online data viewer.
- Publishing a report on the methods developed to assess "Levelized Revenue of Energy."
- Completing a review of wind cost and performance data in preparation for the provision of a wind power cost and performance dataset to be utilized by energy modelers around the world.

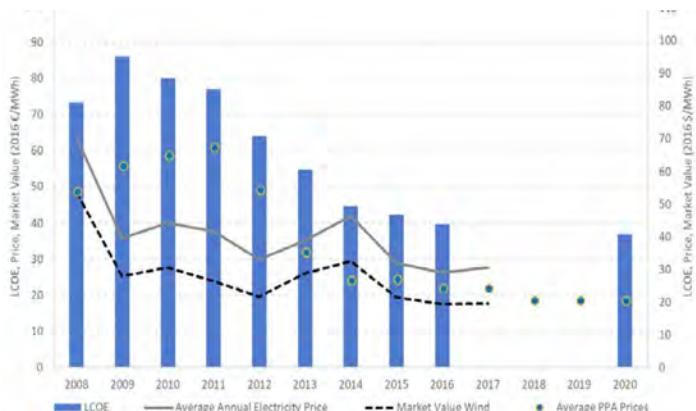


Figure 2. Levelized cost of energy, average wholesale electricity price, and market value of wind in the United States from 2008 to 2016, with projections to 2020 [2]

## Wind Technology, Cost, and Performance Trends in Denmark, Germany, Ireland, Norway, Sweden, the European Union, and the United States: 2008-2016

Throughout the history of Task 26, participants have sought to understand past and present wind energy cost trends using consistent, transparent methodologies and data. In this vein, the task published a detailed technical report in 2018, exploring recent cost trends and drivers in several of the participating countries [2].

This report also provided a long-term perspective on trends in the market value of wind energy, as estimated from wholesale power market data for the countries represented in the report. The method applied reflects a novel approach to understanding opportunities for wind power, as well as insights into the ability of wind power projects to cover the costs.

Over the period of analysis (2008-2016), we observed that market value results were frequently below LCOE estimates. In some cases, market value results for wind also fell below the average wholesale electricity price for wind. Some countries have observed a narrowing of the gap between LCOE and market value, but market value was also observed to decline in several countries over the period of analysis. As a result, the future competitiveness of wind power remains in question, even as LCOEs have declined.

The methods developed and applied to characterize market value in Task 26 have helped seed a whole new series of work efforts in both the task and in much of the analysis community around the Levelized Revenue of Energy (LROE). This new workstream has provided a means to characterize wind energy value while opening up new mechanisms for understanding how to affect wind energy market value through technology, changes to the transmission network, and other means.

## References

- Opening photo: The 2-MW Gamsa wind turbine being installed at the National Wind Technology Center (Photo by Dennis Schroeder)
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- Author: Eric Lantz NREL, United States.

# TASK 27

## SMALL WIND TURBINES IN HIGH TURBULENCE SITES

### Task 27 Contact and Information

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## ABOUT TASK 27

Since 2009, Task 27 of the IEA Wind TCP has 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 this IEC standard did not address the typical turbulence intensity (TI) requirements that were found at small wind turbine sites. There were also 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 the design of appropriate standard requirements.

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

## PROGRESS & ACHIEVEMENTS

Task 27 held four meetings in 2018: two virtual meetings in January and July and two face-to-face meetings in April and September. Experts from Austria, Belgium, China and Taiwan, Ireland, Spain, and the United States attended the first virtual meeting. The second virtual meeting was attended by experts from Austria, Belgium, China, Ireland, Spain, the United States, Poland (observer) and Australia (observer).

The spring face-to-face meeting in Minneapolis, United States, was hosted by the University of St. Thomas in April (Figure 1). This meeting was attended by experts from Austria, Belgium, China and Taiwan, Ireland, Japan, South Korea, Spain, the United States and Poland (observer).

The fall face-to-face meeting was held in Madrid, Spain, and was hosted by the CIEMAT (Figure 2). This meeting was attended by experts from Austria, Belgium, China, Ireland, Japan, South Korea, Spain, the United States, and Poland (observer).



Figure 1. Task 27 meeting attendees in Minneapolis, United States, April 2018 (Photo credit: Ignacio Cruz)

Other highlights and outreach activities included:

- Small Wind Conference 2018: 9-10 April 2018, Twin Cities MN (USA)
- TurbWIND Colloquium (R&I on wind energy; exploitation in urban environment): 6-7 September 2018, Riva del Garda (Italy)

**Table 1. Task 27 Participants in 2018**

Member/Sponsor	Participating Organizations
Austria	University of Applied Sciences Technikum Department of Renewable Energy Vienna
Belgium	Vrije Universiteit Brussel (VUB)
CWEA (sponsor)	Chinese Wind Energy Association, Inner Mongolia Technical University (IMUT), Taiwan Small & Medium Wind Turbine Association (TSWA)
Ireland	Centre for Renewable Energy, Dundalk Institute of Technology (CREDIT)
Japan	New Energy and Industrial Technology Development Organization (NEDO), Kanazawa University (KU)
Korea	Korea Institute of Energy Technology, Evaluation & Planning (KETEP)
Spain	Centro de Investigaciones Energeticas Medioambientales y Tecnologicas (CIEMAT)
United States	National Renewable Energy Laboratory (NREL)
Poland (observer)	Institute of Turbomachinery, Lodz University of Technology (TUL)

## OUTCOMES & SIGNIFICANCE

Task 27 published *Recommended Practice 19: Micro-siting Small Wind Turbines in Highly Turbulent Sites*, a practical guideline with methods to estimate energy production more accurately. The aim of this RP is to help industry obtain better estimates of wind turbine production in highly turbulent sites. To achieve this, dominant wind direction(s), directional blockages from terrain features, surface roughness, and obstacles have to be understood adequately.

The recommended practice provides rules of thumb and key recommendations on how to practically assess small wind turbine production for turbulent sites, including support for the development of site assessment techniques and the education, credentialing, and accreditation of site assessors. This information can be used to ease consumer education needs, evaluate their micro-sites, optimize wind turbine locations, and estimate production and costs. Certified small wind turbines have energy production estimations, with a caveat stating that certification production estimates are for open field test sites, which are not typical of most small wind turbine owner sites.

Task 27 has also developed a Technical Recommendations document for consideration by MT2 IEC 61400-2, fourth edition. This technical report provides a series of recommendations that should be considered in future standards-making activities for IEC 61400-2, based on the task's research results. While these recommendations are preliminary in nature and require further validation, many of the results suggest changes to turbulence characteristics, loads models, and methods, as well as the development of a new turbine design classification.

Small wind turbines are failing around rated wind conditions largely due to high shearing stress in weakly stable conditions. Including the turbulent shearing stress and the Richardson number stability parameters as inputs to load cases and structural requirements will begin to capture more realistic small wind turbine operating conditions. It is recommended that both modeling and measurements be used to validate small wind turbine design.

Finally, Task 27 compiled a compendium of all country case studies, documenting all the CFD modeling, measurements results, and modeling and testing efforts developed during the active working period.



Figure 2. Task 27 meeting participants at CIEMAT in Madrid, Spain, September 2018 (Photo credit: Ignacio Cruz)

### Understanding the Impacts of Turbulence on Small Wind Turbines

Understanding three-dimensional inflow for smaller wind turbine rotors is difficult. Task 27's efforts have begun to show the sensitivities of the turbulent inflow seen by wind turbine rotors and the impact this has on the turbine system design and definitive energy production.

Over time, new modeling tools, site assessment technology, and study methodologies will evolve past the Recommended Practices currently published. For example, today there are new, inexpensive wind measurement systems and a better technical understanding of the impact and details of the inflow. As a result, new qualitative and quantitative methods will evolve.

The timing and the growth of this evolution will be heavily influenced by the speed and growth of global small wind turbine markets. There will continue to be an interest in international collaboration on new research topics. The IEA Wind TCP will fill this important role, providing a basis for future standards development that will have direct impact on better wind turbine designs.

The global market for small wind turbines is potentially very large, but in many ways the technology has not yet had a significant market impact. This is partly due to the long time required to make purchase decisions, as owners must educate themselves. Without streamlined, customer-friendly approaches, the small wind turbine market will continue to be a smaller, niche market. Better site assessment can help ease owner purchase decisions.

### References

- Opening photo: Small wind turbine roof-mounted at CEDER-CIEMAT test facility building in Soria Spain (Photo credit: Ignacio Cruz, CIEMAT)
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# TASK 28

## SOCIAL ACCEPTANCE OF WIND ENERGY PROJECTS

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## ABOUT TASK 28

Wind energy is an important part of policy goals for IEA Wind TCP member countries who are 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 conducted by industry practitioners and academics in Task 28, social acceptance of offshore projects has become 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 Canada, Denmark, Finland, Germany, Ireland, Japan, Portugal, Switzerland, and the United States.

To achieve renewable energy policy objectives, social acceptance needs to focus on the needs of all wind industry stakeholders such as policy makers, regulators, developers, local communities, and special interest groups. For the purposes of the Task, “social acceptance” is 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 Two of Task 28 concluded in spring 2016, and the IEA Wind TCP Executive Committee granted a task extension for Phase Three (2017-2019) at the December 2016 Executive Committee 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 practices, research ideas and methods to enhance participating country insights as well as a cross-cultural understanding of challenges to social acceptance

### Priority Topics for Task 28 Phase Three (2017-2019)

Task participants helped identify four Work Packages for Phase Three of Task 28 through 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.

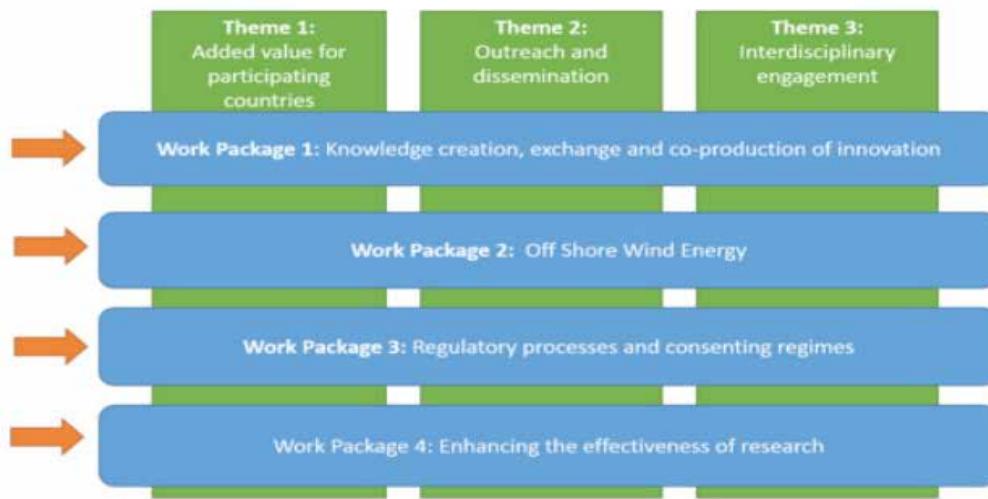


Figure 1. Priorities, themes, and work packages developed for phase three of Task 28.

## OUTCOMES & SIGNIFICANCE

Debates surrounding wind energy projects in the field show that social acceptance is a topic that needs to be better understood if countries are going to accomplish their various policy targets for renewable energy production.

Individual projects require public approval, and proponents and opponents need to work together to improve these projects and help them come to fruition. 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 as the interdisciplinary and international Task 28 approach.

## NEXT STEPS

The first meeting of Phase Three took place in Dublin at the end of March 2017. The meeting was preceded by a seminar, which 100 industry representatives attended. Denmark hosted the next Task 28 meeting in Roskilde in March 2018, and the German participant hosted a meeting in Hamburg in September 2018.

The next meeting is planned for Lisbon in March 2019. Task 28 looks forward to producing a number of deliverables by December 2019.

Table 1. Task 28 Participants in 2018

Member/Sponsor	Participating Organizations
Denmark	Danish Energy Agency, Technical University of Denmark (DTU)
Finland	Akordi, BusinessFinland
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, The Swiss Federal Office of Energy (SFOE), ENCO Energie-Consulting AG
United States	U.S. Department of Energy, National Renewable Energy Laboratory (NREL), Lawrence Berkeley National Laboratory (LBNL)

## References

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Author: Garry Keegan, Infrastructure Projects Consulting, Ireland.

# TASK 29

## ANALYSIS OF AERODYNAMIC MEASUREMENTS

### Task 29 Contact and Information

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## ABOUT TASK 29

The best strategy to improve aerodynamic knowledge is to combine insights from full-scale field measurements with those from wind tunnel measurements. Measurements in the field can be done on representative full-size turbines, avoiding the scaling effects of wind tunnel environments. On the other hand, the stochastic nature of atmosphere, though representative, makes interpretation of results more complicated where extremes and faulty conditions (e.g., extreme yaw) cannot be controlled.

The first three phases of IEA Wind TCP Task 29 primarily relied on wind tunnel measurements. The fourth phase of Task 29 began in 2018 and is utilizing field measurements, which emphasize aero-elastic effects and turbulent inflow.

The task will also continue to work on measurement uncertainties analysis, comparing calculations and measurements, and a deeper investigation of aerodynamic phenomena using the detailed measurements.

This new phase will also include designing a large-scale aerodynamic field experiment (even larger than the DanAero experiment), which will be complementary to previous Task 29 phases that provided valuable information on aerodynamic modeling and from wind tunnel measurements.

Phase three of Task 29 concluded with the publication of the Final report of IEA Wind TCP Task 29, Mexnext (Phase 3), Analysis of Mexico Wind Tunnel Measurements in 2018 [1].

## PROGRESS & ACHIEVEMENTS

The fourth phase of Task 29 kicked off in 2018. The main objective of this phase is to validate, improve and develop aerodynamic models for wind turbine design codes. More specifically, the task will focus on validating and improving models for the following aspects:

- Aerodynamic response to turbulent inflow
- Sheared inflow
- 2D/3D aerodynamics
- Aeroelastic effects
- Transition characteristics in realistic flow conditions

Model assessment will largely, but not exclusively, be based on the detailed aerodynamic measurements taken on an NM80 2-MW turbine from the Danish DanAero field experiment. The data from this experiment have been made available to Task 29 by the DanAero consortium. Different categories of models will be considered (CFD, free wake methods, engineering methods etc.)

The kick off meeting for the fourth phase was held in June 2018, just prior to the Science of Making Torque Conference at PoliMi in Milano, Italy. The most important result of the first year of the new phase was obtaining the DanAero measurements database for Task 29 participants.

A set of detailed aerodynamic measurements taken in the field on a large-scale turbine has long been sought after by the aerodynamic wind community. Previously, detailed aerodynamic field measurements were only available from IEA Wind Tasks 14 and 18; however these measurements were taken in the 1990s on outdated turbines.

The first round of calculations has been defined, and will be carried out by almost the entire project group. Previous experience shows that energy spent explaining some differences in participants' results may, in fact, have been due to trivial input errors; therefore, one of the first activities of this first iteration was to align participants' input descriptions.

## OUTCOMES & SIGNIFICANCE

Task 29 expects that the most important outcomes of this phase will include:

- Improved and validated aerodynamic and aero-elastic models for wind turbine design codes leading to improved insights (e.g., dynamic induction and transition effects, in atmospheric inflow);
- A detailed plan for a new large-scale aerodynamic field experiment; and
- A user-friendly validation platform built around the calculational cases from all IEA Wind TCP Task 29 phases.

## NEXT STEPS

Participants will continue to work on calculational cases and the results will be discussed in early 2019. Once participants have gained sufficient confidence on the inputs, several cases will be carried out in a second iteration, which will then be compared with measurement data.

**Table 1. Task 29 Participants in 2018**

Member/Sponsor	Participating Organizations
CWEA	Chinese Wind Energy Association (CWEA)
Denmark	Technical University of Denmark (DTU), Siemens-Gamesa Renewable Energy
France	ECN, EDF, ONERA, IFP Energies Nouvelles
Germany	Forwind/Fraunhofer IWES, University of Stuttgart (IAG), Kiel University of Applied Sciences, WINDnovation, German Aerospace Laboratory DLR, Enercon, UAS Emden/Leer
Netherlands	Netherlands Organisation for Applied Scientific Research (TNO), Delft University of Technology, Suzlon Blade Technology (SBT), University of Twente, Det Norske Veritas- Germanischer Loyd (DNV-GL)
Sweden	Uppsala University Campus Gotland
United States	National Renewable Energy Laboratory (NREL)

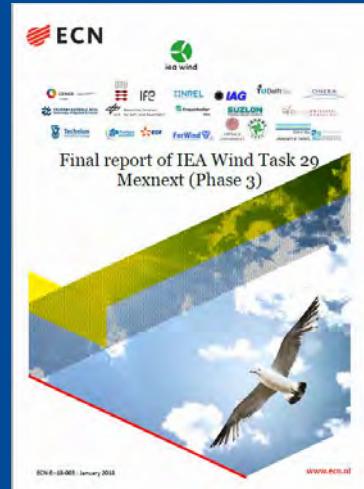
### Final report of Task 29, Mexnext (Phase 3): Analysis of Mexico Wind Tunnel Measurements

This report describes the results from the third phase of IEA TCP Wind Task 29, which focused on improved design models and recommendations on model use to reduce uncertainties in design calculations.

Project results show that current state-of-the-art design models provide accurate aerodynamic load predictions for design conditions in constant axial and uniform inflow, while more scatter is observed in modeling the turbulent wake state, separated flow, three-dimensional effects and tip effects.

A prerequisite for accurate results is a careful consideration of input parameters and output post-processing. This especially holds for CFD simulations, of which the results are highly dependent on the large number of input- and output related choices.

Improvements have been made to engineering models describing, for example, yawed and dynamic inflow effects. However, large uncertainties still exist in oblique, dynamic and non-uniform inflow conditions. Further improvements to unsteady aerodynamic modeling are planned in the fourth phase of IEA TCP Wind Task 29.



*Figure 1. Final report of Task 29, Mexnext (Phase 3): Analysis of Mexico Wind Tunnel Measurements [1]*

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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)

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## ABOUT TASK 30

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.

Through code-to-code comparisons with the OC3 (Offshore Code Comparison Collaboration) and OC4 projects (Offshore Code Comparison Collaboration, Continued) the task worked to verify the accuracy of offshore wind turbine modeling tools. 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 involved three phases and used 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) were:

- 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

Since the start of OC5, 195 people from 78 different organizations in 20 different countries participated in the task. These organizations brought together expertise from both the offshore structure and wind energy communities, including designers, consultants, certifiers, developers, and research institutions.

## PROGRESS & ACHIEVEMENTS

The OC5 project ended in 2018 with the completion of Phase III, which focused on the verification and validation of the full-scale, open-ocean alpha ventus wind farm. The system consists of a REpower 5-M (currently Senvion) wind turbine placed atop an OWEC Tower jacket support structure. This was the first time that the task performed validation of a full-scale, open ocean offshore wind system.

Significant obstacles arose around intellectual property issues (related to the blade properties and controller) and the calibration of the measurements, which are common when working with a full-scale, commercial system and data. These issues were mitigated by using approximated turbine properties (verified against a model with exact properties), and identifying appropriate channels for validation [1].

While there are more obstacles with full-scale data, there are no scaling issues with measurements from wind tunnel or wave tank testing, and there is no need to approximate the complex metocean environment. Thus, this project examined the ability of software tools to accurately represent the complex physical behavior of a commercial project.

The simulation results matched the measurements from alpha ventus fairly well. Differences were driven by:

- Poor calibration of the sensors as shown by inconsistencies in the measurements
- Controller and airfoil properties, which were only approximated in the modeling approach
- The prescribed damping value for the structure—a critical issue is how to define this value without measurement data
- Wind characteristics beyond turbulence on the loads.

The findings from this validation work were summarized in a conference paper, presented at the Ocean, Offshore and Arctic Engineering Conference in June 2019 [2].

The OC5 group also completed a new validation campaign in 2018, which was motivated by an under-prediction of loads during Phase II (focused on the validation of a scaled floating wind semisubmersible). The OC5 group re-tested the semisubmersible to better understand the uncertainty in the low-frequency nonlinear wave response. This work was summarized in a journal article, which will provide the industry with a framework for approaching uncertainty assessment for offshore wind validation campaigns.

## Comparisons of Task 30 Participants' Tools: Jacket Support Structure Results

Participants under-predicted strain, especially in the low frequencies, which is attributed to an inaccurate representation of the damping in the structure.

Figure 1 shows a sample of the task's results, displaying the frequency response behavior of the strain time series at the top of the eastern leg of the jacket support structure.

Black lines represent measurements from different events and colored lines represent the results from different participant's simulations. Vertical dotted lines in the figure indicate the rotor blade passing frequencies (1P, 3P, 6P, and 9P), and global eigenmodes.

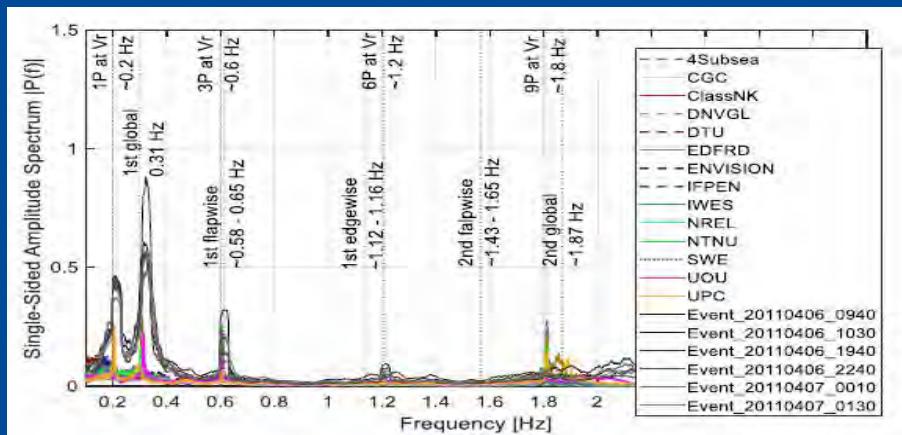


Figure 1. Spectrum of aggregated strain time series of six seeds at KP\_2021 (Eastern leg, bottom). Tools: FAST v8, Bladed V4.8, HAWC2, DeepLinesWind V5R4, ASHES, DIEGO, FloaWDyn, NK-UTWind, MoWIT, SAMCEF Wind Turbines, SIMA, Simpack. Participants: Fraunhofer IWES, NREL, Univ. of Stuttgart, OWEC Tower, DTU, EDF, IFPEN, Principia, ClassNK, 4Subsea, NTNU, Simis AS, Univ. of Ulsan, Polytechnic Univ. Catalonia, Siemens Industry Software, Envision, CGC, and DNV GL

## 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, improvements to 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 the offshore wind industry to develop more optimized designs.

## NEXT STEPS

IEA Wind TCP Task 30 presented an extension proposal (OC6 – Offshore Code Comparison Collaboration, Continued, with Correlation, and unCertainty) to the Executive Committee in 2018, which was approved for the period 2019-2022. The goal is to develop more focused validation projects to better understand some of the observed issues identified in the previous OC projects.

This new project will incorporate higher-fidelity models to inform the validation process and also focus on identifying and quantifying uncertainty in the measurement data.

The specific validation objectives for OC6 were determined through a series of meetings with OC5 participants, as well as offshore wind industry feedback. A phenomenon identification ranking table (PIRT) was developed to identify and rank the most pertinent phenomena of interest.

Table 1. Task 30 Participants in 2018

Member/Sponsor	Participating Organizations
CWEA	Goldwind, CGC, Dongfang Electric, Shanghai Investigation
Denmark	Danish Technical University
France	Ecole, EDF Renewables, IFP Energies, INNOSEA, INSA Rouen
Germany	Fraunhofer IWES, University of Stuttgart SWE, Senvion, Rostock University
Italy	Polytechnic University of Milan
Japan	WEIT, University of Tokyo, ClassNK
Korea	University of Ulsan
Netherlands	MARIN, WMC, ECN
Norway	NTNU, 4Subsea, Marintek, IFE
Portugal	WavEC, EDP, CENTEC
Spain	Alstom, CENER, Tecnalia, Iberdrola, Siemens Industry Software, Polytechnic University of Catalonia, University of Cantabria
United Kingdom	DNV GL
United States	National Renewable Energy Laboratory

## 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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  - [2] Popko, W. et al. (2019). *Validation Of Numerical Models Of The Offshore Wind Turbine From The Alpha Ventus Wind Farm Against Full-Scale Measurements Within OC5 Phase III*, Proceedings of the ASME 2018 38th International Conference on Ocean, Offshore and Arctic Engineering OMAE 2019, Glasgow.
- Authors: Amy Robertson, NREL, United States; and Wojciech Popko, Fraunhofer IWES, Germany.

# TASK 31

## INTERNATIONAL WIND FARM FLOW MODELING AND EVALUATION FRAMEWORK

### Task 31 Contact and Information

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## ABOUT TASK 31

Current wind energy models often overpredict a wind plant's 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.

Traditionally, these topics were analyzed separately, giving rise to different independent research communities (meteorologists, wind engineers, aerodynamicists). Each specialized group has developed a wide variety of models, but there has been little interaction between them [1]. The next generation of wind-energy models needs an integrated approach that can produce a more comprehensive characterization of the modeling system. The objective of IEA

Wind TCP Task 31 is to develop an international verification and validation (V&V) framework to provide sustained improvement of wind farm models [2]. The task leverages data from research experiments and industry alongside a formal validation strategy to provide a continuous evaluation process that improves the predictive capacity of wind farm flow models [3].

The third phase of the task kicked-off in June 2018 and aims to implement the international V&V framework by exploiting data from recent field experiments carried out in the New European Wind Atlas (NEWA) project and the U.S. Department of Energy's Atmosphere to Electrons (A2e) program. In addition, the Offshore Wind Accelerator Wake Modeling Challenge will allow task participants to benchmark the prediction of array efficiency in wind farm wake models using operational data from offshore wind farms.

## PROGRESS & ACHIEVEMENTS

Task 31 operates three work packages: WP 1 on benchmarking of models for wind conditions, WP 2 on benchmarking of models for wake effects, and WP 3 on integrating these benchmarks in a model evaluation protocol that provides guidance to model developers and end-users.

The NEWA Meso-Micro Challenge for Wind Resource Assessment was launched in 2018 to determine the applicability range of meso-micro methodologies across the validation envelope of NEWA experimental sites in complex terrain. These sites included Hornamossen forested rolling hills in Sweden, Rödeser Berg forested hill in Germany, Perdigão double-ridge in Portugal, and Alaiz mountain range in Spain [5, 6]. The Ferry Lidar benchmark in Germany allows for the comparison of mesoscale models on the prediction of wind profiles along a ship track in the Southern Baltic Sea [7]. The validation strategy is based on flow cases that target specific modeling objectives and annual integrations to assess the wind resource and site suitability (annual energy production, turbulence intensity, wind shear, etc.) while addressing the requirements from the IEC 61400-15 and IEC 61400-12-4 standards on resource assessment and numerical site calibration.

From the A2e program, the Scaled Wind Farm Technology (SWiFT) benchmarks provide a detailed characterization of wake evolution and dynamics, including steering effects from a yawed turbine [8]. Additionally, the Offshore Wind Accelerator (OWA) Wake Modeling Challenge allows task participants to benchmark wind farm wake models in the prediction of array efficiency using operational data from offshore wind farms [9].

A new design of the V&V framework is underway based on three elements:

- The Wind Energy Model Evaluation Protocol (WEMEP), which provides online documentation and guidance maintained in a version-controlled git repository.
- A series of mind maps that, through expert elicitation, map the relationships between quantities of interest, model building blocks and phenomena of interest for validation.
- A set of Phenomena Identification and Ranking Tables (PIRT) for gap analysis to define priorities for model development, experiments and validation.

A roadmap for wind and wake models will be produced based on consensus among the corresponding modeling communities [10].

## OUTCOMES & SIGNIFICANCE

By adopting a framework for model evaluation, Task 31 participants expect to facilitate the development of a better integrated model chain, which will cover 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, provide datasets that can be used to challenge those models, and develop end-user requirements on quality-acceptance criteria for models to meet industry standards.

## NEXT STEPS

Task 31's next term will focus on publishing the V&V framework to grow engagement from the modeling communities and build consensus around a roadmap for wind and wake models.

Ongoing benchmarks will be documented and published using open-science practices to improve traceability and interoperability of the validation repositories. Stay updated and engage with the Task 31 community in The Wind Vane Blog [11].

**Table 1. Task 31 Participants in 2018**

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

## References

Opening Figure: The DOE/Sandia Scaled Wind Farm Technology (SWIFT) facility at the Reese Technology Center (Lubbock, Texas) (Photo credit: Sandia National Laboratories/Lloyd Wilson)

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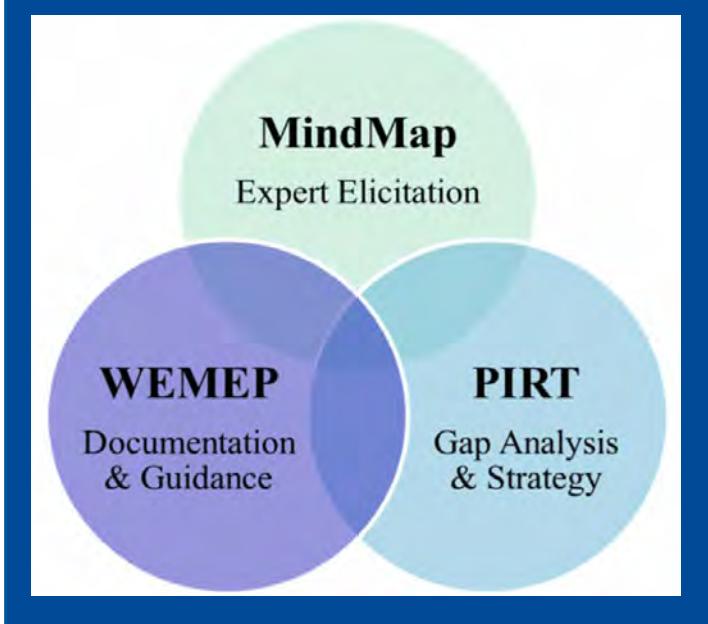
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[11] The Wind Vane Blog, Edited by Javier Sanz Rodrigo and Patrick Moriarty. <http://thewindvaneblog.com/>

Author: Javier Sanz Rodrigo, CENER, Spain.

## International Framework for Wind Farm Flow Models

The Wakebench's international framework for wind farm flow models will use online tools to map the state-of-the-art and guide future model development, experiments, and validation activities.



# TASK 32

## LIDAR: WIND LIDAR SYSTEMS FOR WIND ENERGY DEPLOYMENT

### Task 32 Contact and Information

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## ABOUT TASK 32

Wind lidar technology allows for the measurement of data across the whole wind turbine rotor disk, across the entire wind plant, or even for several kilometers up- or downwind. As a result, it is a key enabling technology for the future of wind energy, opening the way to larger turbines that use fewer materials to produce more energy, more reliably.

Wind lidar was first commercialized more than ten years ago and it is now accepted for many applications in the wind energy industry, particularly in resource assessment on land and offshore. But despite its advantages, wind lidar has not displaced traditional anemometry and some barriers remain to its adoption for wind energy applications.

Since 2011, IEA Wind TCP Task 32 has worked to identify and mitigate barriers to adopting wind lidar, including site assessment, power performance, loads and control, and complex flow. The task also supports innovative uses in a fifth application area called “out of the box.”

Task 32 organizes regular focused workshops to address each area’s challenges. Together with the annual general meeting, these workshops provide an international forum for industrial and academic partners to exchange ideas and experiences using lidar in wind energy. Participants share progress from individual research activities, measurement projects, and the performance of lidar devices.

## PROGRESS & ACHIEVEMENTS

Task 32 held five workshops and an annual meeting in 2018. Around 230 people took part in these events, contributed to documents, or participated in round-robin exercises. Participating institutions included research centers, universities, wind measurement companies, and lidar and wind turbine manufacturers.

### Certification of Lidar-assisted Control Applications.

Wind lidar can measure the winds a few rotor diameters upwind of a turbine, allowing feed-forward wind turbine control. A workshop was held at the DNV offices in Hamburg. Researchers, certification agencies, and end users identified solutions for certification and widespread adoption of lidar-assisted control. The workshop resulted in the publication of “Best Practices for Certification of Lidar-Assisted Control Applications” [1].

**Windfield Reconstruction in the Induction Zone.** A round-robin was initiated by Ørsted using data from a turbine in the Burbo Bank offshore wind farm. To address difficulties of up-wind measurement on larger turbines, participants analyzed a dataset of nacelle lidar measurements, aiming to reconstruct the wind field in the induction zone upstream of the turbine. A follow-up workshop was held in January 2019 to share results and discuss the methods that participants used. This gave an indication of the potentially strong influence of induction on topics such as power curve verification,

wind turbine power performance, and wind farm power performance.

**Remote Sensing, Modeling, and Data-driven Approaches—Task 32 and Task 36 Joint Workshop.** Wind lidar can also be used to monitor wind several kilometers upwind of a turbine or wind plant, potentially providing several minutes notice about incoming wind ramps or other challenging wind conditions. Advance warning about these types of events and associated changes in power output could help the integration of wind energy on to the electricity grid. The workshop resulted in a journal publication summarizing the opportunities for minute-scale forecasting techniques.

**Resource Assessment, Wind Turbine Siting, and Power Performance Testing.** Wind lidar data can also be used to estimate wind turbulence; however, there are many ways to use the data from a lidar to estimate turbulence and there are no standards at this time. In a two-day workshop organized with Ørsted in Denmark, participants considered how lidar-derived turbulence data could be used for load verification and site suitability. Different methods for estimating turbulence data from lidar measurements were presented by wind turbine manufacturers, lidar suppliers, researchers, and consultants. Barriers to the widespread application of these methods for wind turbine load verification and site suitability studies were identified and potential solutions were discussed.

**Floating and Offshore Wind Lidar.** Floating wind lidar and lidar mounted on wind turbines or other structures have largely displaced traditional met masts offshore. This change was partly enabled by Task 32's 2017 *Recommended Practice 18: Floating Lidar Systems*. Since then, the technology and its acceptance in the wind industry has further developed, and so a workshop was held in 2018 to identify areas that require further work and progress from stakeholders, including vendors, users, and the research community. The workshop resulted in a prioritized list of actions for the international community to support the continued adoption of floating wind lidar systems.

**e-WindLidar.** Wind lidar generates a large amount of data in a range of formats, making it difficult to share workflows, methods, and results. This can act as a barrier to adoption and innovation. This challenge could be overcome through the adoption of data standards and more effective metadata. The Technical University of Denmark (DTU) hosted a workshop on e-WindLidar to provide scientists, manufacturers, practitioners and end users of lidar data with an introduction to FAIR data principles (free, accessible, interoperable, and repeatable) and their application to lidar data. Several open source tools were also introduced that will enable data sharing and the development of community models going forward.

## OUTCOMES & SIGNIFICANCE

Task 32 considers that the continued deployment of wind lidar for wind energy needs new standards, more experts, better understanding of the physics of wind lidar measurements, and community data tools. Our activities in 2018 directly addressed these needs by testing existing standards and providing technical input to new standards, as well as developing Recommended Practices.

We also supported the training of new experts by providing opportunities to learn about current practices and ongoing research and to apply these ideas in workshops. We used round-robin exercises to improve our understanding of the physics of measurements in the induction zone. Additionally, we helped stimulate the creation of new community-based lidar tools by identifying uses cases and providing a forum for collaboration.

### What's Next for Wind Lidar?

There is a huge amount of research and development taking place in wind lidar for wind energy applications. Task 32 members identified the broad opportunities and barriers to deployment of wind lidar in a paper in *Remote Sensing* (Clifton et al, 2018). Another paper in *Energies* (Würth et al, 2019) showed the potential for wind lidar and other technologies to enable grid integration of wind energy, and what would be needed to make it reality. Finally, several papers showed how lidar can be used for wind turbine control (Simley et al, 2018 and Schlipf et al 2018). Together, these publications form the basis of a strategy for wind lidar research and development.

## NEXT STEPS

Task 32 will continue to provide a forum for the exchange of knowledge and experience relating to wind lidar. A task extension was approved in 2018. Workshops are planned for 2019 on themes including uncertainty modeling, wind turbine controls, and the use of nacelle mounted lidar for power performance. These events and the activities that they trigger and enable will support the deployment of wind lidar for wind energy applications.

**Table 1. Task 32 Participants in 2018**

Member	Participating Organizations
Austria	Energiewerkstatt
Canada	AXYS, TechnoCentre Éolien
CWEA	Envision, Goldwind, Huaneng Clean Energy Research Institute, MingYang
Denmark	COWI, EMD International, Ørsted, 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 Corp, WEIT
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, ORE Catapult, Ørsted, 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 Univ., DNV GL, US DOE, Envision Energy, E.ON, GE, Mitsubishi Electric Research Laboratories, NREL, PNNL, Renewable NRG Systems, Sandia, Siemens, Univ. of Colorado Boulder, Univ. of Maryland, Univ. of Wyoming, V-Bar

### 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)

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# TASK 34

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



### Task 34 Contact and Information

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## ABOUT TASK 34

The impact of wind energy development on wildlife has been a concern for decades and can present challenges to deployment. The environmental effects can vary by species (e.g., bats versus eagles), habitat (e.g., land-based versus offshore), and jurisdiction (e.g., monitoring and mitigation requirements vary across countries). These effects can cause projects to be delayed, abandoned, or changed from normal operations, resulting in reduced power generation.

Given the global reach of wind energy development, collaboration among international stakeholders is essential—particularly when affected species migrate across borders. When developers, operators, natural resource managers, and other stakeholders exchange information on best management practices for monitoring and mitigation, they can make more practicable decisions, balancing the need for renewable energy while sustaining and protecting wildlife.

IEA Wind TCP Task 34, also known as WREN (Working Together to Resolve Environmental Effects of Wind Energy),

serves as the leading international forum for facilitating the deployment of wind energy technology around the globe. The task works to provide a better understanding of environmental issues and demonstrated solutions for wildlife challenges.

WREN leverages the resources and expertise of member 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 Tethys (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: Tethys, white papers, and outreach and engagement. In addition to providing access to relevant literature and products developed within Task 34, Tethys provides information on key contacts, archives of webinars and online meetings, upcoming events, and other social media outreach as deemed appropriate. Updates to Tethys include:

- Adding 297 documents related to wind energy
- Increasing website visits by 33.8% from the previous year
- Adding 464 new subscribers to Tethys Blast
- Updating the platform to simplify coding and ensure compatibility with mobile phones.

WREN members participated in the 12th National Wind Coordinating Collaborative's Wind Wildlife Research Meeting in November 2018 and gave presentations on "Developing an Ecological Risk-Based Management Framework for Wind Energy Development" and "Tethys Knowledge Management System Enhances the International Understanding of Wind Energy and the Environment."

A short science summary on "European wolves and wind energy development" was released in February 2017 (Fig. 1).

WREN hosted four webinars in 2018, all of which were recorded and posted on Tethys (Table 2). In addition, the first WREN expert forum, which focused on bats and barotrauma, was conducted in October 2018. Two articles were also published:

- May et al. 2018. "Considerations for Upscaling Individual Effects of Wind Energy Development towards Population-Level Impacts on Wildlife." *Journal of Environmental Management* 230:84–93
- Sinclair et al. 2018. "Resolving Environmental Effects of Wind Energy." *WIREs Energy and Environment*. DOI: 10.1002/wene.291.

# OUTCOMES & SIGNIFICANCE

Siting and operational decisions must be made based on the best available science. 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 related to monitoring and mitigation strategies for offshore and land-based wind energy
- Development and testing of 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 the global wind-wildlife community and to disseminate scientifically-based information to a wider range of stakeholders, including decision makers for proposed projects where species and habitat concerns may be problematic. This widespread dissemination can help reduce the leveled cost of energy, lower barriers to deployment, and minimize wildlife impacts.



Figure 1. European wolves and wind energy development short science summary.

## Population-level Impacts on Wildlife

In its current phase, WREN is developing white papers on key overarching topics relevant to wind energy and wildlife issues. May et al. (2018) describes the current approach for reporting adverse effects of wind turbines on various wildlife (e.g., bird and bat species). The paper suggests upscaling these individual effects to population-level impacts as a way of identifying the potential consequences of wind energy development.

This shift from our current approach will be crucial for understanding whether the impacts of wind turbines are sustainable for certain species. Moreover, knowing the population-level impact allows for the appropriate level of mitigation necessary for healthy populations to be applied. The paper uses case studies to highlight methods and metrics to detect the response of wildlife to wind energy development, with the goal of providing support to better inform risk-based decision making.

Table 2. WREN Webinar Topics

Webinar Topic	Description	Date
First Look at a New Generalized Fatality Estimator, GenEst	An overview of GenEst and how it can be used to estimate fatalities at wind energy facilities	23 Aug 2018
Tethys Wind Webinar	A showcase of the content and resources available on Tethys from a wind energy perspective	25 June 2018
Reconstruction after Decommissioning	Reconstruction after decommissioning from offshore wind, land-based wind, and adjacent industry perspectives	4 May 2018
Smart Curtailment: A Global Perspective	A discussion of smart curtailment strategies from the European and North American perspectives	17 Jan 2018

## NEXT STEPS

In 2019, WREN members will continue working on white papers detailing the cumulative effects of analysis and green versus green—balancing the local impacts of wind energy on wildlife versus wind energy's global benefits of reducing carbon dioxide emissions. The task plans to host webinars on integrating wind energy in the multiuse offshore space and comparing impacts on Griffon vultures and California condors.

Two expert forums are being developed on offshore collision versus avoidance and estimating abundance and distribution. Several short science summaries are being drafted covering topics related to bats, land-based soaring birds, and European grouse. An outreach implementation plan will be enacted for Tethys to increase visibility and content. Two in-person meetings are planned for 2019—one in May in Inverness, Scotland, and the other in October in Washington, D.C.

Table 1. Task 34 Participants in 2018

Member/Sponsor	Participating Organizations
Belgium	Royal Belgian Institute of Natural Science
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	nateco AG
United Kingdom	Marine Scotland, Science
United States	National Renewable Energy Laboratory, Pacific Northwest National Laboratory; U.S. Dept. of Energy

## References

Opening photo: Lesser noctule bat (*Nyctalus leisleri*) flying above the water surface. (Photo credit: Jens Rydell).

Authors: Cris Hein, National Renewable Energy Laboratory; Karin Sinclair, National Renewable Energy Laboratory, United States.

# TASK 36

## FORECASTING FOR WIND ENERGY



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## ABOUT TASK 36

Wind power forecasting is an essential part of the energy transition. High penetrations of wind power in the grid are only possible with accurate wind power forecasts for the next minutes, hours and days.

IEA Wind TCP Task 36 combines about 250 people from forecast vendors, end users, and academia to advance the field of forecasting, increase the value of wind energy forecasts, and streamline the related business processes. The aim of the task is to improve both the accuracy and the value of wind power forecasts. The task works on three strings:

- Work Package 1 is related to the numerical weather prediction improvements necessary to gain more accurate forecasts. Participants improve models and gain access to data by collaborating with global weather centers and other weather modelers.
- Work Package 2 calculates the uncertainty of the power conversion step, and is primarily populated by vendors of the forecasts.
- Work Package 3 assesses how to improve the business practices of end users with regard to probabilistic forecasts.

## PROGRESS & ACHIEVEMENTS

The numerical weather prediction information portal was kept up to date throughout the research process. Participants from several national weather providers discussed the use of tall tower data for online verification.

Other information on the portal includes a list of ongoing and older research projects, links to benchmarking exercises with freely-available forecasting data, a yearly list of meteorological field campaigns including the pointers to their data, and some ideas for future research issues.

For forecasts in the minute scale, the task organized a common workshop with IEA Wind TCP Task 32 Lidar and discussed the use of remote sensing instruments (predominantly lidars, but also radars or satellites) for forecasting on very short time scales. Use cases for these instruments are wind turbine and wind farm control, power grid balancing, and energy and ancillary services trading.

The discussion on the reliability of lidars for online power forecasting in all kinds of weather conditions will continue in the second phase of Task 36. The organizers of the workshop also wrote an open-access paper on the results [1].

To wrap up phase 1, Task 36 held a series of four webinars in November 2018. These webinars gave an overview of the task, an introduction to Forecast Solution Selection, some examples for probabilistic forecasting in practice, and a demonstration of how Denmark can achieve up to 150% hourly wind penetration through good forecasting. The webinars are available on the task's YouTube channel [2].

Participants also presented an overview poster at several conferences, including presentations at the EGU in Vienna and the WindEurope Summit in Hamburg, as well as a special conference session at the ESIG Forecasting Workshop in St. Paul, United States.

The task will conduct interactive workshops at the ESIG Meteorology & Market Design for Grid Services Workshop, the International Conference on Energy Meteorology in Lyngby in June 2019 and at the Wind Integration Workshop in Dublin in October [3-5].

## OUTCOMES & SIGNIFICANCE

In the light of the current climate crisis, it is essential that more renewable energy becomes cheap and essentially carbon-free. However, too much wind power without accurate forecasts can endanger the stability of the grid.

Task 36 addresses this issue and thereby increases the potential amounts of variable renewable energy that the grid can absorb. Since the issue is shared with solar power, we will work together with IEA PV Task 16 on solar forecasting.

Standardizing forecast offerings and the language used to describe them can ease market access for large companies in search of a forecasting system, as well as small and agile forecast vendors.

### IEA Wind TCP Recommended Practice (RP): Forecast Solution Selection

This first phase of Task 36 was spent primarily on developing an IEA Wind TCP Recommended Practice (RP) on Forecast Solution Selection.

The three parts of the RP are related to the acquisition process of a new or updated forecasting service. While the first part outlines the steps needed to get a forecast provider for the first time, it also contains a flow chart by which end users can determine the need for a full benchmarking or trial process.

If it is determined that such a process is necessary, part II of the RP details how such a benchmark or trial should be set up. It also outlines a number of typical pitfalls that can occur during the process and prevent the result from being reliable. The third part of the RP is then devoted to the evaluation of this benchmark process, both from a forecast accuracy and from a service quality perspective.



Figure 1. The IEA Wind TPC Recommended Practice on Forecast Solution Selection, in three parts

## NEXT STEPS

Task 36 will soon be going into its second phase for the years 2019-2021. While many topics of the work plan will continue, some new topics that are relevant to the forecasting industry and end users are being taken up.

Among those will be a full uncertainty propagation from input uncertainty to end user display, as well as an NWP benchmark exercise, a streamlining or standardization of data flows, and a look into the value of forecasting in different market setups.

Table 1. Task 36 Participants in 2018

Member/Sponsor	Participating Organizations
Austria	Zentralanstalt für Meteorologie und Geodynamik
CWEA	China Electric Power Research Institute, China Meteorological Administration, Envision, North China Electric Power University, Xinjiang Goldwind, Zhejiang Windey
Denmark	Technical University of Denmark, Denmark's Meteorological Institute, DNV GL, ENFOR, WEPORG, Energinet, Vestas, Vattenfall, ConWX
Finland	VTT Technical Research Centre of Finland, FMI, Vaisala
France	MINES ParisTech, MeteoSwift, MeteoEolien, 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 University, Enercon, Tennet
Ireland	Dublin Institute of Technology, University College Dublin
Norway	Meteorologisk Institutt, Christian Michelsen Research, Kjeller Vindteknikk
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, Greenlytics
United Kingdom	MetOffice, Reading University, Strathclyde University, UK National Grid
United States	PNNL, National Renewable Energy Laboratory, National Oceanic and Atmospheric Administration, National Center for Atmospheric Research, Electric Power Research Institute, MESO, Inc., University of North Carolina Charlotte

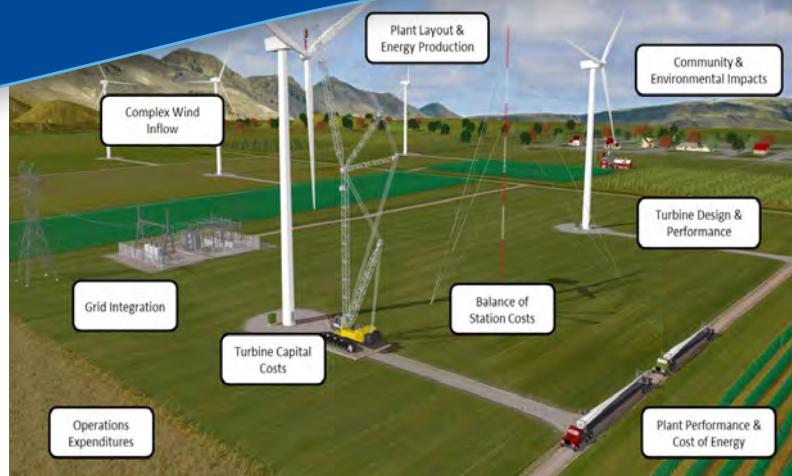
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- Opening image: Wind Power Forecasting for Grid Integration (Source: Corinna Möhrlen, WEPORG)
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- [4] [www.wemcouncil.org/wp/icem2019-workshop-session-iea-task36/](https://www.wemcouncil.org/wp/icem2019-workshop-session-iea-task36/)
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# TASK 37

## WIND ENERGY SYSTEMS ENGINEERING: INTEGRATED R,D,&D



### Task 37 Contact and Information

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## ABOUT TASK 37

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 (see opening figure on the complexity of wind systems). 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 R,D&D at different fidelity levels (WP 1)
- Reference wind energy systems (WP 2)
- Benchmarking Multidisciplinary Design, Analysis, and Optimization (MDAO) activities at different system levels (both turbines and plants) (WP 3)

## PROGRESS & ACHIEVEMENTS

In 2018, significant progress was made in each work package. In WP 1, the Task developed a working version of the wind turbine ontology for rotor aero-structural design and several member organizations (NREL, DTU, TUM, SNL and others) are now actively using the ontology to share turbine design information in a standard format. The new ontology implementation is based on json schema as an international standard that the Task can build upon [1].

For WP 2, two reference turbine designs went through final stages of development and review: 1) a low-windspeed 3.4-MW land-based turbine developed by TUM and 2) a 10-MW offshore turbine developed by DTU. The designs were published in a comprehensive technical report that includes detailed design information as well as performance and loads analyses [2]. The designs are also implemented in the new ontology format and are available in github which allows for tracking of design changes through software version control [3-4].

An offshore wind plant design reference was also completed including specification of the layout, preliminary electrical, and

support structure (monopile) design. The details of the design were presented at the Science of Making Torque from Wind 2018 conference and a full technical report is in process [5].

For WP 3, on benchmarking MDAO activities, a final cross-comparison review of results for the aerodynamics-only blade optimization study was completed at the annual meeting in 2018.

The exercise showed the difficulty of establishing a benchmark not just on models but on optimization processes. Moving forward, a different, two-phase benchmark method was designed in which a first case was provided with a model (to remove model difference effects) and in a second case participants used their own model. The first application involved a wind plant energy optimization study, the results of which will be presented at a conference in 2019.

In addition, Task meetings were held in conjunction with the Science of Making Wind from Torque 2018 Conference in Milan, Italy in June 2018. A second task meeting was held in conjunction with the SNL Blade Workshop in Texas in August.

## 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, to new materials for wind turbine blade design, and tall-tower applications for land-based technologies. A list of publications using the reference turbines is under development.

For the other work packages, guidelines and MDAO case study documents will 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.

## NEXT STEPS

In 2019, the focus will be on wrapping up Phase I of the Task and publication of several documents associated with each of the work packages.

- WP 1: Finalization of version one of the ontologies, complete with software release and technical report
- WP 2: Finalization and updates of the designs in the online repositories
- WP 3: Publication from at least one, if not two, MDAO case studies for turbine and plant applications

Additionally, the Task will host the Biennial Wind Energy Systems Engineering workshop in the fall of 2019. CENER has agreed to host the event in Pamplona, Spain and the overall event will be co-organized by CENER, NREL, and DTU Wind Energy.

**Table 1. Task 37 Participants in 2018**

Member	Participating Organizations
CWEA	Goldwind
Denmark	Technical University of Denmark (DTU) Wind Energy, LM Wind Power, Vestas Wind Systems
Germany	Fraunhofer IWES, Technische Universität at München (TUM), Nordex Energy GmbH
Netherlands	Delft University of Technology
Norway	SINTEF Energy Research, Christian Michelsen Research
Spain	National Renewable Energy Centre of Spain
United Kingdom	BVG Associates Ltd., DNV GL, Offshore Renewable Energy Catapult
United States	National Renewable Energy Laboratory, Brigham Young University, Sandia National Laboratories, Siemens Gamesa Renewable Energy (SGRE), Envision Energy, GE Global Research, University of Massachusetts

## New Reference Turbine Designs

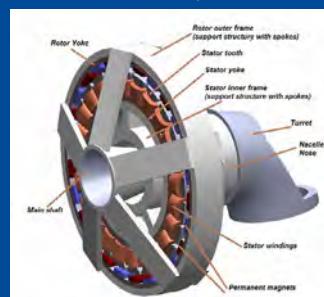
A key accomplishment was the publication of both the technical report and associated data for the two new reference turbines. The reference designs improve upon the state of the art in multiple ways. First, the offshore turbine developed by DTU has a lower specific power than the original machine, which shifts it closer to where industry is in practice. In addition, the detailed design of the drivetrain, including an optimized generator, is provided with the design and its properties are incorporated into the aeroelastic model of the turbine for self-consistent analysis of loads and control.

There had not been a reference turbine developed for land-based applications since the WindPACT turbines in the early 2000s and no previous reference turbine specifically focused on low-wind applications. The new IIIA low-wind speed 3.4-MW turbine developed by TUM fills that critical gap, which is important to both the research and industry community.

Figures 1 and 2 show the updated blade design of the new offshore 10-MW turbine as compared to the original DTU 10-MW turbine, including details of the new generator and hub-nacelle system.



*Figure 1. Details of the blade design of the old DTU 10-MW reference turbine versus the new IEA Wind Task 37 10-MW reference turbine (Source: Frederik Zahle, DTU Wind Energy)*



*Figure 2. Detailed direct-drive generator design of the hub and main frame system for the new Task 37 10-MW reference turbine (Source: Latha Sethuraman, NREL)*

## References

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- Authors: Katherine Dykes, Garrett Barter, Pietro Bortolotti, NREL, United States; Frederik Zahle, DTU Wind Energy, National Laboratory for Sustainable Energy, Denmark; and Karl Merz, SINTEF Energy Research, Norway.

# TASK 39

## QUIET WIND TURBINE TECHNOLOGY



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## ABOUT TASK 39

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 practices in the prediction, measurement and assessment of noise, as well as investigate regulatory aspects.

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:

- Addressing interdisciplinary education and guidance and supporting interdisciplinary discussion
- Addressing technical aspects of design, modeling, assessment, and measurement, including subjective effects
- Developing recommended practices

To date, there has been broad participation in task meetings, involving experts from various 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.

In addition to the participating countries that have formally joined the task, a number of countries have expressed interest in participating in Task 39 or have joined task meetings occasionally since the initial kick-off, but are not fully committed yet. These countries and organizations are:

- Canada (HGC Engineering, Aercoustics)
- China/CWEA (Goldwind, CGC)
- Finland (Poyry)
- The Netherlands (ECN, TU Delft)
- Norway
- Switzerland (Prona SA)
- United Kingdom (ION Acoustics, Hayes McKenzie, Salford University, Innogy Renewables)
- United States (CH2M, NREL, UC Davis)

## PROGRESS & ACHIEVEMENTS

At the last task meeting in Hamburg in September 2018, the participants worked to define a revised version of the work program with three main work packages. They also identified a number of potential sub-tasks consisting of relevant research topics.

The participants also continued their progress on the currently major active sub-tasks. A state-of-the-art report about amplitude modulation was published on the Task 39 webpage. The database about international wind turbine noise regulations has been extended, and participants are now deciding on the format for the final document. This is an important aspect to consider, as the database should be easily accessible and readable to a large audience, including policy-makers.

The wind turbine noise benchmark has been extensively discussed between participants, as well as in collaboration with Task 29, and a first round of comparisons was agreed upon in 2018.

In addition, a road map for two subsequent rounds was drafted. A new benchmark exercise has been proposed, which will be concerned with creating a database of aerodynamic and noise measurements for the validation of models from serrated airfoil. Even if serrations are already widely implemented by the industry, there exists little advanced scientific knowledge to accurately predict the noise emissions from serrated airfoils. The industrial approach so far is highly empirical. Developing such methods may improve the industrial design capabilities.

The measurement campaign will be conducted in the newly-built acoustic wind tunnel facility at DTU Wind Energy. Several participants have expressed their interest in joining this project, as well as possibly contributing to the database using their own facilities.

Task 39 was represented at the last IEC meeting, which concerned the revision of the IEC 61400 standard "Wind energy generation systems, Part 11-2: Measurement of wind turbine noise characteristics in receptor position." At the next meeting, Task 39 will discuss how to position itself in this context and what its role should be.

## OUTCOMES & SIGNIFICANCE

From a general point of view, developing noise mitigation technologies and recommending best practices for regulatory and siting processes is an important step toward public acceptance, which could eventually facilitate the deployment of wind energy. IEA Wind TCP Task 28 has already advanced the potential for enhanced community engagement to address such problems.

On the technical side, the benchmarking and comparisons of models between research institutes and industry contribute to improve the design tools for quiet wind turbine design and siting. This should also help in developing best practices on how to use these tools. Furthermore, the review report on existing noise regulations worldwide may provide a valuable overview for policy-makers, especially in countries whose wind energy development is in an early stage.

## NEXT STEPS

Task 39 is still open for additional participants to improve its international impact. The next task meeting is planned as a side-event to the Wind Turbine Noise 2019 conference in Lisbon in June. This will be an opportunity to approach many actors in the field of wind turbine noise.

Work is continuing on the database of national regulations, the state-of-the-art reports, and writing of fact sheets, as well as the two ongoing benchmarks.

### Benchmarking Wind Turbine Noise Codes

One of the most active sub-tasks at the moment is the Wind Turbine Noise Code benchmark. This effort is a coordinated activity with Task 29 Phase IV. Task 29 focuses on validating aero-elastic wind turbine simulation codes using the so-called DANAERO database. The present benchmark is linked to validation exercises that concentrate on acoustics.

Many institutions have expressed their interest in contributing to this benchmark. It is indeed a unique opportunity to cross-validate institutions' and companies' wind turbine noise codes and compare the results to actual measurement data. The first results are expected to be presented at the Wind Turbine Noise 2019 conference in Lisbon in June.

### References

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

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# TASK 40

## DOWNWIND TURBINE TECHNOLOGIES

### Task 40 Contact and Information

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## ABOUT TASK 40

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

Progress in design standards, design, and analysis methods have contributed to the development of downwind turbines in recent years.

Following the trend toward larger offshore wind turbines, downwind turbines drew interest again, and some demonstration projects were launched. The accumulated data from these projects can verify the modern design and analysis methods for downwind turbines and evaluate their current benefits and problems.

The objective of Task 40 is to coordinate international research and investigate the benefits of downwind turbine technologies. The task is expected to publish an IEA Wind TCP recommended practices on relevant technologies, as well as journal and conference papers.

Task 40 consists of the following work packages (WPs) regarding downwind turbine technologies:

- WP 1: Model development and verification; 2-MW baseline model, tower shadow, nacelle-rotor interaction, stability and control, and complex terrain;
- WP 2: Design and LCOE assessment; blade optimization, and scalability;
- WP 3: Recommended practices; standard evaluation and recommended practices.

## PROGRESS & ACHIEVEMENTS

Task 40 was approved for a three-year period in June 2017. Japan and the United States started participating formally in 2017 and Germany and Spain joined in 2018. The task kick-off meeting was held in December 2017 for participants to update plans for the upcoming phase. Task 40 was officially launched in March 2018.

### WP 1: Model Development and Verification

A 2-MW baseline aeroelastic turbine model was developed. The data from this model is comparable with the operating experience of commercial 2-MW downwind turbines, which have experienced a wide range of operating conditions including typhoons. The model will be applied to the development and verification of models.

Several numerical simulations such as CFD, FSI, and BEM had been conducted for downwind turbines with tubular and truss towers in WP 1-2. By comparing the results, some of the conditions of the models for more accurate load estimation were made clear.

Two tower shadow models were reported for tower load models in BEM [1, 2]. The information about the positive effects of nacelle-rotor aerodynamic interactions on the performance of downwind turbines are informed and discussed in WP 1-3 [3].

The advantages of downwind turbines in yawing stability and its enhancement by individual pitch control were studied theoretically and experimentally in WP 1-4, when storm loads of the model were validated with the field measurement data [4, 5].

In WP 1-5, 3D wind was measured with various anemometers and remote sensing technologies at a typical complex terrain, where the advantages of downwind turbines are clear [6]. The result should extend the performance evaluations of downwind turbines in complex terrains.

## WP 2: Design and LCOE Assessment

WP 2 especially involves extremely large scale downwind turbines. Quantifying 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 large turbines [7-10].

Information on the methods and general procedures in WP 2-1 and WP 2-2 were exchanged in 2018. In collaboration with Task 37 Wind Energy Systems Engineering, parts of Task 37 were adapted to also include the downwind turbines used in Task 40.

## WP 3: Recommended Practices

The task will develop a recommended practice by integrating and summarizing the achievements in WP 1 and 2. The main technical points of the report were summarized in 2018.

## OUTCOMES & SIGNIFICANCE

The main outcomes of Task 40 will be the following changes to downwind turbine technologies:

- Organize a global network that coordinates research and verification efforts
- Identify and quantify perceived technical benefits and risks and propose resolutions
- Quantify opportunities for LCOE in particular large-scale systems
- Identify potential barriers and improvement in standards/regulations and propose recommended practices

Task 40 identifies, resolves, and innovates the technologies of downwind turbine design and analysis for further LCOE reduction and the proliferation of land-based and offshore wind power plants through their collaboration.

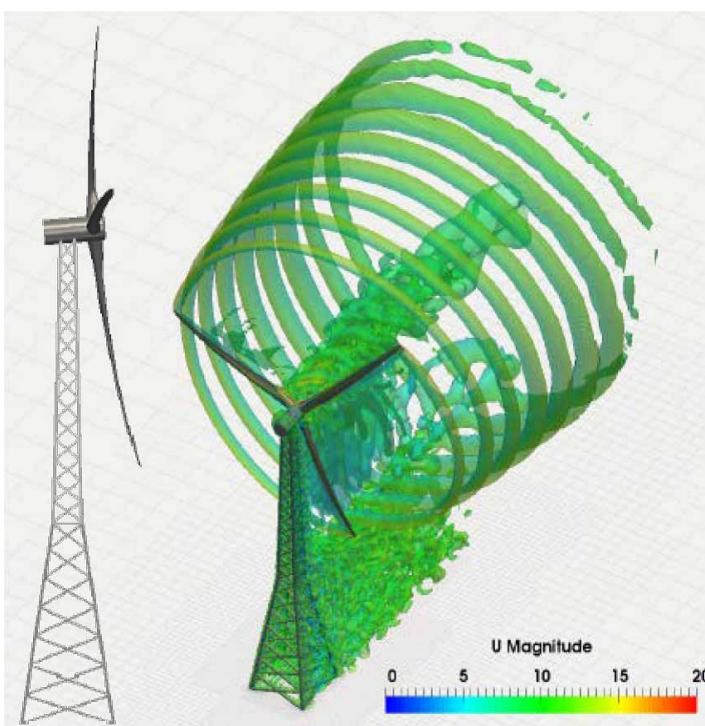


Figure 1. FSI analysis of the 5.3-MW downwind turbine supported by the truss tower [11]

## NEXT STEPS

Task 40 expects to complete the following activities in 2019:

- WP 1: An upwind baseline model will be released as well as the controllers. Other studies in the WP will be applied for the modeling and evaluation of the aerodynamics of downwind turbines.
- WP 2: The achievements in WP 1 will be reflected for a more accurate estimation of the pros and cons of super large downwind turbines. Part of the achievement of the Segmented Ultralight Morphing Rotor (SUMR) project will be transferred to Task 40.
- WP 3: Regulations and guidelines will be surveyed for the relevant technologies.

Table 1. Task 40 Participants in 2018

Member/Sponsor	Participating Organizations
Germany	Fraunhofer IWES
Japan	National Institute of Advanced Industrial Science and Technology (AIST), Nippon Kaiji Kyokai (ClassNK), Hitachi, Ltd. (Hitachi), Kyushu University (KU), The University of Tokyo (UTokyo), Wind Energy Institute of Tokyo, Inc. (WEIT)
Spain	National Renewable Energy Centre (CENER), X1Wind
United States	National Renewable Energy Laboratory (NREL), Boulder Wind Consulting (BWC)

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# TASK 41

## ENABLING WIND TO CONTRIBUTE TO A DISTRIBUTED ENERGY FUTURE

### Task 41 Contact and Information

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### ABOUT TASK 41

Distributed energy technology, which produces energy closer to the load, has become a growing portion of the energy supply. Distributed energy is particularly essential for countries with a limited transmission infrastructure, as they will quickly reach integration limits for large central station variable renewable energy and need a more cost-effective solution than upgrading their transmission systems.

The market potential projections in the U.S. show that distributed wind deployment could exceed 20 GW by 2030, by using a wide range of technology, including large wind turbine technology, in distributed applications [1].

Additionally, IEA Wind TCP research identifies that approximately 34% of unserved populations across the globe will be supplied by off central grid solutions which could include distributed wind [2].

However, the necessary mechanical and electrical systems, deployment methodology, and social acceptance strategies are far from optimized, especially in the face of large cost reductions led largely by national investments in large scale wind and solar PV technologies.

This new research collaboration will work to accelerate the development and deployment of distributed wind technology through efforts that will lower their deployed costs while increasing user confidence. The collaboration will include efforts to improve small and distributed turbine standards, address integration challenges, share cost reduction experiences and allow for the expanded sharing of research innovation.

Participants will also actively take advantage of similar work being done in other IEA Wind TCP research tasks as well as by the industry. This effort will engage widely with governmental and non-government organizations to inform and educate about the appropriate use of distributed wind energy.

Task 41 was approved for a four-year period with the member countries identified in Table 1. Poland, which is not a current IEA Wind TCP participant, has also expressed interest in participating. Additional participants are welcome, and the U.S. Department of Energy is currently covering the expenses of the Operating Agent, so no annual fee is expected.

### PROGRESS & ACHIEVEMENTS

In March of 2018, the IEA Wind TCP Task 11 Base Technology Information Exchange hosted a Technical Experts Meeting (TEM) that brought together DW experts to obtain a better understanding of the industry markets and challenges. The meeting was co-located with a meeting of IEA Task 28, Social Acceptance of Wind Energy Projects, to allow for strategic engagement around issues facing the deployment of distributed wind technologies (DWT).

This meeting, combined with the results from the concluding Task 27 Small Wind Turbines in High Turbulence Sites, led to the development of a workplan that addresses the technology and deployment innovations needed to yield aggressive global growth for distributed wind technologies. The collaboration will carry out its work in a series of focused work packages which include the following topics:

- **WP 1** will address existing concerns around the cost, complexity, and effectiveness of existing distributed wind turbine technical standards, as well as develop a technical justification for modifications to these existing standards.
- **WP 2** will look to better understand and implement data collaboration opportunities. Wide scale technology and deployment innovation requires the sharing of information across research and development organizations, including data, documents, and research studies.
- **WP 3** will focus expanding learning around the integration of DW into evolving electricity systems. Expanding insight into markets with increased costs (isolated microgrids) or additional non-monetary benefits (resiliency, reliability, grid support, and diversification) will support expanded market access.



Figure 1. Medium-scale distributed wind turbine installed at an industrial complex outside of Boston Massachusetts, United States. (Source: Aegis Renewable Energy, Waitsfield, VT)

- **WP 4** will expand collaboration across the wider wind power and distributed generation industries, building an understanding of the role that DW can play in supporting markets while expanding the understanding of how innovation in these markets can be applied to DWT.
- **WP 5** will focus on expanding the collaboration around areas of potential innovation to lower the life cycle cost of DW technology, based on a better understanding of how cost savings in large wind can be downscaled to small and mid-sized wind technologies.

## OUTCOMES & SIGNIFICANCE

Task 41 aims to lower the costs and deployment barriers for distributed wind through collaborative research and information dissemination. As described, this effort will undertake a number of activities that will lead to the following outputs:

- A report on recommendations for potential standards changes that will be used to drive additional national and international research
- Formal justified standards recommendations to both IEC and IEC-RE
- Specification, development, and articulation of a data sharing catalog for distributed wind
- A review of modeling practices for wind energy in isolated power systems
- A best practice guide for the design of high renewable contribution isolated power systems
- A state of the industry report for the integration of distributed wind energy into isolated and weak power grid systems
- Expanded collaboration across IEC TCP's on wind power deployment and integration in distributed markets
- A report on downscaling opportunities for mid and small scale wind turbines

The outcome of this work, as well as the work undertaken by participating nations in support of Task 41 through collaboration with efforts outside of the IEA Wind TCP, will lead to the expanded global use of wind energy with a focus on distributed generation applications.

## NEXT STEPS

Task 41 is working actively to implement the work packages described previously, with a strong focus on work packages 1 through 3. Standards-focused meetings are planned in 2019 for North America, Europe, and Asia to get feedback from industry and DW certification experts, leading to a next steps document that will be circulated for discussion. Additional efforts understanding integration, wind modeling approaches, and data needs will also be initiated in the early stages of this effort.

**Table 1. Task 41 Participants in 2018**

Member/Sponsor	Participating Organizations
Austria	Fachhochschule Technikum Wien
Belgium	Vrije Universiteit Brussel
Canada	Natural Resources Canada (NRCan)
CWEA	China Wind Energy Association (CWEA), China General Certification (CGC), Goldwind, and Inner Mongolia University of Technology
Denmark	Denmark Technical University (DTU) & Nordic Folkecenter for Renewable Energy
Ireland	Dundalk Institute of Technology
Japan	New Energy and Industrial Technology Development (NEDO)
Korea	Korea Institute of Energy Research
Spain	CIEMAT
United States	National Renewable Energy Laboratory, Pacific Northwest National Laboratory

## References

- Opening Photo: Large scale distributed wind turbine installed on the distribution network surrounded by family farms, Devon England. (Photo Credit: Ian Baring-Gould, National Renewable Energy Laboratory)
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- Author: E. Ian Baring-Gould, NREL, United States.



**Table 1. Key Statistics 2018, Austria**

Total (net) installed wind power capacity	3.05 GW
Total offshore capacity	0 MW
New wind power capacity installed	230 MW
Decommissioned capacity (in 2018)	29 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 2018, Austria installed 71 turbines with a capacity of 230 MW, compared to 63 turbines (196 MW) in 2017. By the end

of 2018, more than 3,000 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 0.082 EUR/kWh (0.094 USD/kWh). For 2019, it was fixed at 0.081 EUR/kWh (0.093 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 (51.5 million USD) in additional funding; this allows for 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 (exclusive of large hydropower projects), 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 3,900 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].

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; 0.111 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 (57.3 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 (1.1 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 2019, the tariff was fixed at 0.081 EUR/kWh (0.093 USD/kWh). In 2017, a small amendment to the GEA 2012 allocated 45 million EUR (51.6 million USD).

On average, around 460 million EUR (527 million USD) were invested annually from 2012-2018 (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 (1.1 billion USD), create 4,350 wind industry jobs, and could deliver an additional 2% 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% since 2011, with a small, but constant, overall trend upward. 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 1,690 MW of wind capacity with an estimated annual rate of 3.6 TWh of electricity production. One year later, the capacity increased to 2,097 MW, with 4.5 TWh of electricity production—7.2% of the Austrian electricity demand. New installations reached 325 MW in 2015, leading to a cumulative installed capacity of 2,421 MW (8.7% of electricity consumption). The 2015 installed capacity produced more than 5.2 TWh/yr.

With a capacity of 3,045 MW in 2018, 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<sub>2</sub>. The estimated capacity by the end of 2019 is 3,241 MW.

Most wind turbines are in Lower Austria (1,661 MW), followed by Burgenland (1,090 MW), Styria (237 MW), Upper Austria (47 MW), Vienna (7 MW), and Carinthia (1 MW) (Table 2). 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 3.2 MW for newly-installed capacity. In 2018, 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 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 (102 million USD) in 2011 to more than 200 million EUR (230 million USD) in 2014. Rising costs are mainly the result of market failure.

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

A small amendment to the GEA 2012 that occurred in June 2017 somewhat reduced the pressure and political uncertainty surrounding wind power development. Nevertheless, there are still 176 wind turbines (570 MW) in the current queue waiting until 2023 for new funding. If all of the projects in the queue were built, it would free investments of 1 billion EUR (1.1 billion USD), create 4,350 wind industry jobs, and deliver an additional 2% of electricity consumption. Since those projects have already been approved by the legal authorities, significant investors might be frustrated.

## R,D&D ACTIVITIES

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### National R,D&D Priorities & Budget

In Austria, several national R,D&D projects focus on the challenges of wind energy production in cold climates. The "R.Ice" project, launched in April 2016, aims to improve an icing map of Austria and observe icing events at wind turbines using an innovative imaging method. Project "Ice.Control" investigates the use of meteorological prognoses for icing events on wind turbines while Project "N.Ice" investigates the reduction of ice formation by nanostructuring of surfaces with an ultrashort pulse laser.

Austria is also currently carrying out one national research project on small wind turbines. Project "SmallWP@ Home" investigates flow conditions over different roof shapes.

### Collaborative Research

Austria has been a member of IEA Wind TCP Task 19 Wind Energy in Cold Climates since 2009. During the term ending in 2018 Austria lead a subtask which aimed to prepare guidelines and recommendations regarding ice risk assessments. Austria also participated in an evaluation of the blade heating system of Vestas wind turbines for two winter seasons. Austria will continue its work with Task 19 through the next term, which ends in 2021.

Austria has also participated in IEA Wind TCP Task 27 Small Wind Turbines in High Turbulence Sites since 2013, in Task 32 Lidar Systems for Wind Energy Deployment since 2016. Although Task 27 has ended, Austrian participation in Task 32 will continue through the end of 2021.

## IMPACT OF WIND ENERGY

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### Economic Benefits & Industry Development

The Austrian wind power market consists of wind turbine operators, planning offices, and component suppliers for international wind turbine manufacturers. In 2018, the annual turnover of existing wind parks operators was over 515 million EUR (590 million USD).

Austria's wind energy industry includes more than 180 supplier and service companies. These companies are industry leaders in the fields of electricity conduction, wind power generators, wind turbine generator design, and high-tech materials. Local companies are successful in both the land-based and 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 wind energy supply chain industry obtains an export volume of 400 million EUR (458 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-sized wind turbines.

Austrian component suppliers also serve the international wind turbine market. Bachmann Electronic GmbH is a leading manufacturer of turbine control systems. Hexcel Composites GmbH develops and produces materials for blades. Elin EBG Motoren GmbH supplies generators for the global market. There are also several global players with wind competence centers in Austria, such as SKF. There has been an increase of small and medium enterprises entering the market in recent years, largely due to the growth of the domestic market.

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

The recently-published scientific paper Stromzukunft Österreich 2030 quantifies the total investment costs as 1,350 to 1,570 EUR/kW (1,546 to 1,799 USD/kW) and the O&M costs as 36 to 40 EUR/kW (41 to 46 USD/kW) per year.

## NEXT TERM

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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.

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**Table 1. Key Statistics 2018, Belgium**

Total (net) installed wind power capacity	3.17 GW
Total offshore capacity	1.19 GW
New wind power capacity installed	0.36 GW
Decommissioned capacity (in 2018)	0 MW
Total electrical energy output from wind	7.50 TWh
Wind-generated electricity as percent of national electricity demand	8.93%
Average national capacity factor	27%
National wind energy R&D budget	2.73 mil EUR; 3.13 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-km<sup>2</sup> 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 2018, 232 offshore wind turbines were operational, producing 2,867 TWh/yr and providing electricity for approximately 8 million 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.

## 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 to meeting 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 (Table 1).

By 2020, total land-based installed wind power capacity in Belgium should reach 3,000 MW, with an additional 2,292 MW planned offshore for a total of 5,292 MW of wind power. Offshore wind alone will account for 10% of total 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 made a decision regarding the LCOE for the remaining wind parks: Mermaid, Northwester 2, and Seastar. These three parks shall be built at an LCOE of 79 EUR/MWh (90.5 USD MWh). The period of support is fixed at 16 years, with a possible one-year extension in case of low-wind circumstances.

### Progress & Operational Details

Offshore wind-generated electricity first began in 2009 and progressed rapidly to a total of 1,186 MW in 2018. The Belgian government is working quickly to reach the 2020 targets.

Land-based wind power capacity remained low until 2004, at which point installed capacity and production started to double year after year, from 96 MW in 2004 to 1,983 MW in 2018. Land-based wind is on track to reach its 2020 objectives after much progress during the last few years. Additionally, the rated capacity of installed turbines has increased sharply for offshore and land-based wind.

## 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 in-depth IEA 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 European Strategic Energy Technology (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 energy via several projects. An important one is the co-financing of the state-of-the art project OWI-lab ([www.owi-lab.be](http://www.owi-lab.be)). The OWI-Lab was initiated by several leading companies in the Belgian wind energy sector: 3E, CG Power Systems, GeoSea-DEME, and ZF Wind Power (formerly Hansen Transmissions).

These companies worked in close collaboration with the Agoria Renewable Energy Club and GENERATIES, the industrial innovation platform for renewable energy technologies in the Flemish Region. Vrije Universiteit Brussel (VUB) is responsible for the project’s academic research, in close collaboration with the other local universities.

The Belgian government invested 2.73 million EUR (3.13 million USD) in offshore and land-based wind in 2017. This is less than the 4.3 million EUR (4.9 million USD) invested in 2015, mainly due to the reduction of the budget for unallocated wind energy (from 3.5 million EUR [4.0 million USD] in 2015 to 0.07 million EUR [0.08 million USD] in 2016). On the other hand, the budget for wind energy systems and other technologies increased from 0.54 million EUR (0.62 million USD) to 2.45 million EUR (2.81 million USD).

### 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, and Monitoring Solutions
- Operators such as OWI-lab, VJI, and 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 power R&D [1]. This lab has invested 5.5 million EUR (6.3 million USD) in state-of-the art testing and monitoring tools, including:

- Large climatic test chamber (-60°C to +60°C; humidity)
- Floating lidar (FLIDAR)
- Offshore measurement systems
- R&D and 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 [2].

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 [3].



## **Collaborative Research**

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

Another international collaboration program is the North Seas Energy Cooperation. This initiative promotes 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), along with Maros Sefcovic, the Vice President for Energy Union and Miguel Arias Canete, Commissioner for Climate Action and Energy. Belgium was president of the initiative until September 2017, followed by a Dutch presidency which handed it over to Denmark in June 2018. During the Directorates General (DG) meeting in December all DG's agreed to provide an overview of their group's roadmap', including deliverables and timetables, through mid-2019, and to share their progress in meeting those benchmarks.

## **IMPACT OF WIND ENERGY**

### **Environmental Impact**

In addition to adding sustainable energy capacity, offshore wind energy developments also increase biodiversity, specifically organisms such as corals and marine flora. 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<sub>2</sub> emissions, and fulfilling 10% of the national electricity demand.

### **Economic Benefits & Industry Development**

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

The impact on employment is substantial, with jobs created in the design, construction, maintenance, and replacement of wind parks industries, in addition to the permanent workforce. Many of these jobs are created 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.

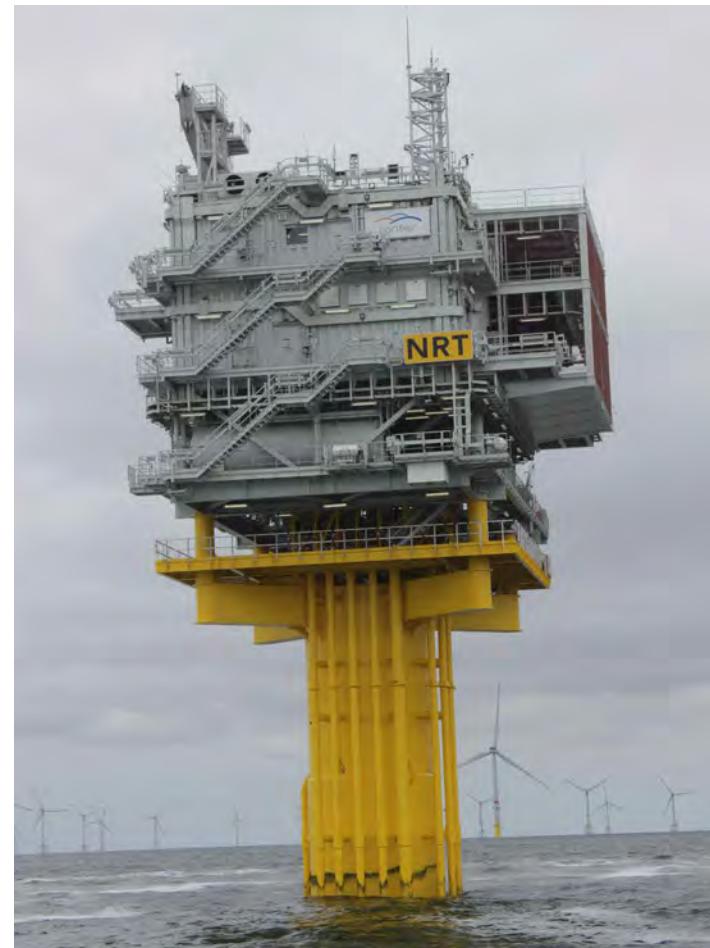


Figure 2. Belgian offshore wind farm in the North Sea

## **NEXT TERM**

The offshore wind parks Rentel, Norther, Seastar, Mermaid, and Northwestern 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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Author: Jan Hensmans, FPS Economy, SMEs, Self-Employed and Energy, Belgium.



**Table 1. Key Statistics 2018, Canada**

Total (net) installed wind power capacity	12.8 GW
Total offshore capacity	0 GW
New wind power capacity installed	0.566 GW
Decommissioned capacity (in 2018)	0 GW
Total electrical energy output from wind	31.8 TWh
Wind-generated electricity as percent of national electricity demand	4.96%
Average national capacity factor	28.37%
National wind energy R&D budget	3.99 mil CAD; 2.55 mil EUR; 2.92 mil USD

## OVERVIEW

Canada's installed wind energy capacity grew to 12,816 MW by the end of 2018, with 566 MW of new wind energy installations commissioned across six projects in three provinces.

These installations represented over 1 billion CAD (0.64 billion EUR; 0.73 billion USD) of total investment [1]. Almost twice as much new capacity was installed in 2018 as in 2017 [2].

## MARKET DEVELOPMENT

### National Targets & Policies Supporting Development

Under the 2015 Paris Agreement, Canada committed to a greenhouse gas (GHG) reduction of 30% below 2005 levels by 2030. In December 2016, in consultation with the provinces and territories, the federal government released the Pan-Canadian Framework on Clean Growth and Climate Change [3].

The plan includes a policy framework for pricing carbon pollution and measures to achieve reductions across all sectors of the economy. The minimum carbon price starts at 10 CAD/tonne (6.4 EUR/tonne; 7.3 USD/tonne) in 2018, rising to 50 CAD/tonne (32 EUR/tonne; 36.7 USD/tonne) in 2022.

While there are no national targets for renewable energy, many provinces do have renewable energy targets, including: Alberta (30% of electricity used by 2030); New Brunswick (40% electricity used by 2020); Nova Scotia (40% of electricity produced by 2020); and Quebec (25% increase over 2013 level of renewable energy output by 2030) [4-7].

Saskatchewan has a target of 50% renewable energy capacity by 2030, which includes approximately 1,900 MW of new wind power capacity [8]. The Northwest Territories Government has set a goal of reducing GHG emissions from diesel-generated electricity by 25% compared to 2015 levels [9].

The Province of New Brunswick's government enacted the Community Renewable Energy program (also known as the "Locally Owned Renewable Energy Projects that are Small Scale" [LORESS] Program) to allow the provincial utility (NB Power) to obtain up to 80 MW of distribution-level renewable energy [10]. Under the program, NB Power procured 38 MW from two First Nations projects, and an additional 20 MW from a community wind energy developer [11-13].

### Progress & Operational Details

New wind-generated electricity is primarily being procured competitively. Following round one of its Renewable Electricity Program (REP), which delivered nearly 600 MW of wind power capacity at record low pricing (a weighted average bid price of 37 CAD/MWh [23.7 EUR/MWh; 27.1 USD/MWh]), the Government of Alberta announced the results of its round two and three calls in December.

Round two, which required a minimum 25% indigenous ownership, yielded five successful wind projects totaling 363 MW at a weighted average price of 38.69 CAD/MWh (24.76 EUR/MWh; 28.36 USD/MWh). Round three produced similar results with three successful projects selected, totaling 400 MW at a weighted average price of 40.14 CAD/MWh (25.69 EUR/MWh; 29.42 USD/MWh) [14].

The provincial utility of Saskatchewan, SaskPower, issued a Request for Proposals for wind-generated electricity and awarded two contracts for a combined total of 377 MW [15-16]. Reinforcing the competitive cost of wind energy, SaskPower received 29 project proposals with an average bid price of 42 CAD/MWh (26.9 EUR/MWh; 30.8 USD/MWh), representing both the price of electricity and the cost of interconnecting [17].

In the Province of Quebec, the 224.5-MW Nicolas-Riou project was the largest Canadian project commissioned in 2018 and the 147.2 MW Mont Sainte-Marguerite project also came online [18-19]. The Province of Ontario saw both the 100-MW North Kent Wind Farm, and the 75-MW Amherst Island Wind Project commissioned [20-21].

In New Brunswick, the Cap Pelé project (a single 2.35-MW turbine) commenced operation and the Kent Hills 3 expansion added 17.25 MW to the Kent Hills wind farm [22-23].

## R,D&D ACTIVITIES

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### National R,D&D Priorities & Budget

Research efforts in Canada support the integration of wind energy into the electricity system. Natural Resources Canada, the federal government ministry responsible for energy, supports wind energy R&D through funding programs at its Office of Energy Research and Development (OERD) and at its energy laboratory, CanmetENERGY.

Specific research activities focus on evaluating how variable renewable energy generation can support electricity grid services and how utilities can best utilize wind forecasts, with a particular interest in ramping, cold climate, and icing forecasts. Canada is moving to reduce diesel consumption in its Northern and off-grid communities and research activities are investigating how renewable generation can work in these microgrids.

Canada has two wind energy research centers, the Wind Energy Institute of Canada (WEICan) and Nergica (formerly TechnoCentre éolien), who work closely with the federal government's research programs. Federal and provincial research funding directed specifically for wind energy totaled 3.99 million CAD (2.55 million EUR, 2.92 million USD).

As part of the Canadian government's clean growth agenda, it continued funding several programs and initiatives. Funding continued for the Energy Innovation Program at 52.9 million CAD (33.85 million EUR; 38.33 million USD) annually to accelerate clean technology research and development.

Other components of the Green Infrastructure program, including 100 million CAD (64 million EUR; 7.33 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.

### Matters Affecting Growth & Work to Remove Barriers

On October 31, Ontario passed the Cap and Trade Cancellation Act of 2018 which officially removed Ontario's cap and trade program law [24]. The Ontario government released a revised plan outlining their approach to reducing emissions, although there is no specific mention of wind energy [25].

In its most recent analysis of national energy supply and demand projections, the National Energy Board indicates wind energy is forecast to add approximately 510 MW of capacity annually through 2040, accounting for 27% of the new electricity generation Canada will need between 2017 and 2040 [26].

### National Research Initiatives & Results

The North American Renewable Integration Study (NARIS) is examining the interconnected power systems of México, the United States, and Canada, from planning through operation, and balancing at 5-minute resolution. The study will assess strategies and technologies to enable high penetration of renewables. Results are expected in late 2019.

The federally-funded Regional Electricity Cooperation and Strategic Infrastructure (RECSI) initiative issued final reports for the Atlantic Canada and Western Canada dialogues [27-18]. This project, announced in the 2016 federal budget, committed 2.5 million CAD (1.6 million EUR; 1.8 million USD) to facilitate regional dialogues and studies. This research identified key electricity infrastructure projects with the potential to significantly reduce GHG emissions in the electricity sector and meet provincial climate change policy objectives.

The federal CanmetENERGY-Ottawa lab continued to collaborate with the University of New Brunswick and Nergica to refine and validate wind plant production forecasting models using inputs from Environment and Climate Change Canada (ECCC) weather forecasts.

In 2018, Nergica produced the Best Practices for Wind Farm Icing and Cold Climate Health and Safety Guide, informed by its extensive work on icing related issues. The guide was published by the Canadian Wind Energy Association (CanWEA) [29].

## Test Facilities & Demonstration Projects

Located in Gaspé, Quebec (QC), Nergica is a center of applied research that stimulates innovation in the renewable energy industry through research, technical assistance, technology transfer, and technical support for businesses and communities. The organization's activity sectors include wind energy, solar photovoltaics (PV), and the integration of renewables into electricity grids. Nergica owns and operates a research site that includes two 2-MW wind turbines, a 16-kW solar PV array, and a hybrid microgrid comprising wind, solar PV, storage and diesel.

Preliminary results are expected this year from an ongoing research partnership with Ouranos, Hydro-Québec, Manitoba Hydro, and Ontario Power Generation, assessing the impact of climate change on Canada's wind power sector. Nergica continues to assist the industry on icing-related issues including ice-induced energy losses and ice protection system performance assessments. More highlights are available in Nergica's 2017-2018 annual report [30].

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 undertook four service scenarios, three of which demonstrated the ability of a wind farm to provide secondary frequency regulation by following an Automatic Generator Control (AGC) set point signal provided by a Canadian system operator.

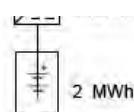


Figure 1. Icing observed on wind turbine blade (Photo credit: Nergica)

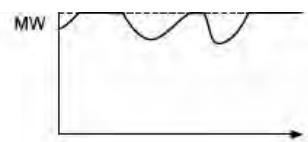
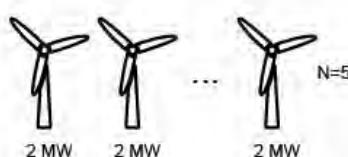
Figure 2 depicts the scenarios: (Scenario 2) type five turbines with the prevailing wind speed above the turbines' rated wind speed; (Scenario 3) type five turbines below the turbines' rated wind speed; and (Scenario 4) type four turbine, with and without a battery, above and below the turbine's rated wind speed.

Results indicate that wind turbines perform well when providing secondary frequency regulation and that providing regulation can be profitable for the wind farm operator. Using battery storage improves performance and income [31]. Scenario one was a specific test undertaken to evaluate the ability of a battery to reduce peak load.

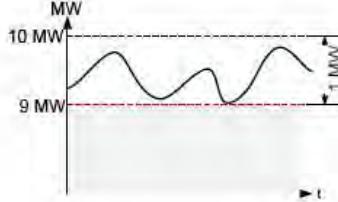
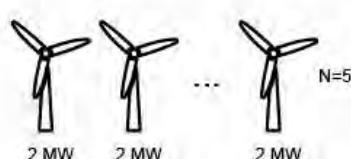
Scenario 1



Scenario 2



Scenario 3



Scenario 4

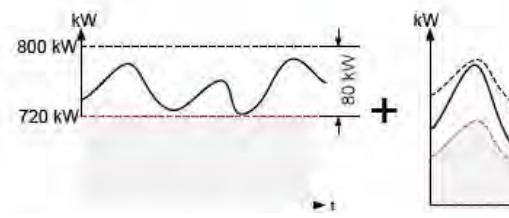
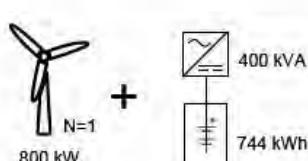


Figure 2. WEICan Service Scenarios: wind turbines and battery following AGC signal (Source: WEICan)

## Collaborative Research

In 2018, Canada participated in the following tasks:

- Task 19 Wind Energy in Cold Climates
- Task 25 Design and Operation of Energy Systems with Large Amounts of Variable 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. The North American Renewable Integration Study (NARIS) brought Canadian researchers together with the US National Renewable Energy Laboratory (NREL), system operators, and utilities in all three jurisdictions.

## IMPACT OF WIND ENERGY

### Environmental Impact

CanWEA released a Wind Energy and Bat Conservation Review that provides industry and regulators with science-backed strategies for avoiding, minimizing, and mitigating the impact of wind turbines on bats. The review summarizes the scientific and practical knowledge gained over several decades with respect to wind energy and bats. It reviews and assesses mitigation options at all phases of project development and advises on measures to offset unavoidable impacts [32].

### Economic Benefits & Industry Development

For 2018, estimates of total employment and economic activity show that new wind energy projects provided 2,576 job-years of employment, or 4.55 job-years of employment per megawatt. This includes both construction and operations and maintenance jobs. In addition, new wind energy projects garnered 1 billion CAD (0.64 billion EUR; 0.73 billion USD) on community investments which, on a per MW basis, translates to approximately 1.8 million CAD/MW (1.2 million EUR/MW; 1.3 million USD/MW) [33].

Alberta's procurement of 763 MW of renewable energy will create jobs and economic benefits for indigenous and rural communities. The REP round two (363 MW) projects meet the required 25% equity partnership with indigenous communities, which provides training opportunities, jobs, revenue sharing, and other economic benefits to participating communities [34].

Pattern Energy Group LP and Nigig Power Corporation, a wholly owned subsidiary of Henvey Inlet First Nation, have started construction of the 300-MW Henvey Inlet Wind facility in Ontario, after finalizing 1 billion CAD (0.64 billion EUR; 0.73 billion USD) in financing. The project is expected to generate lease royalties annually for the Henvey Inlet First Nation, in addition to income from project distributions [35].

The Nicolas-Riou project, located in the Bas-Saint-Laurent region of Quebec, was the largest Canadian project commissioned in 2018. The 224.5-MW project comprises sixty-five 3.45-MW turbines. In addition to the financial benefits distributed to project stakeholders, an annual contribution of more than 1.1 million CAD (0.7 million EUR; 0.8 million USD) is planned for the Bas-Saint-Laurent and Gaspésie regions throughout Nicolas-Riou's 25-year contract with Hydro Quebec [36].

Pattern Energy brought their 147.2-MW Mont Sainte-Marguerite project, comprised of forty-six 3.2-MW turbines, online. With an estimated income of 1.9 million CAD/MW (1.2 million EUR; 1.4 million USD), the project sponsor plans to contribute 5,000 CAD/MW (3,200 EUR/MW; 3,665 USD/MW) to participating municipalities annually for the 25-year project [37].



Figure 3. 15-MW Moose Lake Wind Project, Enercon E-141 near Tumbler Ridge, British Columbia, Canada (Credit: ENERCON Canada)

## NEXT TERM

CanWEA estimates that 1,000 MW of new wind power capacity will be commissioned by the end of 2019. NRCan is supporting the creation of a Utility Forum comprising the ten provincial transmission system operators.

Results from the North American Renewable Integration Study are slated for release in 2019. Development of a forecasting tool, based on Environment Canada wind-speed forecast data, with a goal to undertake testing at Nergica and WEICan, will continue in 2019.

The Forum will oversee research efforts regarding the integration of wind power and other non-synchronous forms of generation to provide electric grid support services, including field demonstrations of wind plant/turbine capabilities. A review of provincial grid codes from a non-synchronous generation perspective is being considered.

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Authors: Mackenzie O'Connell, Ryan Kilpatrick, and Paul Dockrill, Natural Resources Canada.

# Chinese Wind Energy Association (CWEA)



**Table 1. Key Statistics 2018, China**

Total (net) installed wind power capacity	209.5 GW
Total offshore capacity	4.4 GW
New wind power capacity installed	21.1 GW
Decommissioned capacity (in 2018)	---
Total electrical energy output from wind	366.0 TWh
Wind-generated electricity as percent of national electricity demand	5.2%
Average national capacity factor	23.9%
National wind energy R&D budget	101 mil CNY; 12.8 mil EUR; 14.7 mil USD
Target	210 GW by 2020

## OVERVIEW

China continues to have the highest wind power capacity in the world. Wind power remains the third largest generation source in China, following thermal and hydro-electricity sources. In 2018, China installed 21,143 MW of new wind power capacity—an 11.2% increase in growth from last year that brought the country's accumulated capacity to 209,530 MW.

New installations in the mid-eastern and southern regions account for 56.8% of the total new installation capacity. Grid-connected capacity increased to 184,000 MW, thanks to the addition of 20,590 MW installed in 2018. New wind power capacity accounted for 9.7% of installed power capacity nationwide.

The average full-load-hour of wind power was 2,095 hours in 2018, an increase of 147 hours from 2017. Wind-generated electricity totaled 366.0 TWh, which marked a 19.7% increase over the previous year. Wind-generated electricity accounted for 5.2% of China's total electricity generation, an increase of 0.4% over 2017. The average wind curtailment rate was 7%, 5% lower than in 2017.

In 2018, the Chinese government issued a series of policies and regulations to reduce wind curtailment and promote the development of distributed wind power. Chinese companies also 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

The National Energy Administration (NEA) issued guidelines for energy work in 2018. These guidelines encouraged the wind industry to control the wind power construction scale in severe generation curtailment areas, promote the construction of distributed and offshore wind projects, and propel the construction of projects that demonstrate wind power parity, among other recommendations.

In addition, the NEA issued a notice on relevant requirements for wind power construction management in 2018. The notice has led to the competitive allocation of wind power projects.

The allocation of wind power project will be determined by bidding in 2018. Hebei, Jiangsu, Shanghai, Guangdong, Ningxia, Shanxi and others have adopted the allocation method of competitive bidding.

Ningxia released the first batch of wind power projects, which determined the developers and on-grid price through bids; the lowest price is 0.14 CNY (0.018 EUR; 0.02 USD) than the feed-in-tariff.

The NEA's 2018 management requirements aimed to speed up the construction of distributed wind power projects. The requirements presented measures for promoting distributed wind power development 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. More than eight cities and provinces, including Hebei, Shanxi, Henan, Guangdong, Guangxi and others have developed plans for distributed wind projects, and more than 8,000 MW from distributed projects will be developed in the future.

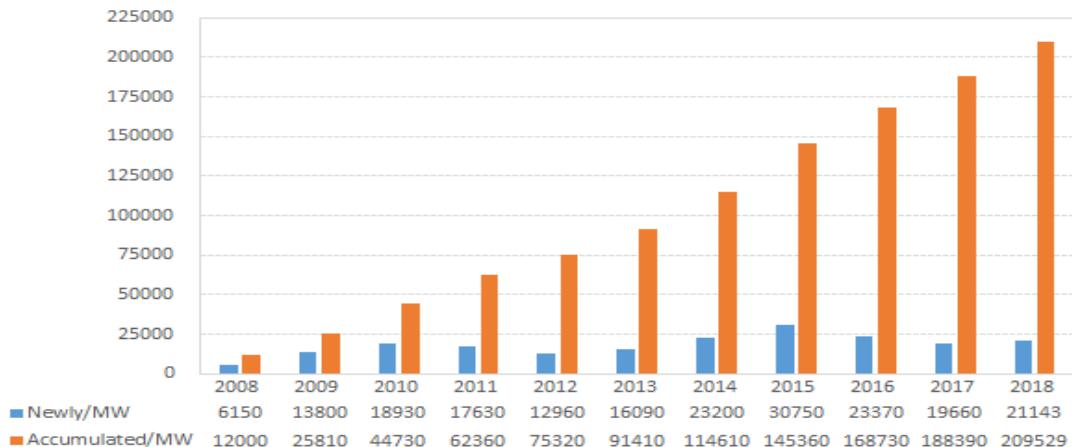


Figure 1. New and accumulated installed wind power capacity in China, 2008-2018 (Source: CWEA)

## Progress & Operational Details

By the end of 2018, China installed 21,143 MW of new wind power capacity (excluding Taiwan). This accounted for 43% of new global wind capacity for the year. The accumulated wind power capacity in China reached 209,530 MW. This accounts for 38.9% of wind power capacity worldwide, maintaining China's status as the nation with the highest wind power capacity in the world.

Compared to 2017, the rate of new wind power installations increased by 7.5% and cumulative installed power capacity increased by 11.2%. Wind power generation reached 366 TWh in 2018—5.2% of total electricity generation.

China installed 9,610 new wind turbines in 2017, bringing the national total of operating turbines to 123,853. The average capacity of these newly installed wind turbines was about 2.2 MW, an increase of 4.8% since 2016. The total installed capacity will exceed 30 GW in 2020 and will even surpass about 70 GW in 2030.

The five provinces with the greatest new installed capacity were:

- Hebei (2.6 GW)
- Henan (2.3 GW)
- Jiangsu (1.8 GW)
- Qinghai (1.7 GW)
- Shanxi (1.6 GW)

Together, these provinces accounted for 48% of the new capacity nationwide. Nearly 57% of all the new installations in China are located in the nation's middle, eastern, and southern regions. The average weighted full load hours among operating wind farms totaled 2,095 hours, which marked an increase of 147 hours compared to 2017.

In 2018, nine provinces issued offshore wind project development plans: Fujian, Guangdong, Hainan, Hebei, Jiangsu, Liaoning, Shandong, Shanghai, and Zhejiang. More than 50% of offshore wind's grid-integrated capability is located in Jiangsu and Shanghai. In 2018, there were more than 22 projects—totaling about 7,000 MW—approved or under construction in Fujian, Guangdong, Hebei, Jiangsu, Liaoning, Shanghai, and Zhejiang.

## Matters Affecting Growth & Work to Remove Barriers

Integration and consumption are still significant problems that limit wind power growth in China, but wind curtailment continues to be the main restriction on wind power development.

The annual curtailed wind-generated electricity in 2018 was 28 TWh. Xinjiang (23%), Gansu (19%), and Inner Mongolia (10%) provinces had the highest wind curtailment rates in China. The curtailed wind-generated electricity Xinjiang province accounted for the 80% of the total curtailment in the country.

To resolve this problem, the government increased consumption of wind power and encouraged inter-provincial generation right transfer trading in 2018. Consequently, the wind curtailment rate reduced 5% from the previous year.

Because feed-in-tariffs can increase the financial burden on wind power developers (and the resulting deficit can sap their motivation), it is essential to perfect market mechanisms. Additionally, the higher power price of wind has made it more difficult to compete with coal-fired generation.

The NEA released a notice on actively promoting the work of wind power and photovoltaic power generation without subsidies, with the hope that this will drive cost reduction, increase market competitiveness, and encourage the construction of wind projects of parity.

# R,D&D ACTIVITIES

## National R,D&D Priorities & Budget

In 2018, the Ministry of Science and Technology of the People's Republic of China launched the National Key Research Program for renewable and hydrogen energy.

The program, which includes 38 tasks, began implementation in 2018 and aims to improve the innovation capability of renewable and hydrogen energy in China. The total budget is over 656.5 million CNY (83.3 million EUR; 95.4 million USD), and the budget for wind power is above 101.1 million CNY (12.8 million EUR; 14.7 million USD). Four research projects are related to wind power:

- Research complex wind resources for wind power generation, as well as their application and verification
- Develop a full-size ground test system for a 15-MW wind turbine transmission chain
- Research blade test technology and test the system of a large offshore wind turbine
- Create key technologies that will optimize design, mass manufacturing, installation, commissioning, and operation for large offshore wind turbines and key components

## National Research Initiatives & Results

In 2018, some manufacturers finished installing wind turbines larger than 5 MW, such as CSIC Haizhuang, Goldwind, Mingyang, and Shanghai Electric. The largest wind turbine (7.25 MW) was installed in Jieyang, Guangdong province, by Mingyang.

Ice formation on wind turbine blades is a worldwide problem for turbines operating in cold climates. Blade icing not only imperils the safety of the wind turbine itself, but it also reduces power generation capacity.

The Center of Aeromechanical Research and Development, Goldwind, Hunan University and Shantou University took part in the IEA Wind TCP Task 19 (Wind Energy in Cold Climates) and made some advances in 2018. The team finished a refrigeration experiment on the Goldwind HQ63-17 airfoil in a tunnel, as well as a test of the electric deicing protection system.



## Test Facilities & Demonstration Projects

In 2018, the Institute of Electrical Engineering, CAS finished the research project "Research on transmission chain test technology of large wind turbines." They also established the national standard "Technical specification for ground test of wind turbine drive chain" and completed a detailed design scheme of a wind turbine drive chain ground test system.

## Collaborative Research

By the end of 2018, the Chinese Wind Energy Association (CWEA) had arranged for 28 domestic wind power companies, research institutes, and universities to participate in IEA Wind TCP Tasks:

- Task 11 Base Technology Information Exchange
- Task 19 Wind Energy in Cold Climates
- Task 25 Design and Operation of Energy Systems with Large Amounts of Variable Power
- Task 27 Small Wind Turbines in High Turbulence Sites
- Task 29 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 36 Forecasting for Wind Energy
- Task 37 Systems Engineering
- Task 39 Quiet Wind Turbine Technologies

Wind power research results in China include:

- A study on the breakup and impingement characteristics of super cooled large droplets
- 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
- A dynamic calculation program and model comparisons of offshore wind energy
- A study of largescale wake flow field characteristics
- An optimized wind turbine reliability data and evaluation index
- A study on wind plant coding
- A revision of the relevant national standards



Figure 2. The photos of the refrigeration experiment of the Goldwind HQ63-17 airfoil in tunnel

# IMPACT OF WIND ENERGY

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## 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 if China is to realize its 15% target for non-fossil fuel energy in primary energy consumption.

In 2018, wind-generated electricity totaled 366 billion kWh. Wind power saved about 130.5 million tons of standard coal per year, and also reduced 277 million tons of CO<sub>2</sub>, 0.95 million tons of SO<sub>2</sub>, and 0.8 million tons of NO<sub>x</sub>. Based on wind-generated electricity predictions for 2020, wind power will save 150 million tons of standard coal per year and reduce 455 million tons of CO<sub>2</sub>, 1.6 million tons of SO<sub>2</sub>, and 1.3 million tons of NO<sub>x</sub>. 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 offshore wind capacity. China will invest 7,800 CNY/kW (990 EUR/kW; 1,134 USD/kW) into land-based wind power and investment of and 16,000 CNY/kW (2,030 EUR/kW; 2,326 USD/kW) into offshore wind power, bringing the total investment in wind energy during the plan period to more than 600 billion CNY (76.1 billion EUR; 87.2 billion USD).

By developing the wind energy industry, China will be able to 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.

## NEXT TERM

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In 2018, China has implemented policies on the compulsory quota system and wind power project bidding. This will 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.

In 2017, more than 90 developers had new installations in China. The accumulated installed capacity of the top ten developers accounted for 70% of the total installed capacity. The top fifteen developers in China accounted for 72.4% of new wind installed capacity.

Twenty-two manufacturers in China have new wind energy installations. Goldwind was the top manufacturer of new installations with 6,710 MW—31.7% of the new wind installations. The top five manufacturers accounted for 75% of the new wind installations in 2018.

In the past five years, market share has gradually concentrated in large companies. The top five manufacturers' market share has increased from 54.1% in 2013 to 75% in 2018, and the top ten manufacturers' market share increased from 89.5% in 2017 to 90% in 2018.

In 2017, many wind turbine manufacturers (including CSIC Haizhuang, Envision, Goldwind, Mingyang, Shanghai Electric, and United Power) released new products. Goldwind, Envision, and Mingyang released the 6-MW, 4.5-MW, and 5.5-MW offshore wind turbines, respectively. In 2018, the new products achieved mass production and were installed in the Xinghuawan wind farm in Fujian province.

## References

Opening photo: Wind farm in China (Photo credit: CWEA)  
Authors: He Dexin, Du Guangping, and Lyu Bo, Chinese Wind Energy Association (CWEA), China.



**Table 1. Key Statistics 2018, Denmark**

Total (net) installed wind power capacity	6.124 GW
Total offshore capacity	1.7 GW
New wind power capacity installed	0.657 GW
Decommissioned capacity (in 2017)	0.022 GW
Total electrical energy output from wind	13.893 TWh
Wind-generated electricity as percent of national electricity demand	41.7%
Average national capacity factor	24.4%
National wind energy R&D budget	175 mil DKK; 23.4 mill EUR; 26.8 mil USD
Target	55% renewable energy by 2030

## OVERVIEW

Installed wind power capacity increased by 657 MW in 2018, including 437 MW of new offshore wind power. This brings Denmark's total capacity to 6,124 MW (Table 1). In 2018, 33% of Denmark's energy consumption came from renewable sources; 38% from oil, 15% from natural gas, 9% from coal, 2% from non-renewable waste, and 3% from imported electricity [2]. Wind-generated electricity met 41.7% of the domestic electricity supply (the highest in Europe) compared to 43.4% in 2017. The wind energy index in 2018 was 90% compared to 102% in 2017.

In June, the Dutch government presented the National Energy Agreement, which includes binding commitments. Under this agreement, the planning expands the supply of energy from offshore wind by at least 2,400 MW. Thus, Denmark will have approximately 2,650 MW of offshore wind power installed by 2023, followed by an additional minimum of 2,400 MW by 2030. Other important areas covered by the Energy Agreement are a new support scheme for experimental wind turbines, and technology-neutral tenders.

## MARKET DEVELOPMENT

### National Targets & Policies Supporting Development

On 29 June 2018, the Danish Parliament made an Energy Agreement based on political agreement between all political parties which will be valid for the period 2020 to 2024 [3]. For wind energy, three offshore wind farms will be established to meet the 2,400 MW target by 2030.

The agreement includes a screening process to identify offshore wind farm locations for 10 GW of installed capacity in the Danish waters of the North and Baltic seas. This is in line with the aim that renewable energy must be able to cope with market conditions.

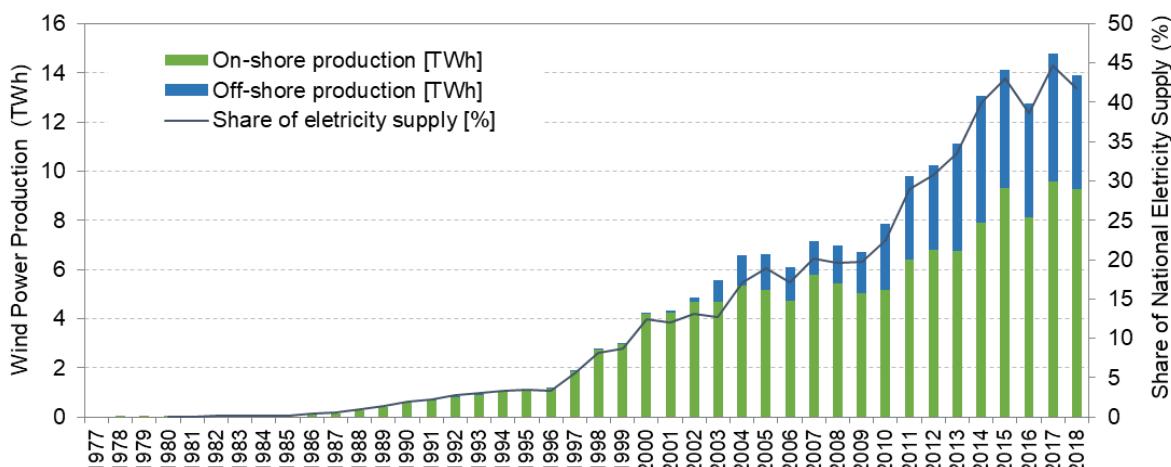


Figure 1. Wind-generated power and share of the national electric energy supply in Denmark since 1977 [1]

Technology-neutral tenders of solar photovoltaics, land-based and nearshore wind power, wave power, and hydroelectric power will be supported by an allocation of 561 million EUR (643 million USD) during the agreement period.

The number of land-based wind turbines larger than 25 kW will be reduced from the current level of approximately 4,300 wind turbines to a maximum of 1,850 in 2030. The policy will be gradually implemented during the agreement period, based on annual reviews and ongoing monitoring of progress.

After 2020, the parties intend to increase public funding for research, development, and demonstration projects in the fields of energy technology and climate. During the agreement period, funding for these efforts will increase to 134 million EUR (153 million USD).

These funds will be prioritized within the framework of the government's goal of investing at least 1% of GDP in research. The Energy Agreement expects to invest approximately 66 million EUR (76 million USD) in 2019, increasing to approximately 374 million EUR (428 million USD) in 2025.

Based on the Energy Agreement, direct support for new household wind turbines ceases in 2020 [4]. However, a scheme supporting installation of test or prototype wind turbines is established for installations either inside or outside the national test centers.

### Progress & Operational Details

Figure 1 shows Denmark's wind-generated electricity production since 1977, when the first turbine was connected to public grid. Today, the net installed wind power capacity is more than 6,000 MW. Of this total, offshore installed capacity accounts for 1,700 MW. Wind-generated electricity accounted for close to 45% of total electricity consumption in the past five years.

Figure 2 shows how the monthly wind-generated electricity production varies during 2018 and 2017, as well as a five-year average.

The accumulated wind power capacity related to a design lifetime of 20 years. As of the end of 2018, 6,125 MW of wind power capacity has been installed. In 2000, this number was approximately 2,000 MW. Thus, by 2020 more than 30% of the installed capacity will be over 20 years old (Figure 3).

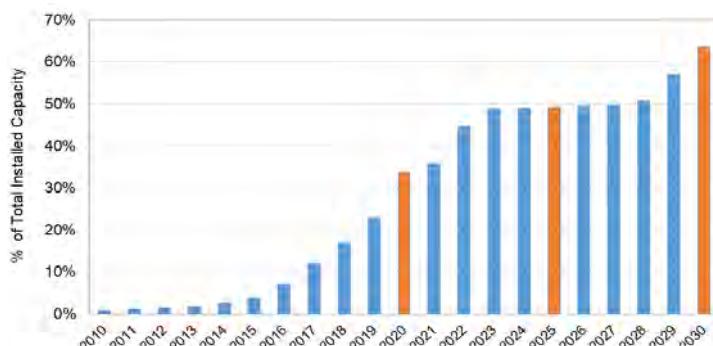


Figure 3. Installed capacity exceeding design lifetime of 20 years (%)

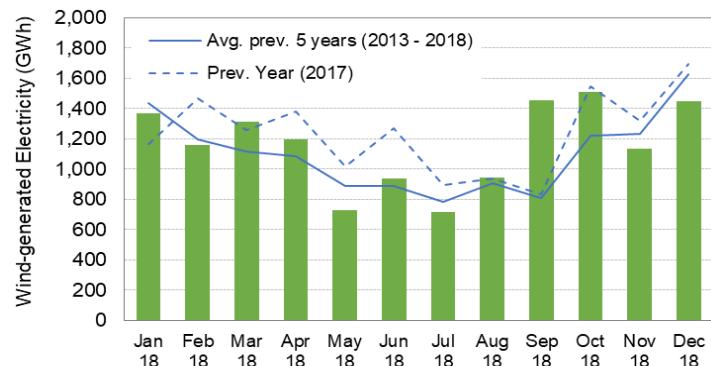


Figure 2. Monthly wind-generated electricity production [1]

Figure 4 illustrates the wind power capacity in MW that is provided by installations which exceed the 20-year lifetime on an annual basis. Both Figure 3 and 4 only take into account the installed capacity. Projects in the pipeline or in the planning stage are not included.

### Matters Affecting Growth & Work to Remove Barriers

With the Energy Agreement of 29 June 2018, the first Danish technology-neutral tender was launched in 2018 for wind energy and photovoltaic projects for access to funding of 32 million EUR (37 million USD). The next tender is planned for 2019.

The result of the tendering in 2018 was three contracts for 138 MW of land-based wind projects and three contracts for 104 MW solar PV projects with an average premium of 0.31 EUR/kWh (0.35 USD/kWh).

Announcements from large IT companies such as Apple, Google, and Facebook, which plan build data centers in Denmark, led to a debate on how such data centers might stand in the way of Denmark's transition to green power. Apple has announced that the company wants to be green-energy self-sufficient and plans to build a wind farm and solar power plant for that purpose.

Several RE investors have recently announced that they will install wind and/or solar PV projects without state aid. It is expected that this trend will continue, and could even advance further with the increase in power-purchase-agreements (PPA's) between RE investors and large power consumers such as data centers.

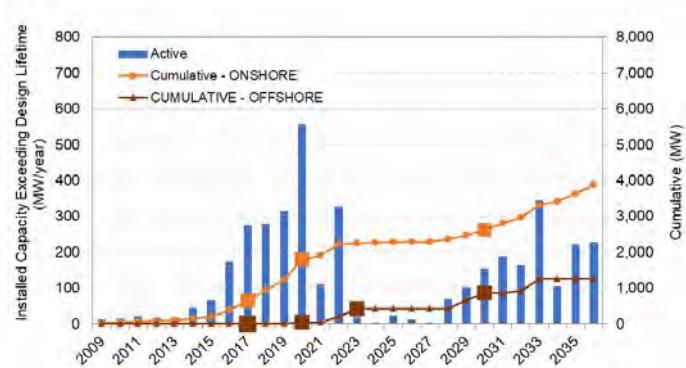


Figure 4. Annual installed capacity exceeding design lifetime of 20 years (MW/year)

## R,D&D ACTIVITIES

### National R,D&D Priorities & Budget

The two largest public funding programs related to technical and societal energy solutions are The Energy Technology Development and Demonstration Programme (EUDP) and Innovation Fund Denmark (IFD) [5, 6]. Financial support is given in accordance with EU state aid rules, including that foreign project participants can receive EUDP support according to the same rules as Danish participants.

The Danish Energy Agency administers EUDP, which supports private companies and universities to develop and demonstrate new energy technologies, including wind energy. Innovation Fund Denmark supports strategic and applied energy research. Innovation Fund Denmark has a specific energy investment strategy, which was updated in 2018.

In 2018, EUDP and IFD granted 18 wind power R&D projects a total of 175 million DKK (23.4 million EUR; 26.9 million USD). Detailed information on funded projects and public energy research can be found on each project website [5-8].

Megavind is Denmark's national partnership for wind energy, representing both industry and research organizations. The 2018 Megavind annual research and innovation agenda outlined six key R&D themes that were derived directly from Danish companies' internal R&D roadmaps. The R&D themes were further supported by five so-called innovation drivers that provide criteria for assessing the potential impact of R&D projects [9].

R&D priorities in Megavind also reflect the R&D priority developments at the European level, undertaken in the European Technology and Innovation Platform for Wind Energy (ETIPWIND) and the Joint Programme for Wind Energy under the European Energy Research Alliance (EERA JP WIND).

In September, the Ministry of Higher Education and Research approved the Energy Innovation Cluster (EIC) as Denmark's innovation network for land-based and offshore energy production with a grant of 1.6 million EUR (1.8 million USD) and a total project portfolio of over 52 million EUR (60 million USD). EIC will focus on the value of the innovation-promoting effort, with wind industry and universities as members [10].

### National Research Initiatives and Results

The results of publicly funded wind energy projects in 2018 are available at the national energy research portal [7]. Examples of projects are listed below:

The LifeWind project completed inspection of several wind turbines for life extension in October 2018 [17]. This EUDP-funded project aims to demonstrate procedures that can quantify the risk of failure, the remaining structural reliability, and the maintenance costs when operational wind turbines exceed their certified life. These procedures are based on the level of available data that is recorded.

In December 2018, Vestas dismantled its 900-kW multi-rotor concept after a two-and-a-half-year testing and validation campaign [18]. The Danish manufacturer observed many

technical benefits from the four-turbine prototype, including a 1.5% power gain. The turbine was installed at the test site of DTU Wind Energy, Risø Campus, in early 2016 as a research and development project.

The results of a Danish health study (conducted from 2015 to 2019) with research on possible connections between wind turbine noise and health effects was published during 2018 and completed in February 2019 [11]. The study compares data on cardiovascular disease, diabetes, negative birth outcomes and redemption of prescriptions for blood pressure medicine, sleeping medication, and antidepressants with exposure to the calculated average nocturnal outdoor and indoor noise from wind turbines. The study has not provided conclusive evidence of a correlation between exposure to wind turbine noise and the triggering of blood clots in the heart or stroke.

In 2018, EUDP funded the project RELIABLADe - Improving Blade Reliability through Application of Digital Twins over Entire Life Cycle. RELIABLADe (2018 to 2022) develops and demonstrates techniques to create a unique Digital Twin for each individual wind turbine blade with their unique defects and imperfections.

### Test Facilities & Demonstration Projects

In order to support development of large wind turbines, the Danish government set up a special pool of 26 million EUR (30 million USD) as FIT (feed-in-tariffs) for experimental and test wind turbines in 2018 and 2019. The funds are awarded on a first-come, first-served basis. At the national test centers in Høvsøre and Østerild, the 2018 support FIT of 0.017 EUR/kWh (0.02 USD/kWh) was granted for a three-year period. If established outside the two national test centers, the turbines are exempted from tendering process and can receive a FIT for 20 years at 0.014 EUR/kWh (0.016 USD/kWh) in 2018, and the average of the land-based tendering bids in 2018 when presented in 2019.

In 2018, the Parliament decided that the two national test centers, operated by DTU Wind Energy in Østerild and Høvsøre, can be expanded with two test sites each. This would allow for the testing of nine wind turbines in Østerild and seven wind turbines in Høvsøre.

The construction of the new Large-Scale Facility at the DTU Risø Campus—part of the Villum Center for Advanced Structural and Material Testing (CASMaT)—was completed in 2017, and operations began in November [16]. The Poul la Cour Wind Tunnel was inaugurated in April 2018. The wind tunnel's combination of Reynolds Number and acoustic properties is unique in the world [12]. It received support from the Danish Agency for Science and Higher Education and Region Zealand.

### Collaborative Research

Denmark utilizes public support to enable Danish companies, universities, and research institutions to participate in collaborative international projects. Denmark's work helps to promote R,D&D for energy technologies in TCPs under the International Energy Agency (IEA), the European Union, and Nordic Energy Research programs.

# IMPACT OF WIND ENERGY

## Environmental Impact

Assuming that each kWh of wind-generated electricity displaces a kWh of average electricity consumption, the 13.9 TWh of wind-generated electricity that Denmark produced in 2018 corresponds to the following environmental reductions (based on the environmental declaration from the Transmission System Operator (TSO) Energinet.dk) [13]:

- 2.8 million tonnes of CO<sub>2</sub> (199 g/kWh)
- 556 tonnes of SO<sub>2</sub> (0.04 g/kWh)
- 2.49 tonnes of NO<sub>x</sub> (0.17 g/kWh)
- 139 tonnes of particles (0.01 g/kWh)

On the basis of a number of EU judgments, the Ministry of the Environment and Food in 2018 has carried out an environmental assessment of the executive order on acoustic noise from wind turbines [14]. Simultaneously, the Ministry revised the Executive Order with a number of technical changes based on new professional knowledge. The Executive Order was revised in the following areas: regulation of clearly audible tones; differentiation between sound insulation figures for cottage areas and for ordinary housing; adjustment of the calculation method for sound propagation above water; adaptation of the transitional provisions; and equality of supervision for offshore and land-based wind turbines.

The aim of promoting social acceptance of onshore windfarms means that revision will be made to the existing RE-schemes. In relation to the value-added scheme, a sales option scheme will be introduced. The buyer scheme will be reviewed in order to ensure that it is prepared for future developments with larger turbines. Finally, a fund construction is in preparation, replacing the former green scheme. The intention is to promote municipal incentives for increased renewable energy by giving wind turbine developers the opportunity to give direct subsidies to the municipality to promote local or recreational values in the municipality as well as cultural and informative activities.

## Economic Benefits & Industry Development

In 2017, the Danish wind industry once again achieved a new record in turnover. Turnover rose 20.4%, or 3.2 billion EUR (3.7 billion USD), from 15.9 billion EUR (18.2 billion USD) in 2016 to 19.2 billion EUR (22 billion USD) in 2017.

Exports in 2017 reached 1.1 billion EUR (1.3 billion USD) and accounted for 3.7% of total Danish exports. From 2016 to 2017, the industry experienced a decline in exports of 3%, which is due to fluctuations in the number of large offshore wind turbine projects and to the wind turbine market decreasing a larger share of the Danish production of wind turbines than usual. At the same time, employment grew 6.2%, from 31.201 in 2016 to 31.871 in 2017. Since 2006, employment in the wind industry has increased 15.8%. At the same time, exports have increased by 37.6%, while turnover increased by 55.8%.

Newer data from 2018 will be available in the Danish Wind Industry Association's report entitled "Branchestatistik 2019" (expected release June 2019) [15].

## NEXT TERM

- The coming years will reveal the effects of the 2018 energy agreement. The biggest impact is expected to be installation of a minimum 2,400 MW of offshore wind power capacity in the next decade.
- The first wind farm (Thor) organized under the Energy Agreement will be out for tender in 2020. The call will be a combined call covering both the offshore wind farm and the grid connection infrastructure in terms of offshore substation, export cables, and onshore substation. to the national TSO.
- The future research agenda is expected to focus on system integration and digitalization of wind energy.
- New orders on acoustic (noise) and certification will be developed and implemented.
- Denmark will work for development of The North Sea Energy Cooperation.
- Danish parliament is expected to pass a new climate law with binding goals and measures towards a fossil free society by 2050, including new goals for RES and wind power.

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# European Commission & WindEurope



**Table 1. Key Statistics 2018, EU**

Total (net) installed wind power capacity	179 GW
Total offshore capacity	18.5 GW
New wind power capacity installed	10.1 GW
Decommissioned capacity (in 2017)	0.42 GW
Total electrical energy output from wind	363 TWh
Wind-generated electricity as percent of national electricity demand	13.7%
Average national capacity factor	23.8%
National wind energy R&D budget	72.4 mil EUR; 82.9 mil USD
Target	32% RES by 2030

## OVERVIEW

The European Union has a fixed target to generate at least 32% of its energy from renewable sources by 2030. Furthermore, it has adopted a long-term vision of climate neutrality by 2050. Together, these goals represent a powerful driving force for renewables, particularly wind energy.

While the road ahead seems exciting, it will not be without shortcomings. In 2018, the market experienced a 36% reduction in new installed capacity. There are good reasons to believe that regulatory changes account for that deceptive figure, and that the pace of new installations will accelerate again in the future. For example, corporations are increasingly procuring green energy directly from wind farms. Furthermore, costs remain subdued, with CAPEX reductions of 43% for land-based wind and 76% for offshore wind since 2015. These reductions can be credited to technological developments and

the auctioning of wind energy capacity. By the end of 2018, 179 GW of wind power was connected to the grid, which represented 14% of the EU's electricity demand, 2 percentage points more than in 2017.

In the research domain, 2018 saw 72.4 million EUR (82.9 million USD) supporting new wind energy projects – mostly on offshore technology and maintenance and monitoring. Floating wind has been gaining particular traction as of late, with more than 63 million EUR (72.2 million USD) granted by the EU for research and innovation (R&I) since 2009. Last year, the EU also completed several projects. ELICAN and TELWIND, for example, showed how an innovative, self-installing telescopic tower could reduce floating offshore installation costs, while Aeolus4Future addressed the critical need for training highly-skilled researchers on wind energy systems.

## MARKET DEVELOPMENT

### National Targets & Policies Supporting Development

By 2030, the EU will have to generate 32% of its energy from renewable sources. Two other climate and energy framework headline targets also need to be reached by 2030: at least 40% cuts in greenhouse gas emissions (from 1990 levels), and at least 32.5% improvement in energy efficiency.

As a part of the framework, the regulation on the governance of the Energy Union and Climate Action has set out planning, reporting and monitoring mechanisms to achieve those targets. In response, Member States have drafted national energy and climate plans, which include measures to ensure the non-discriminatory participation of renewable energy, demand response, and storage in all energy markets.

In November 2018, The European Commission published the Communication "A Clean Planet for All," a strategic long-term vision for climate neutrality by 2050. The strategy is consistent with the Paris Agreement objective to keep temperature increases well below 2°C—and pursue efforts to limit it to 1.5°C—and shows how such ambitious goals can be attained by investing into technological solutions, empowering citizens, and aligning action in key areas such as industrial policy, finance, and research.

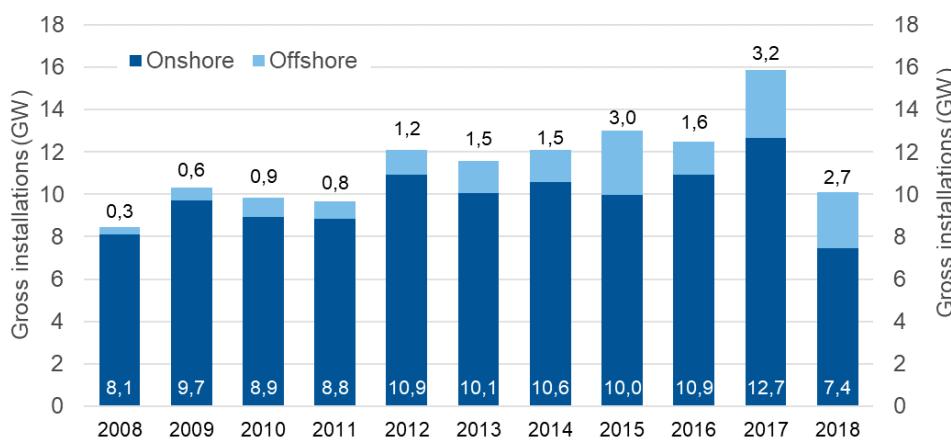


Figure 1. Gross annual and offshore wind installations in the EU [11]  
(Source: WindEurope)

## Progress & Operational Details

In 2018, 10.1 GW of wind power capacity was installed across the European Union, a 36% decrease from 2017 (Figure 1). This significant drop was related to regulatory changes Member States instituted to comply with the revised EU State aid guidelines for environmental protection and energy (see further details below). Offshore wind represented 26% (2.65 GW) of the total new wind installations, while decommissioning stood at 421 MW. France, Germany, and the UK together accounted for 60% of the new capacity [11].

Fleet-wise, the most powerful land-based wind turbines were installed in Germany and Austria (average rating of 3.2 MW). The average newly installed offshore turbine was rated 6.8 MW—15% larger than in 2017. The largest turbine in the world was installed in the UK: the V164-8.8 MW from MHI Vestas Offshore Wind, with a rotor diameter of 164 m [1].

Higher-rated power translates into a decreased capital expenditure (CAPEX) per MW. While in 2015 around 2 million EUR (2.3 million USD) were required for each MW of installed land-based wind, in 2018 investment needs fell 43%, to an average of 1.4 million EUR (1.6 million USD) per MW. Offshore wind has seen an even more dramatic decrease: from almost 4.5 million EUR (5.2 million USD) per MW in 2015 to just under 2.5 million EUR (2.9 million USD) per MW in 2018, equivalent to a 76% fall [11].

These positive figures make wind energy an increasingly relevant electricity source. In 2018, it met 14% of the EU's electricity demand—2 percentage points higher than in 2017. The highest shares were achieved in Denmark (41%), followed by Ireland (28%) and Portugal (24%) [11].

## Matters Affecting Growth & Work to Remove Barriers

Although the Energy Union does result in a certain degree of regulatory convergence among Member States (particularly regarding market design), a lack of harmonization between countries persists in areas like spatial planning and permitting. For example, there are no common guidelines regarding site selection and the impacts on the environment and local communities, which prevents authorities from switching from a precautionary principle to an evidence-based approach [2].

Restrictions related to the aviation sector also conflict with wind deployment, mostly due to interference with surveillance equipment or with low flight and training zones. The offshore sector faces specific challenges regarding spatial planning.

Although Denmark and the UK may allow the multi-purpose use of the marine space occupied by wind farms, this is not yet the case in most EU countries. This exacerbates conflicts between industries, as competition grows between offshore wind and aquaculture and fisheries.

Another issue of concern is that of import tariffs. In July 2018, The European Commission applied a 25% duty fee on steel imports whenever the EU exceeds a conservative, predefined import volume. Since February 2019, import volumes will increase by 5% every year until 2021. Although the intention is to shield the European steel industry from aggressive steel production incentives in the United States and China, EU manufacturers relying on cheaper imported steel have estimated a 18% turbine production cost headwind, as steel makes up over half the material they require. Eventually, this may put European turbine manufacturers at a disadvantage compared to overseas competitors [10].

**Offshore and land-based wind tenders:** The shift from feed-in-tariffs to tender-based support schemes promoted by the State aid guidelines prompted increasingly competitive prices for wind energy. For example, more than 3.1 GW of offshore wind have been allocated under zero-subsidy bids in Germany and the Netherlands, while bid prices decreased by 65% in tenders held in Denmark from 2010-2016 and in the United Kingdom from 2013-2017 (Figure 2) [4].

Similar trends have been observed for land-based wind. For example, Spain allocated more than 4.6 subsidy-free GW in three tender rounds held in 2016 and 2017. In Germany, the winning bid price decreased by 33% in three technology-specific auctions in 2017. Italy saw the average winning price drop by 44% in four rounds from 2013 to 2016, while the capacity allocated nearly doubled [4].

**Power-purchase agreements:** Increasingly competitive renewable electricity prices, in relation to wholesale market prices, are stimulating industrial consumers to procure their energy needs directly with the producers of renewable power (particularly wind energy) through power purchase agreements (PPAs). Asset owners also benefit from PPAs by reducing their merchant risk exposure and ensuring a predictable income flow. In Europe, the majority of the corporate wind-PPA capacity is found in the Netherlands, Norway, Sweden, and the United Kingdom. So far, the high-tech sector is the main buyer of these agreements. In total, 4.8 GW of wind-PPAs have been signed since 2000, with deals above 1 GW annually for the last three years [1].

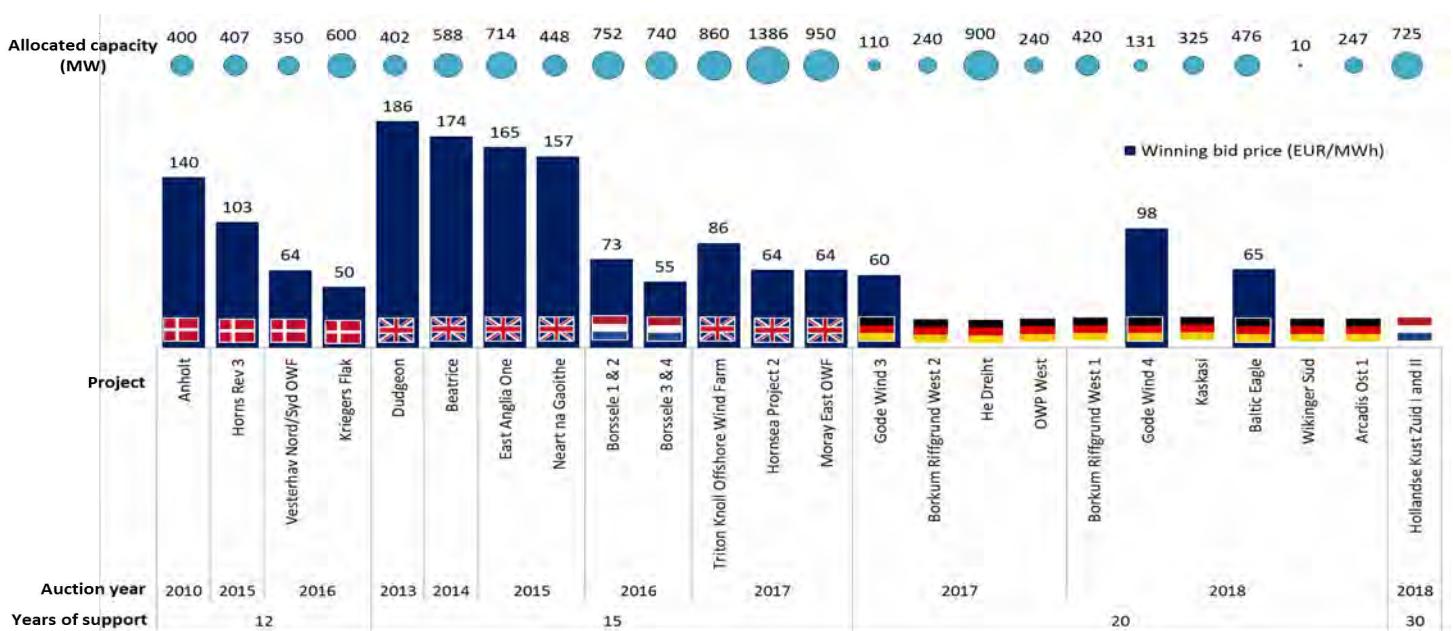


Figure 2. Results of offshore wind tenders in EU Member States (2010-2018) [4]

## R,D&D ACTIVITIES

### National R,D&D Priorities & Budget

Horizon 2020 (H2020) is the main funding instrument for energy R&I at the EU level, with a budget of about 6.0 billion EUR (6.9 billion USD) for the period 2014-2020. In 2018, 65 million EUR (74.5 million USD) were allocated to projects specifically focused on wind energy, but the figure increases to 72.4 million EUR (82.9 million USD) if other projects where wind is a significant component are included (Table 2) [4].

Figure 3 depicts how funding has been distributed across main priorities since 2009 under the previous and current R&I framework programs. A large part of the EU R&I funding (almost 70% for projects starting in 2018) has been devoted to offshore wind technology in order to develop next-generation offshore wind turbines, reduce costs, and move towards the commercialization of floating turbines [4].

Floating technologies have been gaining traction, particularly since FP7 (e.g. with the FLOATGEN and DEMOWFLOAT projects, which demonstrated different floating concepts at pre-commercial scale). Together with the 11 projects financed so far under H2020, this brings total EU support to floating offshore wind to more than 63 million EUR (72.2 million USD) since 2009.

### National Research Initiatives & Results

The EU achieved significant research results in 2018, as 20 wind energy projects came to an end during the year. We have highlighted a few below [4]:

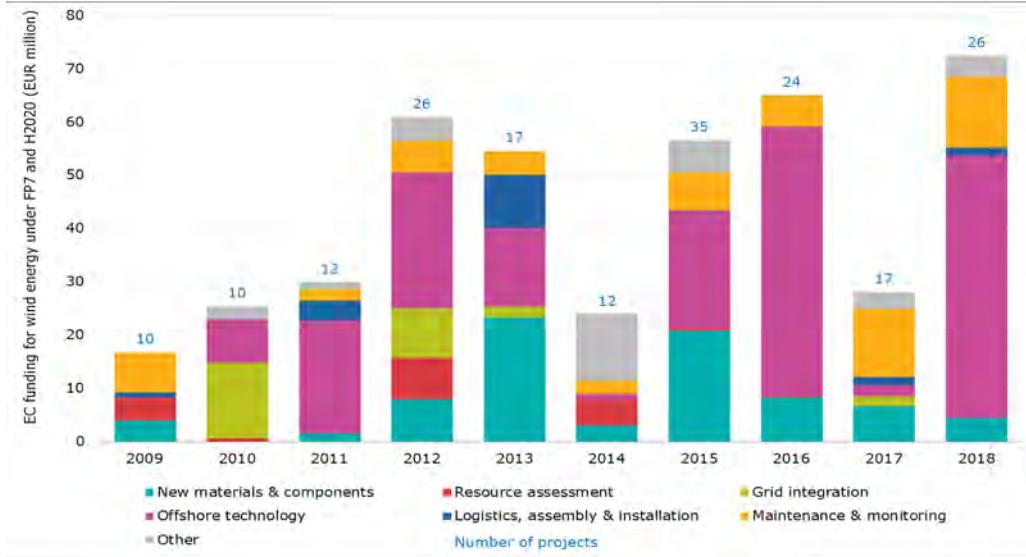
- TELWIND tested a novel, low-cost floating substructure integrated with a self-installing telescopic tower in a lab environment for further use with +10-MW offshore wind turbines. EU support: 3.5 million EUR (4.0 million USD).
- ELICAN followed-up on TELWIND and demonstrated the technology through a 5-MW prototype installed off the coast of Las Palmas, in the Canary Islands (Spain). EU support: 11 million EUR (12.6 million USD).
- VirtuWind demonstrated the technical and economic benefits of introducing open, modular and secure control infrastructure for the wind energy industry. EU support: 4.9 million EUR (5.6 million USD).
- Aeolus4Future created a training network with ten institutions across seven countries to provide researchers with a technical background in wind energy systems. EU support: 3.8 million EUR (4.4 million USD).

Table 2. Wind Energy-Specific Funding Under Horizon 2020 Granted to Projects Starting in 2018

H2020-Funded Projects	Total Project Cost mil EUR (mil USD)	EC Contribution mil EUR (mil USD)	Number of Projects
Wind energy projects	84.12 (96.36)	65.04 (74.51)	20
Projects with a significant wind energy component <sup>1</sup>	9.01 (10.32)	7.35 (8.42)	6
Total funding for wind energy	93.13 (106.69)	72.4 (82.94)	26

<sup>1</sup> 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)

Figure 3. Evolution of EU R&I funding priorities on wind energy under FP7 (2009-2013) and Horizon 2020 (2014-2018) [4]. Projects specifically on wind energy and those with a significant wind energy component are accounted for (see Table 2). The number of projects funded is shown at the top of each bar. Note: The item "other" includes projects that cannot be classified in other categories. Some examples include projects on emerging technologies such as airborne wind energy systems, social acceptance, and critical rare earth elements.



A high number of SME projects were also completed in 2018:

- On new floating concepts: X1 Wind (a self-orientated platform with a single point mooring system and a downwind structural design that removes the active yaw system, the ballast system, and the tower) and WTSS (a floating support structure with no mooring lines and a single point anchoring, which optimizes assembly, installation, and decommissioning)
- On novel wind turbines designed to work under low speed and turbulent wind profiles (e.g. urban environments): WindiBox, EOLI FPS and INNOWIND
- Other areas: Skypull (demonstration of a 100 KW airborne wind energy system), Ventura Habitat (a novel blade maintenance system), and YURAKAN (a high power rated novel cyclone converter generator for land-based wind turbines)

## New R&I projects

- RealCoE aims to develop the next generation +12-MW offshore wind turbine with a modular design that is easily customized. It will also investigate business models to optimize investment and lower financial risks and will propose digitalization at every stage of the process. EU support: 24.8 million EUR (28.4 million USD)
- i4Offshore proposes a full-scale demonstration of a highly innovative offshore system solution at a challenging deep-water site, featuring a next-generation direct drive wind turbine, a hybrid-material gravity jacket foundation optimized for low-cost manufacturing, and new very-low-cost array cable-in-pipe solution. EU support: 19.8 million EUR (22.7 million USD)
- TotalControl aims to develop and validate advanced integrated wind power plant and wind turbine control schemes. All essential interactions between the wind turbines shall be accounted for, including production and load aspects. EU support: 4.9 million EUR (5.6 million USD).

## IMPACT OF WIND ENERGY

### Environmental Impact

In order to analyze the environmental impact of wind energy within the EU energy system, the JRC-TIMES model analyzed three different scenarios [6]. *Diversified* and *ProRES* reach the CO<sub>2</sub> emission reduction target for 2050 (80% as compared to 1990 levels) but *Diversified* allows for new nuclear capacity while *ProRES* doesn't. *Zero Carbon* is even more ambitious and aims for net zero emissions by 2050. Carbon capture and storage is possible under *Diversified* but not under the two other scenarios.

The power and the transport sectors experience the strongest emission reductions until 2050 (from 2,400 Mt/year in 2010 to 850 Mt/year or 330 Mt/year in 2050 in the *ProRES* and the *Zero Carbon* scenarios, respectively) [6]. In scenarios that exclude the usage of CCS (*ProRES* and *Zero Carbon*), transport becomes the main consumer of electricity by 2050, as this vector is used directly in electric vehicles and in the production of hydrogen and derived synfuels.

Consequently, the power sector undergoes a substantial transformation towards increased low-carbon generation capacity, which reaches 5,700 GW by 2050 in the *Zero Carbon* scenario. Solar and wind power will account for most of the change, with 540-1,500 GW of wind capacity in the 80% CO<sub>2</sub> reduction scenarios, and up to 1800 GW in *Zero Carbon* (Figure 3) [6].

Similarly, the modeling projections based on the EU long-term strategy 2050 ("A clean planet for all") suggest that wind capacity will increase to 700-1,200 GW by 2050, representing more than half of the power generation in 2050 [2].

## Economic Benefits & Industry Development

In 2018, new asset financing for European wind power projects stood at 26.7 billion EUR (30.5 billion USD)—a 20% increase from 2017 and over 60% of all in new power capacity investments in the region [9].

In terms of jobs, the wind energy industry directly and indirectly employed about 260,000 persons in the EU in 2016. It contributed 36.1 billion EUR (41.4 billion USD), or 0.26%, to the EU's GDP [7]. The industry remains a global net exporter with a 2.4 billion EUR (2.7 billion USD) positive trade balance in products and services.

Over 80% of European wind energy companies have a commercial presence (including manufacturing sites) in more than 80 countries outside Europe. Five of the ten biggest wind turbine manufacturers in the world are EU-based [7].

## NEXT TERM

The EU will continue to invest in a diversified portfolio of wind energy R&I projects in Horizon 2020. Offshore technologies, particularly floating, will likely be prioritized. After 2021, Horizon Europe, the next R&I framework program, will be in place.

The main building blocks are already known: a mission-oriented approach, the continuation of the European Research Council, the creation of the European Innovation Council, and the new generation of European Partnerships as well as an increased collaboration with other EU programmes. Broad mission areas have been defined (including one on carbon-neutral and smart cities), but additional details on the programming will be fleshed out during the upcoming strategic planning phase.

Repowering and decommissioning are becoming a key concern for the wind energy market in the EU. Today, about 4 GW of installed capacity is more than 20 years old, plus an additional 18 GW within the next 5 years. By 2030, that number could increase to 40-60 GW [11]. This raises the question how many of these wind farms can be repowered, and how administrative and regulatory procedures will facilitate the challenge.

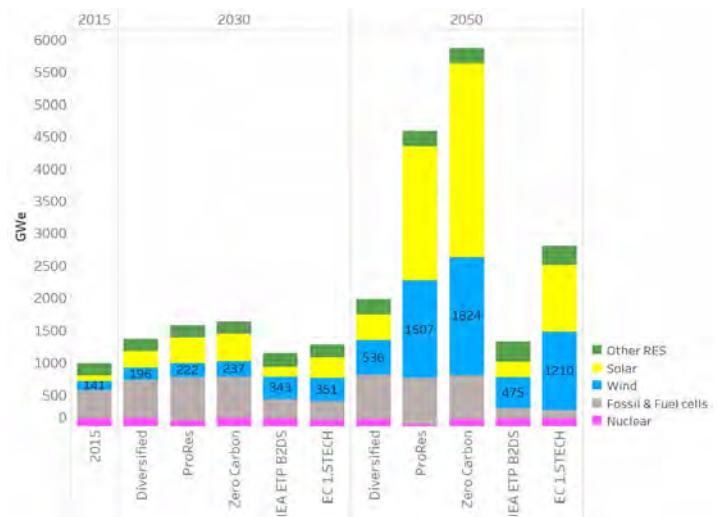


Figure 4. Installed generation capacities in the EU by 2050 for different decarbonization scenarios of the JRC-EU-TIMES model, as well as for the IEA ETP B2DS and EC 1.5TECH scenarios [2-4, 6]

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Opening photo courtesy of Pixabay/Distel2610

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**Table 1. Key Statistics 2018, Finland**

Total (net) installed wind power capacity	2.0 GW
Total offshore capacity	0.07 GW
New wind power capacity installed	0 GW
Decommissioned capacity (in 2018)	0.003 GW
Total electrical energy output from wind	5.86 TWh
Wind-generated electricity as percent of national electricity demand	6.7%
Average national capacity factor	32.3%

## OVERVIEW

In 2018, Finland consumed 87 TWh of electricity with a peak demand of 14.2 GW. Carbon emissions from power generation in Finland totaled only 105 g of CO<sub>2</sub>/kWh.

Wind power installations stagnated ahead of the first competitive tender for renewable energy sources (RES), which took place at the end of 2018. By the year's end, installed wind power capacity amounted to 2,041 MW with 5.86 TWh of production. Renewables provided about 36% of the country's electricity consumption in 2018: 15% from hydropower, 14% from biomass, and 6.7% from wind power (up 1.1 percentage points from 5.6% the previous year).

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. With this in mind, a technology-neutral competitive bidding scheme for renewable energy source (RES) was released in the fourth quarter of 2018. The auction released 1.4 TWh/a of renewable electricity generation, with each bidder offering annual energy generation and maximum premium. The scheme only awards the maximum premium when the electricity market is below 30 EUR/MWh (34 USD/MWh), and it awards no premium at electricity market prizes above 30 EUR (34 USD/MWh).

Finland initiated construction of ten onshore wind projects totaling 444 MW without subsidies. These projects will begin operating in 2019 and 2020 and can be used in Power Purchase Agreements.

## 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 by 2020. The estimated share of RES in 2018 was 37%, very close to that 2020 goal.

Finland is also close to meeting the wind power goal set by the 2008 Climate and Energy Strategy; the country produced 5.9 TWh of wind-generated electricity in 2018, just shy of the 6 TWh/yr goal that was set for 2020, and new capacity will be coming online in the near future.

Finland's next objectives are:

In 2011, Finland's Energy Authority implemented and managed a market-based feed-in system with guaranteed pricing. The guaranteed price for wind power was set at 83.50 EUR/MWh (95.65 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 quarter four of 2018, the Energy Authority released the first technology-neutral competitive bidding scheme for RES. As of April 2019, the results of the bid were very positive:

- All the energy put to tender (1.4 TWh/a) was assigned to land-based wind projects
- The costliest project will receive a subsidy of 3.97 EUR/MWh (4.55 USD/MWh), payable in full only when the monthly cost of electricity is 30 EUR/MWh (34 USD/MWh) or less. At monthly market prices above 33.97 EUR/MWh (38.91 USD/MWh), the subsidy goes to zero.

Wind in Finland is rapidly evolving towards an unsubsidized model. The trend is underpinned by the 444 MW of capacity under construction, with no subsidy involved. 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 in November 2017. The last wind farm was approved through the FIT system in January 2018. The FIT-based system led to a market of 516 MW across 153 turbines in 2017. Three turbines, with a total capacity of 3.4 MW, were dismantled. The operating wind power capacity reached 2,044 MW.

No turbines were installed during 2018, but two turbines were dismantled totaling 3 MW. The average turbine rating is now 2.9 MW for all installed turbines. The largest single wind farm operating in Finland has 34 turbines with 3.45 MW each, a total rated power of 117 MW, and an expected annual energy output over 0.4 TWh/a.

Finland's total offshore capacity is 72.7 MW, including 44.3 MW built on caissons and 28.4 MW on small artificial islands. The 42-MW offshore demonstration wind farm in Pori on the Finnish west coast started operation in August 2017. After an initial rush to secure sites for larger offshore wind power plants, interest in development has been low—largely due to the improved economy of land-based turbines and a lack of incentives offshore.

In this sense, the technical maturity of very high towers is a key enabler for Finnish land-based wind. For example, the Viinamäki wind farm currently under construction uses Vestas V150 turbines with 175-m hub height.

The capacity factor of the single offshore wind farm Tahkoluoto (T1-T10) is high at 40%, and the average country-level capacity factor is also relatively high at 32% [3].

Wind-generated electricity increased by 22% in 2018 (from 4.8 TWh to 5.9 TWh), reaching 98% of Finland's goal for 2020 and 6.7% 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 32.3% (compared to 32.5% in 2017). The production index for wind power averaged 95% in 2018 (compared to 96% in 2017). Turbines in forested areas have high towers and larger rotors, and these designs provide considerably higher capacity factors than earlier turbine designs.

The average spot price in the electricity market Nordpool was 47 EUR/MWh (54 USD/MWh). This price is 42% higher than previous year's price of 33 EUR/MWh (38 USD/MWh).

## Matters Affecting Growth & Work to Remove Barriers

The trend toward a market-driven wind sector in Finland is underpinned by the success of the first competitive bidding scheme for RES and the fact that substantial wind development is in progress without subsidies.

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.

Public acceptance of wind power remains high. According to a 2017 annual survey on energy attitudes, 75% of Finns support increasing wind production capacity.

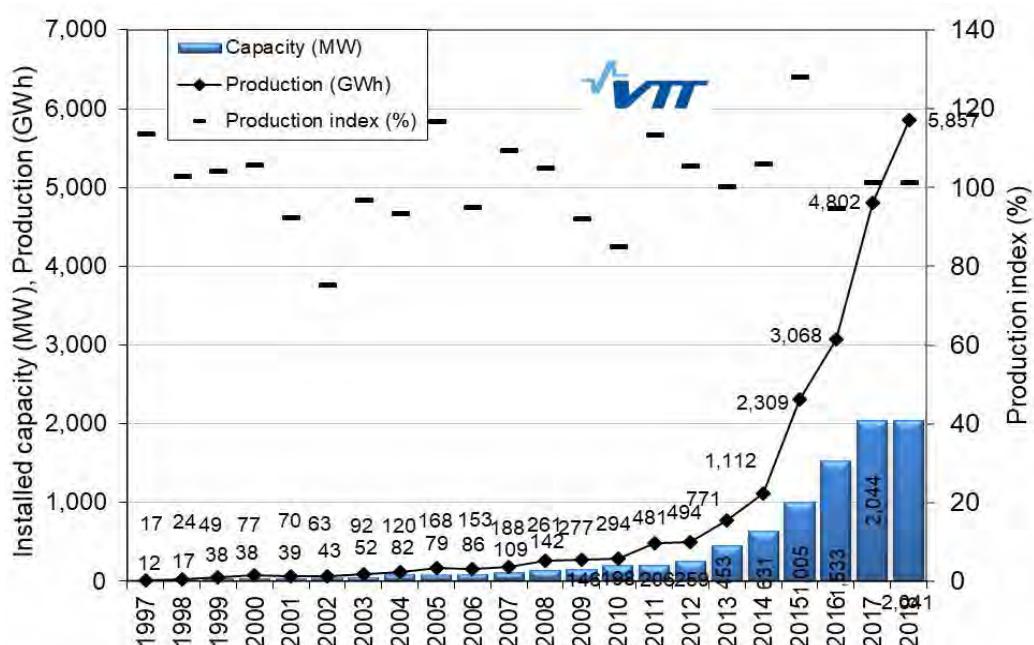


Figure 1. Development of wind power capacity and production in Finland. Production index gives the yearly generation compared to long term average (100%), based on Finnish Meteorological Institute (FMI)

# R,D&D ACTIVITIES

## National R,D&D Priorities & Budget

The Finnish Funding Agency for Technology and Innovation, BusinessFinland, is the main public funding organization for research, development, and innovation in the country, promoting competitiveness and international growth for Finnish companies. The agency focuses 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, BusinessFinland funds individual industry-driven projects. The public funding level for wind power R&D projects in 2018 was around 1.5 million EUR (1.7 million USD) (Figure 2). Ongoing wind power-related R&D projects are mostly industrial development projects.

## National Research Initiatives & Results

The Baltic Offshore Wind ecosystem was established in 2018 to build new wind power concepts that will be piloted in the Baltic Sea region.

The ecosystem has already gathered a significant number of energy companies, including investors and technology and service suppliers in construction and maintenance. At this stage, the Baltic Offshore Wind ecosystem includes Arctia, Meritaito, Boskalis Terramare, Pori Offshore Constructions, Prysmian Group Finland, Rajakiiro, Rauma Marine Constructions, Finnish Sea Service, Finnish Hyptery, SSAB, and Wärtsilä.

## Test Facilities & Demonstration Projects

In 2018, VTT performed a test campaign in the Icing Wind Tunnel (IWT) facility to compare the particle size distributions measured by different droplet sensors. The test campaign was performed as a collaborative effort undertaken the Finnish Meteorological institute (FMI), Oulu University, Danish technical University (DTU) and VTT.

## 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, which produces valuable information in identifying issues important for wind R&D in Finland
- Task 19 Wind Energy in Cold Climates (Operating agent VTT), which brings results to developers in Finland. A sub-chapter on ice throw in Task 19's Recommended Practices report helps the work of the Finnish Wind Power Association (FWPA) in preparing safety guidelines.
- Task 25 Design and Operation of Energy Systems with Large Amounts of Variable Power (Operating agent VTT).
- Task 36 Forecasting for Wind Energy (Vaisala, VTT, and FMI).
- Task 28 Social Acceptance of Wind Energy Projects (Acordi).

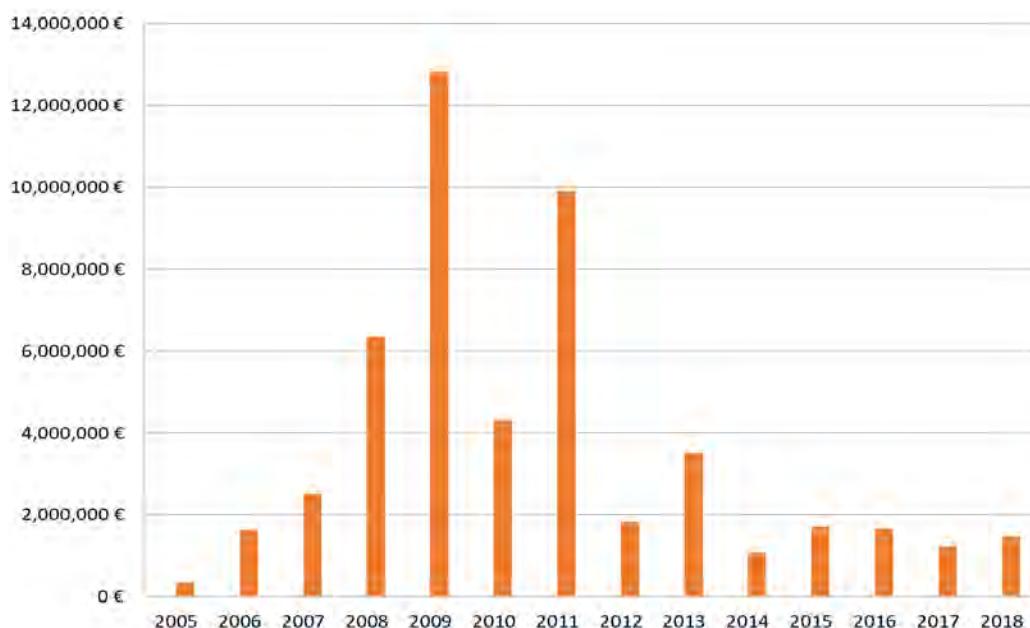


Figure 3. National R&D funding for wind energy related projects by Tekes (BusinessFinland as of January 2018); funding to research organizations represents usually 60% of the project budget

# IMPACT OF WIND ENERGY

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## 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<sub>2</sub>/kWh. Wind power production saved up to 4.1 million tons of CO<sub>2</sub> in 2018. The emissions of all power generation in Finland were up to 105 g/kWh, with a 95 g/kWh increase compared to 2017. Wind power helped mitigate the magnitude of this increase. Condensing Power generation was up from 3,284 to 4,906 GWh [4].

## Economic Benefits & Industry Development

Locally, the municipality receives property tax revenue from wind power. Depending on the power plant value and the municipal tax rate, the annual real estate tax of a 3-MW wind turbine is 6,000-11,500 EUR/yr (6,875-13,175 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 (114,500-230,000 USD).

Finland's technology sector is employing 2,000-3,000 people [5]. These individuals work to export wind turbine components, design wind farms, and work in construction and operation & maintenance (O&M). There are more than 100 companies in the whole value chain and the majority of wind farm planning and construction happens domestically.

## NEXT TERM

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Following the success of the first competitive bidding scheme for RES and the increasing appetite towards PPAs shown by large electricity consumers (which is driving the construction of 444 MW of unsubsidized wind capacity as of February 2019), it is reasonable to expect land-based wind installations to continue in Finland.

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. Several industrial enterprises have become global suppliers of major wind turbine components.

For example, Moventas Wind is the largest independent global manufacturer and service provider of gears and mechanical drives for wind turbines. ABB is a leading producer of generators and electrical drives for wind turbines and wind farm electrification (both land-based and offshore). The Switch supplies individually-tailored, permanent magnet generators and full-power converter packages to meet the needs of wind turbine applications, including harsh conditions.

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 the 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.

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- Opening photo: Kayaking in the Pori offshore wind farm (Source: Hannele Holttinen)
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Author: Raul Prieto, VTT Technical Research Center, Finland.



**Table 1. Key Statistics 2018, France**

Total (net) installed wind power capacity	15.1 GW
Total offshore capacity	2 MW
New wind power capacity installed	1.5 GW
Decommissioned capacity (in 2018)	0 GW
Total electrical energy output from wind	27.8 TWh
Wind-generated electricity as percent of national electricity demand	5.7%
Average national capacity factor	22.1% (estimate)
Target	24.6 GW land-based; 2.4 GW fixed offshore in 2023

## OVERVIEW

Wind power is an increasingly significant source of renewable electricity production in France, accounting for nearly 30% of all installed renewable power capacity. In 2018, France experienced a solid year for wind power industry development, with over 1.5 GW of newly installed wind power capacity. These installations bring the country's total land-based installed wind power capacity to over 15 GW, which was the target for 2018.

These high installation rates follow the same trend as recent years, although they suffered from legal uncertainty regarding the process of administrative authorizations. Wind energy generated an annual electrical energy output of 27.8 TWh—a significant increase from 2017. While this increase is the result

of higher installed power capacity, the nation's capacity factor remains unchanged from the year before. Wind covered 5.7% of the national electricity demand.

France organized new calls for tender for land-based wind power in 2018 with continuously reduced costs. The third round of tender for offshore wind was formally launched for up to 600 MW in the Dunkerque area, as well as preparation for a new tender in the Oléron area. The draft of the energy planning exercise was released, indicating ambitious targets for land-based wind and more modest numbers for offshore. The first commercial call for tenders for floating wind farms was also announced.

## 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 and new policy tools for the transition to a low-carbon economy and energy system. 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) defined renewable energy targets for 2018 and 2023. The PPE set new trajectories for each renewable energy source are, including 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

During 2018, a draft of the PPE was released with updated targets for 2023 and 2028. This version is still under review and should be finalized in 2019. For 2023, targets are:

- 24.6 GW land-based wind power capacity
- 2.4 GW fixed offshore wind
- 20.6 GW solar energy
- 25.7 GW hydroelectricity

The PPE also includes a schedule for coming offshore wind tenders. For the first time, floating wind tenders are included, as explained in Table 2. The PPE is currently being revised and submitted to a public debate that will run through 2018 and will define new objectives for the upcoming periods.

**Table 2. Planned Offshore Wind Tenders by Award Year**

Technology	Year						
	2019	2020	2021	2022	2023	2024	>2025
<b>Bottom-fixed</b>	500 MW Dunkerque (70 EUR/MWh)	1,000 MW Manche Est, Mer du Nord (65 EUR/MWh)	--	--	1,000-1,500 (60 EUR/MWh)		
<b>Floating</b>	--	--	250 MW Bretagne (120 EUR/ MWh)	250 MW Med. (110 EUR/ MWh)	--	250 to 500 MW depending on cost	500 MW/ year

### Progress & Operational Details

During 2018, France had a solid year deploying over 1,500 MW of new wind power capacity, for a total of 15 GW. Thanks to a slightly better capacity factor than the previous year, wind-generated electricity production reached 27.8 TWh—a 23% increase over 2017.

The percentage of electricity demand met by wind energy increased to 5.7%, which allowed France to reach the target set by the PPE for the end of 2018. The installation rate should, however, increase to 2 GW per year to meet the 2023 target.

During 2018, awardees of the first and second offshore tenders were confirmed after renegotiating the FIT with the administration. This was deemed necessary to adapt to the observed cost reduction in the European market.

The third call for tender, which was for the area offshore of Dunkerque and for a capacity of up to 600 MW, was also formally launched following a competitive dialogue phase. Preparation work for additional offshore wind farm areas, including both fixed wind and floating, is also ongoing.

The first offshore wind turbine was grid-connected in 2018, as part of the framework of a floating wind demo project (see below).

Annual wind-generated electricity production increased in 2018, due to a good year for installations and a slight increase of the capacity factor, which is estimated at 21.1%. With an average nameplate capacity of 2.4 MW per wind turbine installed in 2018, the average wind turbine hub heights and rotor diameter were 87 m and 96 m in 2017, respectively [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.

The first 500-MW tender for land-based wind was closed in 2018, leading only to the attribution of 118 MW for an average cost of 65.4 EUR/MWh (75 USD/MWh). This was the result of some uncertainties surrounding the authorization process in 2018.

### Matters Affecting Growth & Work to Remove Barriers

In 2015, the Energy Transition for Green Growth Act confirmed an already ongoing trend toward the simplification of the permitting and licensing process.

A national work group at the Ministry made several recommendations for measures to adopt in 2017, such as applying a single environmental authorization process for a whole territory, reducing deadlines for appeals within this single authorization process, implementing incentives for residents to acquire shareholdings in limited companies involved in local renewable energy projects, and fully applying the "Complément de remuneration" funding mechanism).

Other recommendations included:

- Attribution of 20% of the IFER ("imposition forfaitaire sur les entreprises de réseaux") tax to the town where the wind farm is installed
- Decision given by a single administrative legal court in case of litigation
- Time limitation for opposition to wind farm installation projects
- New legal framework for offshore wind farms ("permits with variable characteristics") to allow for evolution of the technology after the project is awarded

During 2018, the Conseil d'Etat (French Council of State) made a legal decision to remove the environmental authority from the regions Prefects to avoid conflicts of interest. This created uncertainty around the permitting process which negatively affected project authorizations.

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.

# 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 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 (PIA), which is dedicated to industrial projects, and funded by subsidies, reimbursable aids, and possible equity.

After a 2009 call for proposals 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 nation's focus on floating wind. Even though no national statistics are compiled on the R&D budget, 2018 remains a very active year with support to the four floating-wind pilot farm projects.

## National Research Initiatives & Results

The DGE (drone génératrice éolien) project launched to develop an airborne wind energy device. The project is led by the start-up BladeTips Energy with the support of ADEME. Several 20-kW prototypes have been built and tested in flight conditions.

The SmartEole project, funded by the ANR with several industrial and academic partners, was finalized in 2018. Researchers presented their results during a dedicated international workshop. The project focuses on wind turbine control at the blade, turbine, and farm levels. More specifically, the project included several highly-instrumented test campaigns on a land-based wind farm, using nacelle-based, bottom, and scanning lidars. Work was also performed to assess the potential of wind farm control at the blade scale using plasma and air jet actuators.

France is also active in several projects related to the integration of wind and renewables on the grid, including the OSMOSE H2020 project led by RTE, the "Poste intelligent" (smart substation) led by Enedis with PIA funding, and Smart Grid projects such as Smart Grid Vendée project run by Enedis.

## Test Facilities & Demonstration Projects

The four floating wind farms pilot projects awarded in 2016 have progressed on permitting and engineering work. These projects aim to be installed by 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 dépôts, EDPR and Eiffage (near Leucate in the Mediterranean), which will host three GE Haliade 6-MW wind turbines on a floater designed by Principle Power and built by Eiffage

In 2018, the 2-MW demonstrator by IDEOL was installed after towing and connection within the framework of the H2020 FLoatgen project. This was 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 Energy Systems with Large Amounts of Variable 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 International Wind Farm Flow Modeling
- 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)
- Task 36 Forecasting for Wind Energy is also being considered.

# IMPACT OF WIND ENERGY

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## Environmental Impact

Wind energy was the second largest source of renewable energy in France (after hydroelectricity) in 2018; wind-generated electricity provided approximately 30% of the overall installed renewable power capacity, which amounted to 51.2 GW at the end of 2018. In terms of electricity production, wind contributed to 26% of the total renewable energy production, equaling to 5.7% of the total electricity consumption.

## 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 accounted 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 the LM Windpower blade factory that is currently being installed.

A variety of suppliers already exist in the French market, such as Atlantique Offshore Energy (formerly STX) for offshore substations and 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 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 (2.1 billion USD). Of this total, 1.3 billion EUR (1.5 billion USD) is devoted to investment in new parks, and 5 million EUR (5.7 million USD) is intended for the operation and maintenance of existing wind turbines.

## NEXT TERM

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In 2019, the PPE should be adopted and the new targets for wind power capacities should be set. France will likely resume the development of offshore wind parks, starting with the attribution of the tender for Dunkerque and by preparing tenders in other areas.

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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.



**Table 1. Key Statistics 2018, Germany**

Total (net) installed wind power capacity	58.98 GW
Total offshore capacity	6.42 GW
New wind power capacity installed	3.26 GW
Decommissioned capacity (in 2017)	0.25 GW
Total electrical energy output from wind	111.59 TWh
Wind-generated electricity as percent of national electricity demand	18.68%
Average national capacity factor	22.2% (estimate)
National wind energy R&D budget	90.59 mil EUR; 103.8 mil USD
Target	At least 80% RES in electricity consumption by 2050; 40-45% by 2025; 55-60% by 2035

## OVERVIEW

Renewable energies met about 40.4% of Germany's national electricity demand in 2018. Wind-generated electricity produced the largest share of this energy—nearly 48.94% [1,17]. Germany currently has 30,518 wind turbines, which account for nearly 59 GW of installed wind power capacity. These installed turbines produced 111.59 TW of electricity, even though 2018 was a rather weak wind year [1, 4, 7].

In 2018, new installed wind power capacity totaled 3,263 MW, compared to 6,284 MW in 2017. This decrease in capacity growth is due to the fact that almost all calls for bids in three auctions in 2017 were won by community-owned projects [24-26]. Those projects could take part in these bids without a Federal Emission Control Act permit, but they do need to get this approval before building the wind farms. As a result, these projects will probably only be realized by 2022 due to the time needed for the approval process [1-4, 7].

Additionally, many project developers tend to postpone completion on planned wind farm projects because they anticipate a better energy-output to investment ratio through the ongoing turbine development.

In September 2018, the Seventh Energy Research Programme was by the federal government. This broad R&D program addresses topics like energy efficiency, reduction of energy consumption, sector coupling, and digitalization with an ongoing focus on wind energy research and development.

An additional call for proposals will test possible energy systems of the future in the form of Regulatory Test Beds (RTBs). These RTBs are part of the energy transition, and will test innovations concerning the shift from nuclear and fossil-fuel energy towards renewables. RTBs will be tested within a specific time in a certain area to examine new technologies and regulatory frameworks. In this manner, newly-tested technologies can be proven effective and innovation-friendly. The practice of using RTBs are expected to lead to a better acceptance by the general public.

There have also been specific calls for proposals on digitalization issues related to the energy transition and correlating the energy transition with the society. These calls could also have an impact on future wind energy R&D projects [19-21, 27].

## MARKET DEVELOPMENT

### National Targets & Policies Supporting Development

Wind energy capacity will contribute to the overall goal of providing 65% renewable electricity to Germany by 2030 and at least 80% by 2050. Offshore wind power capacity is expected to reach the national target of 15 GW by 2030, although an increase of this target is currently under debate. An intermediate target of 7,700 MW is expected to be reached by 2020. After that point, it is expected that the auctions will lead to an increase of installed capacity to reach the current 15 GW national target [12].

No hard target exists for land-based wind energy capacity in Germany. Regular auctions for land-based wind will tender an anticipated 2,700 MW per year from 2018–2021 and about 2,900 MW per year after 2022 (Table 2). Additional land-based auctions will likely tender 4,000 MW from 2019–2020 [9].

In addition to those technology-specific auctions, Germany also holds technology-open auctions. For those, land-based wind energy and PV are offering projects in mutual competition. Volumes are 400 MW in the respective years

2018, 2019, 2020 and 2021. However, all auctions in 2018 and 2019 have been won by PV projects so far [22, 23].

All tendered yearly volumes (land-based and offshore) are split into several smaller auctions each year. In order to reach the target of 65% renewable electricity by 2030, volumes for tenders will have to be increased in the future.

### Progress & Operational Details

Deployment of both land-based and offshore wind energy slowed down compared with the previous year. Germany added 2,273 MW of land-based capacity (5,009 MW in 2017)—including 94.52 MW of so-called pilot wind energy turbines, which are used for innovation purposes—and 990 MW of offshore capacity (1,275 MW in 2017) [12].

Both land-based and offshore wind produced more electrical energy than in 2017. Land-based wind provided 92.25 TWh (88.02 TWh in 2017), and offshore contributed with 19.34 TWh (17.675 TWh in 2017).

Capacity factors for 2018 were comparable to 2017; the land-based capacity factor reached 20.5% (21% in 2017) and offshore reached 37.3% (42.1% in 2017). As such, wind energy contributed 48.49% of all renewable electricity production (48.61% in 2017) and 18.5% of the country's gross electricity consumption (17.5% in 2017).

Enercon held the largest market share of turbine manufacturers in 2018 with a 52% share. The next largest market shares belonged to Vestas (25%) and Nordex (9%). The typical land-based project size of 2.88 wind turbines (3.02 WTs in 2017) and 9.26 MW (8.96 MW in 2017) stayed almost stable.

The average characteristics of a turbine installed in 2018 were a rated power of 3.11 MW (2.92 MW in 2017), 129 m hub height (126.6 m in 2017), and 114 m rotor diameter (111 m in 2017) [12].

Only three manufacturers shared the 2018 offshore installations: MHI Vestas (47%), Siemens Gamesa Renewable Energy (38%) and GE Renewable Energy (15%). The average characteristics of an offshore turbine installed in 2018 were a power rating of 7.02 MW (5.65 MW in 2017), a 106.1 m hub height (96.2 m in 2017), and a 157.2 m rotor diameter (137.6 m in 2017). These characteristics indicate a significant move toward larger machines [12].

**Table 2. Auction Targets in Germany, 2018-2030**

Year	Offshore	Land-based
2018	--	2,800 MW
2019	--	2,675 MW + 1,000 MW
2020	--	2,700 MW + 1,400 MW
2021	500 MW	2,650 MW + 1,600 MW
2022	500 MW	2,900 MW
2023-2025	700 MW per year	2,900 MW per year
2026-2030	700-900 MW per year	2,900 MW per year

### Matters Affecting Growth & Work to Remove Barriers

The shift from feed-in-tariffs to auctions has affected wind energy growth in Germany. The first land-based auctions have almost completely been won by community-owned projects. These community-owned projects enjoyed some amenities in the first call for bids, most notably not needing a valid Federal Emission Control Act permit to make an offer or being given an extended realization period compared to commercial wind park planners.

Because this arrangement was supposed to enable diversity but in actuality led to the opposite, it has been abrogated until 2020. In the meantime, it is expected that the projects that won the 2017 auctions will require more time to install their wind turbines, and there is a risk that some projects will not get a permit due to Emission Control Act matters [33]. This has led to a noticeable dent in land-based installations.

A large share of all planned projects are also taken to court, due to a lack of acceptance for wind energy projects [23]. Because of this the recent tender volumes were not fully utilized, and this will likely lead to an additional dent in land-based installation in the near future.

Offshore, the scheme has been changed for future auctions. The change from a feed-in-tariff to an auction system was followed by a shift to a so-called central auction system. This central system will apply to all wind farms and will be commissioned from 2026 onwards [34]. In that scheme, authorities will select sites to be tendered and will perform the necessary preliminary investigations. The transition between those two auction systems will result in 0 MW auctions in 2020 and possibly 0 MW offshore installations in 2020.

## R,D&D ACTIVITIES

### National R,D&D Priorities & Budget

Germany pursues a broad R&D program, rather than focusing on a specific subject. Ongoing research funding is largely aimed toward reducing turbine life cycle costs and guaranteeing more efficient operations. Other key aspects of German research projects in 2018 included:

- Making complex wind turbine sites easily accessible
- Ensuring a good grid integration of wind-generated electricity
- Looking at wind farm wake effects

This focus includes weight reduction and robust design of wind turbine components, the forecasting of site-specific wind resources taking meteorological specifics into account, and always having a strong focus on environmental and ecological aspects like radar interferences and impacts on marine mammals along with holistic considerations of social acceptance (e.g. contributing to the IEA Wind TCP Task 28) [7].

As mentioned previously, in September 2018 the Seventh Energy Research Programme was passed by the federal Government. Eight energy research networks contributed to this research program in 2018, with nearly 3000 registered experts conducting this work. The latest network focuses especially on start-ups within the energy sector.

In 2018, Germany spent 90.59 million EUR (103.78 million USD) on 121 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 (Figure 1). Compared to the 95.97 million EUR (109.94 million USD) spent in 2017, this continues a steady level of funding over the past few years. The 420 ongoing wind energy research projects equaled 59.73 million EUR (68.42 million USD) in 2018. All of these projects emphasize application-oriented wind energy research within the effective Sixth Energy Research Programme of the Federal Government [7].

Additionally, the Federal Ministry of Education and Research (BMBF) also supports basic oriented research on all areas mentioned in the Seventh Energy Research Programme, which includes wind energy topics like looking at high-performance materials for wind turbines. There is also an ongoing fund's flow for wind energy projects executed on a Federal State basis [30].

### National Research Initiatives & Results

In 2018, there were 1,305 offshore wind turbines, with an installed capacity over 6 GW, operating in the German North and Baltic Seas. In order to fulfil the aim of the Renewable Energy Sources Act to increase offshore wind energy production up to 15 GW by 2030, further wind farms will be built. At the end of their operational life, these wind farms need to be decommissioned in a cost-efficient and environmentally-friendly way.

The research project SeeOff aims to support stakeholders in developing and evaluating efficient, project-specific decommissioning strategies that minimize cost, , comply with legal requirements, ensure safety at work, protect the environment, and are publicly accepted. The Federal Ministry for Economic Affairs and Energy BMWi is funding this project with 1.13 million EUR (1.29 million USD) [8].

Offshore wind farms are currently being installed in the German Exclusive Economic Zone (EEZ) in the North and Baltic Seas as part of the German Energy Transition from fossil fuel and nuclear energy to the renewable energy era.

The foundations of offshore wind turbines (OWT) are usually realized by means of open steel monopiles with a large diameter (6-8 m). Operation life of an OWT is set to 25 years. After this time, the OWT and its foundation have to be decommissioned according to the current regulations. Corresponding to the current state-of-the-art, cutting devices are intended for the decommissioning of the foundation piles.

By leaving the remaining pile in the seabed, valuable areas for repowering are not only blocked, but at risk of creating potential hazards for the fishing and offshore industries. The project DeComp develops technical methods to completely remove an obsolete offshore foundation. The Federal Ministry for Economic Affairs and Energy BMWi is funding this project with 0.97 million EUR (1.11 million USD) [13].

The design of a rotor is typically based on ideal material properties and design safety factors. Neither manufacturing defects nor material degradation are taken into account, which often results in failures or damages during certification tests or in the field. The aim of the German-Danish project ReliaBlade is to predict the actual structural reliability of a rotor blade and make blades more cost-efficient through optimized material usage and more appropriate maintenance concepts.

The prediction requires an accurate knowledge about the structural condition of each individual blade during its lifetime. In order to obtain this knowledge, researchers investigate a number of common manufacturing defects and operational failure modes to determine their influence on the rotor blade structure.

ReliaBlade covers a multi-level test program that researches the effects of manufacturing defects, such as fiber waviness, as well as material degradation, such as inter fiber failure or bond line cracks. In this internationally-operated project, the German partners Leibniz Universität Hannover and Fraunhofer-Institut für Windenergiesysteme (IWES) work together with partners from the Technical University of Denmark (DTU). The Federal Ministry for Economic Affairs and Energy BMWi is funding this project with 6.40 million EUR (7.33 million USD) [15].

The project BladeFactory aims to further reduce the costs of rotor blades. This shall be achieved through a differential structural design, new manufacturing technologies, parallelized and shortened production steps, and an extended and experimentally-validated knowledge of the influence of process parameters on the component quality.

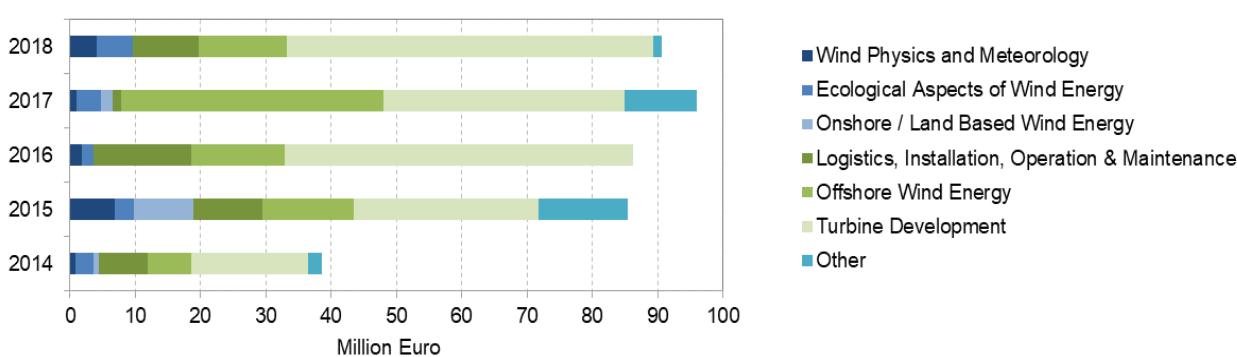


Figure 1. Development of German R&D funds from 2014–2018 (Source: Federal Ministry for Economic Affairs and Energy BMWi) [7]

A geometry scanning system and an automated comparison between the measured and the desired contour in a CAD program will enable serial producers to record the geometry of blade components as well as entire blades. The Federal Ministry for Economic Affairs and Energy BMWi is funding this project with 7.0 million EUR (8.02 million USD) [7].

Certification of the electrical characteristics of wind turbines for grid compliance verification purposes is performed through long-term, cost-intensive field tests. These test campaigns are particularly challenging, as wind conditions can be unpredictable. The project Hil-GridCoP seeks to investigate testing procedures for electrical characteristic verification of wind turbines on test benches in a laboratory environment as a solution to this challenge.

The main goal of this joint research project is to successfully implement new strategies for the certification of relevant measurements on a newly-designed test bench. The Federal Ministry for Economic Affairs and Energy BMWi is funding this project with 9.54 million EUR (10.93 million USD) [7].

### Test Facilities & Demonstration Projects

In order to enable further technological progress and cost reductions in offshore wind, Germany must provide testing and demonstration areas for offshore wind power plants, foundations, and other components. Therefore, the Federal State Mecklenburg-Vorpommern has designated a marine test field called NaT-Off to test near-shore (10 km) wind power plants and make them easily accessible. The water depth in this area is around 20-28 m.

During the first 4-year-phase, the actual demands on a test facility like NaT-Off will be determined. The grid connection is planned for 2024. NaT-Off will then be available for the testing and development of new and high-performance wind turbines, single components, foundations, and concepts for logistics and grid connection technologies. To ensure the public accepts this project, an acceptance concept for this large-scale test area will be developed. The Federal Ministry for Economic Affairs and Energy BMWi is funding this conceptual project with 0.94 million EUR (1.08 million USD) [16].

### 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 participated in 13 of 16 active research tasks in 2018.

All of Germany's task participants also execute nationally-funded projects in their related topics, benefitting the worldwide information exchange within their IEA Wind TCP Tasks. Representatives from the University of Stuttgart and University of Applied Sciences Flensburg lead task work as the operating agents of Task 32 Lidar Systems for Wind Energy Deployment.

There are several ongoing R,D&D projects in Germany that focus on environmental issues; two examples are SilentHammer and Helbird.

**SilentHammer:** The aim of the project SilentHammer is to protect marine mammals by reducing the underwater noise that is produced during the installation of offshore wind energy plants due to pile excitation. Primary measures reduce the noise emission directly at the source by lowering the applied hammer energy. Secondary measures aim to reduce the noise in the water column, such as bubble curtains or cofferdam systems.

Due to the huge dimensions of the monopiles, both noise emission and the requirements on the noise mitigation are increasing. The research project focuses on the primary measures to reduce the noise emission at the source itself by determining an optimal shape for the ram mass and further hammer components, as well as investigating the hammer operation from an acoustic viewpoint. The Federal Ministry for Economic Affairs and Energy BMWi is funding this project with 0.33 million EUR (0.38 million USD) [11].

**Helbird:** The overall goal of the project Helbird is to examine the possible impacts of the wind park cluster north of Helgoland on seabirds and marine mammals during the operation phase of the wind turbines. During broad survey campaigns, distribution patterns of seabirds and marine mammals were characterized and checked for specific reactions to wind farms, such as avoidance or attraction behavior.

Possible ways that wind farms affected the behavior of seabirds and marine mammals were investigated by visual observation from converter platforms. The spatial habitat use and flight behavior of Helgoland's breeding birds was investigated with GPS data loggers and evaluated with respect to the impacts of offshore wind farms, including ship movements. The Federal Ministry for Economic Affairs and Energy BMWi was funding this project with 1.29 million EUR (1.48 million USD) [7].

Germany participates in the European SET-Plan Implementation Plan Wind Working Group for offshore wind. The EU-funded SETWind project will update and work with the Implementation Plan to maintain its status as a dynamic reference point for offshore wind energy research and innovation. The project will stimulate the implementation of targets together with relevant stakeholders through nationally-funded projects coordinated across borders. The Federal Ministry for Economic Affairs and Energy (BMWi) tends to support those cross-border research activities through its national funding scheme.

## IMPACT OF WIND ENERGY

### Environmental Impact

In 2018, about 37.8% of the German energy demand could be covered by renewable energy sources, leading to savings of 140 million tons of carbon dioxide equivalents. Overall, wind energy is the single largest source of renewable energy, and it accounts for 52.96% of total CO<sub>2</sub> equivalents avoided by all renewable energy sources [1].

## NEXT TERM

Wind energy continues to be central to the German Energy Transition as one of the main supporting pillars. 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: Offshore Wind Park Alpha Ventus (Source: BMWi; Photo credit: BMWi/Holger Vonderlind)

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**Table 1. Key Statistics 2018, Greece**

Total (net) installed wind power capacity	2.86 GW
Total offshore capacity	0 GW
New wind power capacity installed	0.21 GW
Decommissioned capacity (in 2017)	0 GW
Total electrical energy output from wind	6.3 TWh
Wind-generated electricity as percent of national electricity demand	12.25%
Average national capacity factor	25.14%
Target	7.5 GW by 2020

## OVERVIEW

In 2018, Greece continued to see encouraging growth in its wind energy sector. The country installed approximately 208 MW of new wind power capacity. According to the Greek power market operator, this 7% increase brings the total installed wind capacity to 2,860 MW (Table 1).

The electricity output from wind generation in Greece totaled 6.3 TWh – meeting approximately 12.25% of national demand. 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.

The feed-in tariff (FiT) scheme, applicable with small variations since 1994, was replaced by a technology-specific sliding scale feed-in premium (FiP) by virtue of Law 4414/2016 that came into effect on 9 August 2016.

Electricity from renewable sources in Greece is promoted through a feed-in premium granted by participation in “technology specific” tenders.

In December 2016, a pilot tender for photovoltaic (PV) power took place. In 2018, two tenders for PV and wind energy took place. Apart from that, renewable energy sources (RES) are eligible for a net metering scheme, mainly for PV and small wind power plants. In addition, a tax regulation mechanism and a subsidy scheme are available under the new Development Law.

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Opening photo: Wind farm in West Greece (near the Rio-Antirrio cable-stayed bridge)

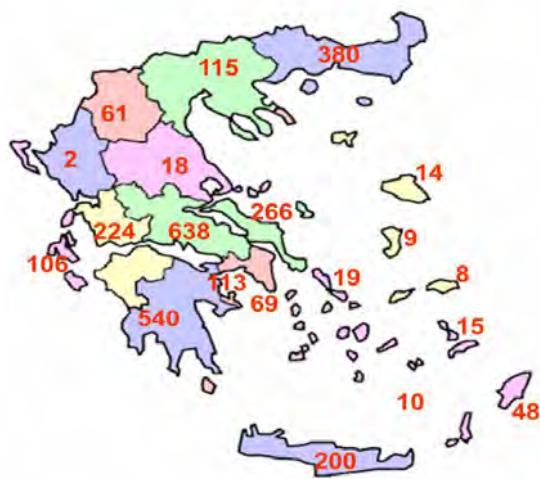


Figure 1. Wind farm capacity in Greece (MW)

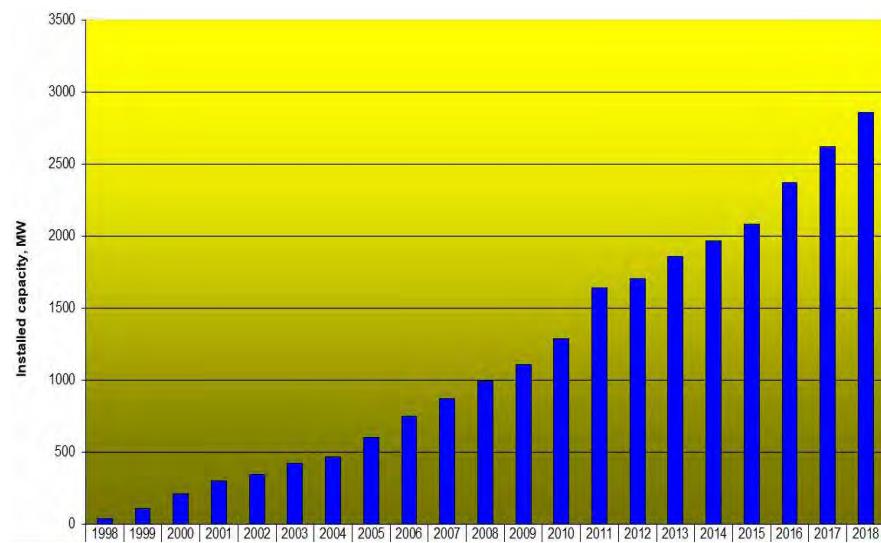


Figure 2. Installed wind power capacity in Greece, 1998-2018



**Table 1. Key Statistics 2018, Ireland**

Total (net) installed wind power capacity	3.67 GW
Total offshore capacity	0.033 GW
New wind power capacity installed	0.36 GW
Decommissioned capacity (in 2017)	0 GW
Total electrical energy output from wind	8.46 TWh
Wind-generated electricity as percent of national electricity demand	27.6%
Average national capacity factor	27.6%
Target	40% RES-E by 2020

## OVERVIEW

New wind farm construction continued in 2018, albeit at a lower rate than the 2017 construction peak. A total of 355 MW of new wind power capacity was added in 2018, bringing the total installed capacity to 3,673 MW.

Significant regulatory change and policy announcements occurred in 2018, including the implementation of the Integrated Single Electricity Market (ISEM), publication of the high-level design of the future Renewable Electricity Support Scheme, and the first round of the Enduring Connection Policy (ECP-1) [1-3].

While wind energy will make a greater than planned contribution to an ambitious 40% renewable electricity target for 2020, a small overall shortfall is projected [4]. In December 2018, a 2030 renewable electricity target of 55% was proposed in Ireland's draft National Energy and Climate Plan [5].

R&D has played an important role in wind energy deployment in Ireland, particularly in grid integration, and will become increasingly important for more ambitious 2030 targets. The Sustainable Energy Authority of Ireland (SEAI) introduced topical priorities for wind energy in its 2018 R,D&D call [6].

## MARKET DEVELOPMENT

### National Targets & Policies Supporting Development

Ireland has an overall target of meeting 16% of its energy demand from renewable sources in 2020 and, within this, also has renewable electricity target of 40%. In common with other EU countries, Ireland must register a National Energy and Climate Plan (NECP) with the European Commission in 2019.

A draft plan provided to the Commission in December 2018, proposed a maximum renewable electricity target of 55% [5]. In early 2019, the Minister for Communication, Climate Action and Environment expressed his dissatisfaction with the targets and measures in the draft NECP and asked state bodies for proposals to improve upon these.

The primary support scheme for renewable electricity is the Renewable Electricity Feed-in Tariff (REFIT), which closed to applications in 2015, with projects supported to be completed by the end of 2019 [7]. A replacement Renewable Electricity Support Scheme (RESS) is anticipated to underpin 2030 targets and, after a consultation in 2017, a high-level design paper was published in 2018 [2].

The full details of the scheme are to be published in 2019 and the first auction is also scheduled to be held by the end of 2019.

### Progress & Operational Details

New wind farm construction to meet 2020 targets continued throughout 2018, albeit at a lower rate than the 2017 construction peak. Wind farms totaling 355 MW in capacity were added in 2018, providing a 10% capacity increase. The total output from wind energy was 8.46 TWh, contributing 27.6% of electricity demand.

The average capacity factor was 28% and curtailment increased to 5%; the latter was held in check by the system operator, Eirgrid, steadily increasing the limit on instantaneous system non-synchronous penetration (SNSP) [8]. The SNSP level was increased from 55% to 60% on a trial basis in November 2016 and permanently in March 2017. This limit was raised again to 65% on a trial basis in November 2017, and set to 65% in April 2018.

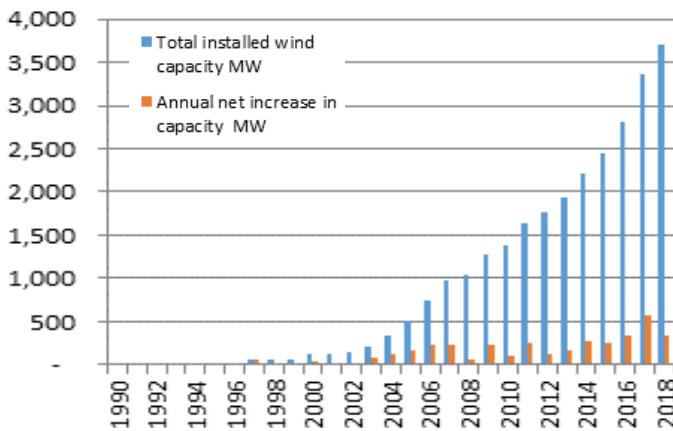


Figure 1. Cumulative and annual wind power generation capacity 1990-2018

A new Integrated Single Electricity Market (ISEM) was implemented in October 2018 [1]. The new market conforms to the EU target market model and incorporates intra-day and balancing markets.

Wind power plants are now balance responsible within this market and must interact continuously with the market. Since its introduction, the ISEM has exhibited greater price spikes, including negative prices, and volatility than the previous market.

Independent wind farm operators who continued their prior passive interaction with the market were disadvantaged. Some reported having to shut down during negative price periods, mostly at night. Operators who engaged with traders to enter into hedging contracts had a much better experience.

The first round of the new Enduring Connection Process (ECP-1) awarded connections to wind farm projects totaling 300 MW [3]. Projects applying for connection under the new process are now required to have planning consent.

There was significant entry of European utilities in the Irish wind energy sector in 2018. Statkraft acquired local developer Element Power and Innogy completed construction of its first wind farm in Ireland. Greencoat Renewables also expanded its investment in wind energy significantly, acquiring or taking a stake in a number of Irish wind farms in 2018.

## Matters Affecting Growth & Work to Remove Barriers

A 2018 SEAI report projected a 38.4% contribution from renewable energy to electricity demand in 2020, which represents a shortfall of 1.6% on the 40% target [4].

The shortfall will largely be due to technologies other than wind energy not meeting targeted output combined with strong growth in electricity demand. While the level of wind farm construction has been consistently high in recent years, it has been constrained by delays in the permitting process and in delivery of grid connections.

Viable projects may fail to meet the deadline for inclusion in the REFIT scheme due to such delays. The transition-in support scheme from the REFIT to the RESS at the end of 2019 may also result in a gap in deployment in the final year of the target period, while the projects winning the first auction round are executed. Corporate Power Purchase Agreements may have the potential to fill this gap and the government is considering measures that could support a greater uptake of these.

The announcement that the high-level design for the future Renewable Electricity Support Scheme would initially involve technology-neutral auctions, later moving to technology-specific auctions, gave new impetus to the offshore wind sector [2].

Two industry reports published in 2018 detailed almost 4 GW of projects currently in the offshore consenting process [9, 10]. The reports identified potential improvements in the consent process which would facilitate the growth of the offshore wind energy sector and contribute to meeting the 2030 targets.

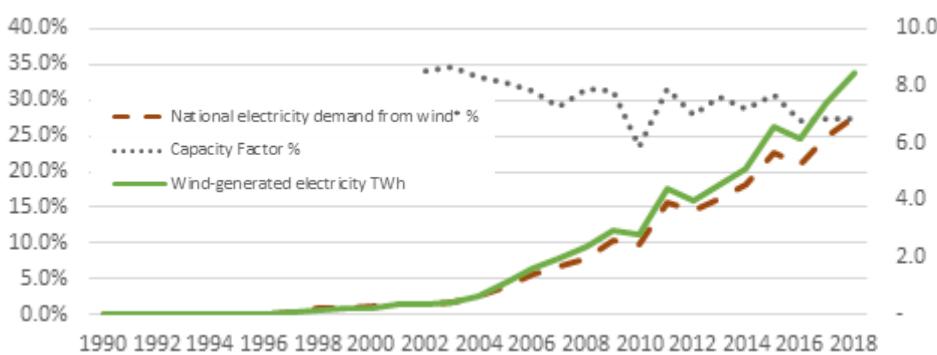


Figure 2. Wind-generated electricity, contribution to demand, and capacity factor, 1990-2018

## R,D&D ACTIVITIES

### National R,D&D Priorities & Budget

The 2016 IEA Wind Annual Report identified the national energy R&D priorities for Ireland. The primary scheme funding renewable energy research in Ireland is SEAI's Sustainable Energy R,D&D scheme. This scheme was revamped in 2018 with an increased budget; the leveraging of co-funding from stakeholder organizations to increase the overall budget; and the introduction of priority topics in specific research areas [6].

The 2019 SEAI call for proposals for the Sustainable Energy R,D&D scheme was advertised in December 2018. Priority wind energy topics included:

- Wind farm power performance and availability improvements;
- Benchmarking wind farm O&M/asset management performance in Ireland;
- Scenarios for the development of the Irish offshore wind energy sector up to 2030 (research fellowship);
- Adaptive or risk-based management of wind farm interactions with hen harriers; and
- Operational excellence/best practice in wind farm asset management;
- Wind Turbine Blades: fouling characterization and droplet erosion mitigation.

### National Research Initiatives & Results

Wind energy related projects that SEAI approved funding for in 2018 were as follows:

- FREMI: Forecasting Renewable Energy with Machine Intelligence;
- Enhanced Controllers to Improve Wind Farm Efficiency;
- Brightwind I-SEM Forecast;
- Robust Real-Time Wind Power Prediction and Early, Accurate Estimation of Downtime for Irish Wind Farms in an Integrated Single Electricity Market (Wind-PEarlaED);
- CAO IRL: Coupled Atmosphere Ocean Wave Forecasts for Ireland;
- Identifying the relative and combined impact and importance of a range of curtailment mitigation options on high RES-E systems in 2030 and 2040; and
- Community Engagement in Wind Energy: Innovative approaches to achieving a social license (Co-Wind).

Other projects in 2018 included EirWind, a MaREI Centre's industry-led collaborative research project. This opportunity was co-designed around the sustainable development of Ireland's marine resources, using offshore wind as the catalyst for innovation and impact, and was funded by industry partners and Science Foundation Ireland [11].

The project utilizes the concepts of Marine Spatial Planning (MSP) where relevant, including interactive use of advanced data-analysis, strategic planning, Irish marine and renewable energy policy initiatives, and stakeholder management.

### Test Facilities & Demonstration Projects

An application was approved to extend the consent for the SEAI SmartBay marine energy test site in Galway Bay to include the testing of floating offshore wind turbines at up to ¼ scale. The awarding of consent has been contested and is currently subject to judicial review.

Work began to extend the consent for the SEAI Atlantic Marine Energy Test Site (AMETS) in County Mayo, which has a current consent for wave energy convertors, to include floating offshore wind technologies. SEAI partnered with Saipem to make an application for EU FP7 funding for a floating offshore wind demonstration project at this site.

An Airborne Wind Energy test site was also proposed for County Mayo in 2018 and work proceeded on the precursors to a formal planning application for this [12].

### Collaborative Research

Ireland currently participates in IEA Wind TCP Tasks 11, 25, 26, 28, 34, 36 and 39. SEAI advertised a new call for participants in IEA Wind Tasks at the end of 2018. Along with renewal of prior participation in Tasks, the call resulted in new participants being appointed for Task 41 and the proposed new Task on Digitalization and Wind Energy. The new SEAI process for organizing national IEA TCP participation will involve regular calls for new participants.

SEAI hosted Topical Expert Meeting #93 on Digitalization and Wind Energy in October 2018. The meeting was exceptionally well-attended and resulted in the proposal for a new Task.

# IMPACT OF WIND ENERGY

## Environmental Impact

Wind energy resulted in 3.1 MT of avoided CO<sub>2</sub> emissions in 2018. Wind energy is central to Ireland's renewable energy targets, as 85% of renewable electricity and half of all renewable energy is provided by wind. An Irish Wind Energy Association (IWEA) report in 2018 identified that wind energy will displace 33 million tons of power-sector CO<sub>2</sub> emissions from 2000 to 2020 [13]. The total carbon emissions from electricity generation in 2017 was 11.7 MT, so a saving of 33 MT is equivalent to almost three years of total carbon emissions in the electricity sector today.

## Economic Benefits & Industry Development

An IWEA report in 2018 identified the economic benefits of wind energy to Ireland [13]. Analysis of the Irish electricity market by independent energy experts Baringa for IWEA estimated that wind energy reduced power prices by a total of 2.4 billion EUR (2.75 billion USD) since 2000.

This total net cost was found to be significantly lower than the gross cost of 3.3 billion EUR (3.8 billion USD). This is due to wind-driven reductions in wholesale power prices, savings on capacity payments, and avoidance of EU noncompliance costs. These savings amount to a total of 3.2 billion EUR (3.7 billion USD), which almost entirely offsets the additional cost of wind.

A further report by the IWEA explored a 70% renewable electricity scenario for Ireland in 2030, with the majority of electricity coming from wind energy [14]. The report found the scenario to be feasible at a reasonable cost where measures are taken to maintain low curtailment levels for variable renewable electricity. The report also found that the 70% renewable energy scenario would come at no additional cost to consumers if levelized costs of renewable energy of 60 EUR/MWh (68.7 USD/MWh) for onshore wind, 70 EUR/MWh (80.2 USD/MWh) for offshore wind and 80 EUR/MWh (91.6 USD/MWh) for solar were achieved.

## NEXT TERM

The publication of Ireland's NECP in 2019 will see the finalization of both renewable electricity targets for 2030 and the related policies, including the Renewable Electricity Support Scheme, that will deliver the targets. Where an ambitious renewable electricity target is ultimately adopted, it will require a significant R&D program to adapt the electricity system to operate with a higher instantaneous penetration of non-synchronous generation. It will also require progress in the offshore consenting arrangements to facilitate development of Ireland's offshore wind energy resource.

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Author: John Mc Cann, SEAI, Ireland.



**Table 1. Key Statistics 2018, Italy**

Total (net) installed wind power capacity	9.96 GW
Total offshore capacity	0 GW
New wind power capacity installed	0.45 GW
Decommissioned capacity (in 2017)	0 GW
Total electrical energy output from wind	17.3 TWh
Wind-generated electricity as percent of national electricity demand	5.4%
Average national capacity factor	20.8%
Target	12,000 MW land-based; 680 MW offshore by 2020; 40 TWh wind energy production by 2030

## OVERVIEW

In 2018, Italy's new installed wind power capacity reached 452 MW—nearly double that of the previous year. Cumulative installed capacity at the end of the year was approximately 9.96 GW. Italy deployed 184 new turbines, bringing the total number of installed wind turbines to about 6,900. Wind-generated electricity consistently covered around 5.5% of the country's total demand.

The increase of the annual installation is due to the 800-MW quota for land-based wind power capacity assigned by tender in 2016-2017. By the end of 2018, the decree, which should set the new rules for renewable production incentives, had not yet been published. The main issues affecting deployment in Italy is the lengthy and the complex process for obtaining permits

for new wind farms (as well as for revamping and repowering interventions) and uncertainty about new incentives, support schemes, and the rules of the future electricity market.

At the national level, many organizations are involved in wind energy R&D&D activities. However, in most cases, these activities are fragmented, making it quite difficult to give a representative value for the national wind energy R&D budget or to evaluate trends.

Italy participates in many EU-funded projects, in EERA JP WIND, and in IEA Wind TCP Tasks 11, 25, and 30. At the end of 2018, Italy also joined Task 29.

## MARKET DEVELOPMENT

### National Targets & Policies Supporting Development

In 2009, Italy set a binding national target to cover 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) of installed wind power capacity and a target of 20 TWh/yr (18 TWh/yr land-based and 2 TWh/yr offshore) for electricity production. Italy reached the renewable production target in 2015.

At the end of 2017, the new National Energy strategy (SEN 2017) was published, outlining national objectives and policies for Italian energy systems by 2030 [1]. In order to reach the new target of 55% renewable penetration of the national electricity demand, the SEN 2017 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.

At the end of 2018, the Draft Integrated National Energy and Climate Action Plan (PNIEC) was sent to the European Commission [2]. This plan set the capacity targets for renewables to be installed within 2025 and 2030. Concerning the wind energy, the capacity targets are 15,390 MW land-based and 300 MW offshore and 18,400 MW land-based and 900 MW offshore respectively. Therefore, Italy expects a significant increase in wind power capacity in the next ten years with many challenges to be faced, including permitting, support schemes, repowering interventions, definition of suitable areas, new electricity market, and power purchase agreements.

From the 2012 decree until the end of 2018, the incentive mechanism supporting renewables was based on fixed energy purchase prices for RES-E plants below a capacity threshold, depending on technology and size (no lower than 5 MW).

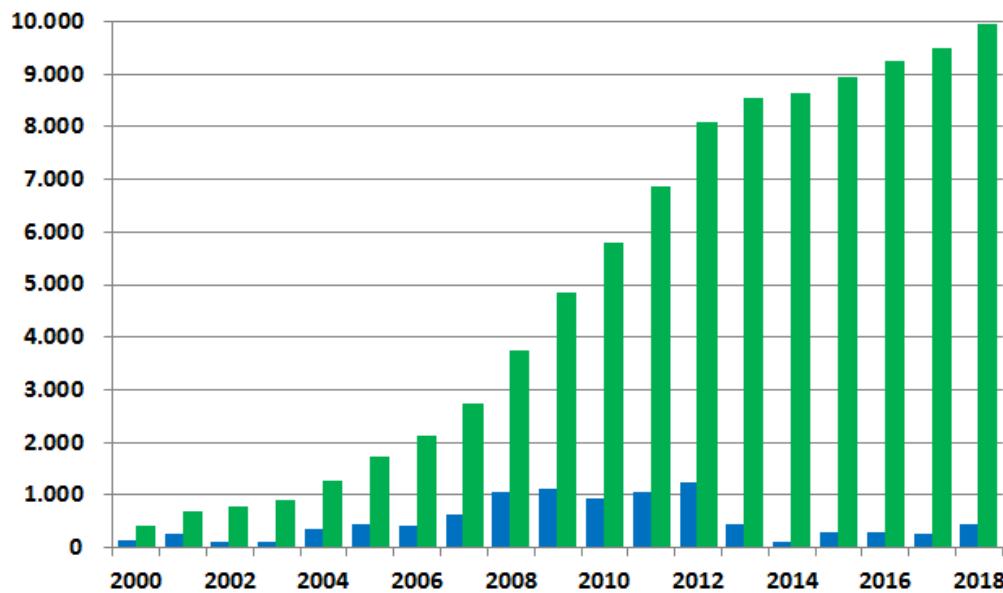


Figure 1. Annual and cumulative wind power capacity trends in Italy (2000-2018) (Source: Elaboration from ANEV Data)

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. During 2018, a new decree with modified support schemes for the next period was in preparation.

The new scheme would implement technology-neutral auctions and the incentive mechanism based on fixed prices will end in 2020.

### Progress & Operational Details

According to the National Wind Energy Association (ANEV), Italy installed a new net wind power capacity of 452.35 MW in 2018. Cumulative installed capacity at the end of the year reached 9.96 GW, all of which was land-based, including decommissioning and repowering. The trend of annual and cumulative capacity from 2000-2018 is shown in Figure 1.

Italy connected 36 new wind farms to the grid in 2018, each with capacities between 0.8 MW and 39.6 MW, 23 of which were greater than 5 MW. Additionally, 182 new turbines were installed, bringing the country's total to around 6,900 operating units. The wind turbines installed during the year averaged 2.5 MW (maximum 3.45 MW); the average size of all wind turbines in Italy is 1.4 MW.

Small plants saw a strong decrease in installation, due to the reduced incentive tariff for these plants. In 2017, new wind plants that were greater than 5 MW accounted for the 67% of the year's total installations, while wind plants smaller than 500 kW accounted for 31%. In 2018, more than 94% of the new plants were greater than 5 MW [3].

TERNA, the national TSO, estimates that wind-generated electricity in 2018 totaled 17.3 TWh—5.4% of Italy's total electricity demand (total consumption plus grid losses) [4].

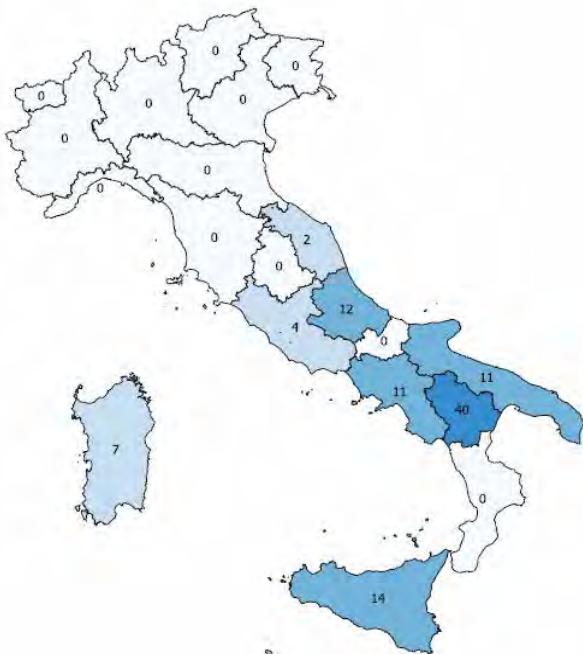


Figure 2. Regional distribution of 2018 new wind power capacity (Source: Elaboration from ANEV Data)



Figure 3. Regional distribution of 2018 cumulated wind power capacity (source: Elaboration from ANEV Data)

In 2018, new wind power capacity was mainly installed in the Basilicata (59%), Calabria (19%), and Campania (11%) regions (Figure 2). Most installations are in the southern regions of Italy due to wind resource availability (Figure 3). The Basilicata region, which hosts one of the biggest national natural parks and many cultural and touristic sites, reached 1 GW of installed wind power capacity.

The average capital cost ranges from 1,840 EUR/kW (2,108 USD/kW) for wind farms with a capacity smaller than 500 kW to 1,200 EUR/kW (1,375 USD/kW) for wind farms with a capacity greater than 1 MW [3].

In 2018, operator E2i Energie Speciali performed two integral reconstruction projects in the Abruzzo region. The Schiavi d'Abruzzo wind plant replaced 15 600-kW turbines with four new 2.5-MW machines, and the Castiglione Messer Marino wind plant replaced 44 Enercon 600-kW turbines with four new 3.3-MW machines. In both cases, the plant's production is expected to double (Figure 4) [5].

### Matters Affecting Growth & Work to Remove Barriers

According to the big wind energy operators, the main issues affecting growth are the long and complex permitting processes, the uncertainty about support schemes, and the rules of the future electricity market.

The number of wind turbines already installed, the high-density population, the complex terrain, widespread tourism, and landscape impacts could also affect the acceptance and growth of further wind capacity in Italy. To overcome these issues, the Draft Integrated National Energy and Climate Action Plan has announced a process aimed to identify suitable areas for new wind park installations.



Figure 4. Schiavi d'Abruzzo integral reconstruction project (Source: Gisella Motta)

Since November 2018, the Dispatching Services Market (MSD) was opened to the so-called UVAM (Unità Virtuali Abilitate Miste - Qualified Mixed Virtual Unit). The UVAM can be composed by aggregating small units, renewables plants, and demand and storage units. The ARERA, the Italian Regulatory Authority for Energy, Networks and Environment, approved the regulation concerning the pilot project for UVAM's participation in the MSD [6].

## R,D&D ACTIVITIES

### National R,D&D Priorities & Budget

Italy's national energy policy is coordinated by the Ministry of Economic Development (MiSE). The Ministry of Environment and Protection of Land and Sea (MATTM) is responsible for coordinating policy on climate change.

The most important program supporting R&D activities in the energy sector is the "National Fund for Electric System Research" (RdS). RdS is aimed at the scientific and technological innovation for the electricity system to enhance competitiveness, security, and environmental compatibility, as well as ensure conditions for sustainable development. Most RdS projects are implemented by public R&D institutions through Program Agreements with MiSE—namely Ricerca sul Sistema Energetico—RSE SpA, the National Agency for New Technologies, Energy and Sustainable Economic Development (ENEA), and the National Research Council (CNR).

From 2015–2018 the RdS Program did not have projects fully dedicated to wind energy. This will continue in the next term (2019–2021); however, many research themes also concern wind energy, such as the renewable resources atlas (see next paragraph), renewables integration, distributed generation, small island energy mix, and the possible contribution of renewable generation to the flexibility and grid regulation.

The 2015–2020 Italian Research Program set by the Ministry of Education, Universities and Research (MIUR) has identified 12 specific areas of competency – including the Blue Growth – that could help establish and implement policies that are expected to significantly impact the social and economic development of the country at both the national and the local levels. The promoters of the National Technological Cluster Blue Italian Growth (CTN BIG) have a significant international standing at the scientific and the economic levels, as well as a wide range of international collaborations with research centers, networks and companies. This ensures a high potential for synergy and a proper strategic positioning of the cluster's actions at international level.

Since the sea economy has always been a globalized sector, CTN BIG is set to stay in line with the development trajectories defined at the world (OECD), European (Marine Board, Waterborne EU Technology Platform, JPI Oceans, Copernicus, EMODnet) and Mediterranean basin (BLUEMED, MONGOOS) levels. This will help the cluster tackle social challenges, which are summarized in the European directive of restoration and maintenance of a Good Environmental Status (GES), and address the specific macroeconomic trends of the sector in a sustainable way.

Among the trajectories identified as primary for the cluster actions, renewable energies from the sea, including offshore wind, are of primary importance. Italy is particularly interested in the potential progresses obtainable from reduced-size plants operating in mildly harsh conditions (typical of the Mediterranean sea) and from multi-purpose platforms where integrated production processes (such as energy harvesting from wind and waves, water desalination and aquaculture) are sustainably optimized.

At the national level, many organizations are involved in wind energy R&D activities. The most of them, typically Universities, set their own budgets for wind energy R&D. Moreover, in many cases the activities are funded in a bigger umbrella concerning the whole renewables. For these reasons, it is difficult to give a representative value for the national wind energy R&D budget or to evaluate trends.

Since the beginning, Italy has 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

In the last research period (2015-2018), RSE developed the Integrated Atlas for the National Energy System and Renewable Sources [9]. This is a WebGIS tool that makes available, among other things, the information about the potential of the different renewable energy sources for the whole national territory.

In this context, the Italian wind potential has been further analyzed to quantify the best zones for wind exploitation, which were identified as areas free from spatial constraints (e.g. protected or fragile areas) with a capacity factor greater than 25%. On the basis of this evaluation, the 2030 objective

for wind energy share in the National Energy and Climate Plan has been validated and allocated to Italian regions by taking into account the resource, technical issues, and regulations and constraints (Figure 5).

### Collaborative Research

Italy is coordinating 3D physical model tests on a floating wind turbine model in regular and irregular waves and under different wind conditions as part of the European Union-Hydrolab+ Initiative. The University of Salento is coordinating this research, with participants from the University of Campania, CNR-INM, and PoliMi. The tests will involve several EU countries (Belgium, Denmark, Ireland, the Netherlands, Spain, and the United Kingdom) and will be performed at DHI in April 2019.

ENEA, the National Agency for New Technologies, Energy and Sustainable Economic Development, together with EcoAzioni, are the Italian partners in the WinWind project and coordinators of the National Desk. This project is aimed at increasing social acceptance and enhancing the development of land-based wind energy in "wind energy scarce regions" (WESR). For Italy, Lazio and Abruzzo are target regions taking advantage of the experience gained in the regions with the greatest diffusion of wind energy: Sardinia and Puglia.

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. The Department of Mechanical Engineering of Politecnico di Milano has a partnership in another Horizon 2020 project, LIFES50+, which studies floating substructures for 10-MW wind turbines.

CNR is a full participant in EERA's joint program on wind energy, while Polytechnic of Milan and RSE are associated participants.



Figure 5. Visualization of the information about constraints related to renewable deployment in Italy. This information can be overlapped and crossed with the wind resource.

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 Energy Systems with Large Amounts of Variable Generation. Polytechnic of Milan participates in Task 30 Offshore Code

Comparison Collaboration, Continued, with Correlation (OC5). At the end of 2018, Polytechnic of Milan, CNR-INSEAN, and the University of Padua also joined Task 29 Analysis of Aerodynamic Measurements.

## 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<sub>2</sub> emissions [7]. In 2018, Italy's wind-generated electricity avoided around 9.3 million tons of CO<sub>2</sub> emissions.

### Economic Benefits & Industry Development

In 2018, the economic impact of wind energy in Italy was an estimated 3.3 billion EUR (3.78 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 547 million EUR (627 million USD). O&M of the online plants contributed approximately 346 million EUR (396 million USD). Finally, wind energy production and commercialization

contributed approximately 2.7 billion EUR (3.1 billion USD). The number of jobs in the wind energy sector was estimated to be stable at 26,000 units, including direct and indirect involvement [8].

There are three big players in the Italian wind energy market, whose shares exceed 3%: Erg Renew (11%), Enel Green Power (8%), and E2i Energie Speciali (7%). Approximately 25 players have 70% shares of the total installed capacity and the rest of the market is shared by another 100 operators.

Foreign manufacturers strongly prevail in the Italian large-sized wind turbine market. Vestas strongly emerged in the 2018 capacity market with 63% of the share, followed by Siemens with 21%. Vestas also leads the cumulated capacity market with 42% of the share, followed by Siemens (22%) and Enercon (11%). Leitwind, the only Italian manufacturer of large-sized wind turbines, accounted for around 1% 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

The decree defining the new support schemes and incentives for the renewables is expected to be published shortly. According to Gestore dei Servizi Energetici (GSE), 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 (263 million USD) [7]. ANEV confirmed its estimation of 67,200 total jobs in the wind energy sector by 2030 [7].

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. 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.

The first offshore wind farm in Italy, a 30-MW Beleolico park in Taranto harbour, has obtained a loan of 82 million EUR (93.9 million USD) from the French business bank Natixis. This will allow the wind farm to be realized in the next term.

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**Table 1. Key Statistics 2018, Japan**

Total (net) installed wind power capacity	3,653 MW
Total offshore capacity	64.6 MW
New wind power capacity installed	261 MW
Decommissioned capacity (in 2017)	0 MW
Total electrical energy output from wind	6.48 TWh
Wind-generated electricity as percent of national electricity demand	0.71%
Average national capacity factor	20.2%
National wind energy R&D budget	6.9 bil JPY; 55 mil EUR; 61 mil USD
Target	10 GW wind power capacity by 2030

## OVERVIEW

In 2018, Japan's total installed wind power capacity reached 3,653 MW—including 64.6 MW of offshore capacity. The annual net capacity increase was 261 MW. Wind energy accounted for about 6.45 TWh of electricity during 2018, which corresponded to 0.71% of the national electricity demand (908.3 TWh).

In Japan, there were formerly no unified legal rules for utilizing general common sea areas; as a result, it was difficult to construct offshore power generation systems in areas other than ports and harbors.

The national Diet passed a new law in December 2018, which will allow for the installation of power generation facilities in general common sea areas. According to environmental impact assessment data—which aggregated the capacities in port and harbor areas (546 MW) as well as general common sea areas (4,817 MW)—offshore wind power generation from installations being planned in 2018 totaled an estimated 5 GW. Additionally, research and development on offshore wind farm technology also increased during the year.

## MARKET DEVELOPMENT

### National Targets & Policies Supporting Development

According to the Fifth Strategic Energy Plan published by the Ministry of Economy, Trade and Industry (METI) in July 2018, renewable energy is expected to become a key component of Japan's electrical power supply by 2030. To achieve this, it will be necessary to reduce the cost of wind power generation and alleviate location restrictions for offshore wind farms, thereby ensuring sustainable long-term power generation.

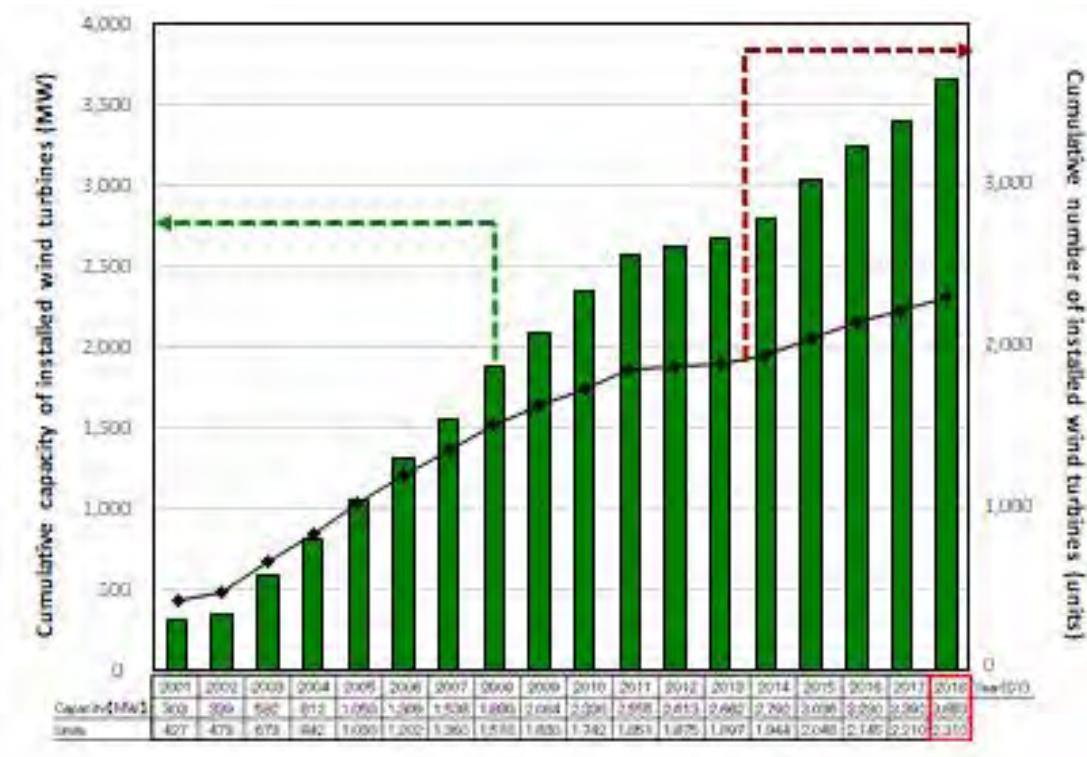
The Diet's law to promote using general common sea areas for renewable energy generation facilities will be implemented in April 2019. Previously, only port and harbor areas were approved for offshore wind use, and there was no clear provision for general common sea areas. This made it difficult for offshore wind generation to utilize general common sea areas. Without a clear provision around these regions, offshore developers were not able to determine who had possessory rights to the area, so the government established a rule to decide the possessory rights of a sea area under the new law.

Now, a legal background has been established for ports and harbors and general common sea areas. Offshore wind developers will be selected through a cost-competitive mechanism and an open call for participating companies, which will help reduce the cost of offshore wind power generation in general common sea areas.

### Progress & Operational Details

Japan installed 261 MW of new wind power capacity in 2018 [1]. The net increase was approximately 55% greater than 2017, which saw a 169-MW increase. Cumulative wind power capacity reached 3,653 MW over 2,310 turbines by the end of the year (Figure 1). The electrical energy output from wind-based sources during 2018 totaled approximately 6.48 TWh—0.71% of national electricity demand.

Figure 1. Deployment and installed capacity of wind power in Japan (Source: Japan Wind Power Association)



Japan's operational offshore wind power capacity remained the same (64.6 MW) between 2017 in 2018. The New Energy and Industrial Technology Development Organization's (NEDO's) *Hibiki* project installed a barge type floating form wind turbine 15 kilometers offshore of Kitakyushu City, in an area about 50 meters deep. The demonstration and operation stage of the project will start in spring 2019.

### Matters Affecting Growth & Work to Remove Barriers

If renewable energy is to continue developing and eventually become a key energy source of the electric power supply, Japan must overcome grid constraints. METI commented on this issue in the Fifth Strategic Energy Plan. Wind power generation is also likely to fluctuate due to on natural weather conditions.

In 2018, Hokkaido Electric Power Co., Inc. and TEPCO Power Grid, Inc. started a demonstration project on electric power grid system control in 2018 for expanding wind-generated electricity to a larger audience. The demonstration project uses an inter-regional interconnection line and flexibility sources in the Tokyo area to expand the reach of wind power generation in Hokkaido.

The wind power generation facilities currently being used in the demonstration project have a capacity of 6.6 MW, and it will gradually increase to 200 MW by the end of March 2021. Hokkaido has considerable wind power generation potential, but limited electricity demand could lead to an electricity surplus. Power grid operations could become unstable if supply and demand is not well-balanced.



Figure 2. Offshore floater under construction at Hitachi Zosen (barge type)

## R,D&D ACTIVITIES

### National R,D&D Priorities & Budget

METI and NEDO administer the national wind power R&D programs in Japan. Many of these programs focus on lowering the leveled cost of electricity (LCOE) for wind power generation, especially offshore wind. The Research and Development of Offshore Wind Power Generation Technologies (FY2018-2022) program achieved the following results in 2018:

- **Low cost construction:** NEDO developed a low-cost construction technology for a fixed-bottom offshore wind power turbine and conducted a feasibility study on cost reduction technology development for foundation construction under a joint industry program. The organization also constructed a foundation that utilizes a jack-up work platform.
- **Barge type floater:** NEDO developed and demonstrated a floating form wind turbine, which can be installed in sea waters of 50 meters or more in depth. The Sakai factory of Hitachi Zosen completed Construction of a barge type floater in June, and it was subsequently assembled at the Port of Kitakyushu and installed 15 kilometers offshore of Kitakyushu City in waters 50 meters deep (Figures 2, 3). The floating form wind turbine is named *Hibiki* and it will start operation in 2019.
- **Novel design floater:** NEDO has been working to develop new element technologies for a floating offshore wind turbine system. In 2018, the organization carried out a study in a potential sea area, prepared various basic designs using advanced elemental technology, and conducted a feasibility study to determine the details for a demonstration experiment, which will take place in 2019. The demonstration project is aiming for a generation cost of 20 JPY/kWh (0.16 EUR/kWh; 0.18 USD/kWh) after 2030.

METI and NEDO also administered another national research and development program, which focuses on further reducing the cost of wind energy. The Research and Development of Advanced Application Technologies for Wind Power Generation (2013- 2020) program involves the following:

#### • **Research and development on advanced wind turbine operation:**

NEDO started a three-year program on advanced wind turbine operation. The purpose of this program is to raise the availability of domestic wind turbines rate to more than 97%, thereby reducing downtime. Researchers will do this by constructing a wind turbine that is equipped with software that detects and wind turbine trouble with artificial intelligence. Domestic wind power developers can use this new software (which is currently in development) to detect and evaluate problems after a wind turbine lightning strike.

NEDO is also promoting fixed-bottom offshore wind farm development. The organization started providing support for development in port and harbor sea areas in 2013. By 2017, they had supported offshore wind development projects at Kashima Port, Mutsu-Ogawara Port, Akita and Noshiro Port, and Ishikari Bay New Port, respectively. In FY2018, NEDO started a feasibility study project in general common sea areas, entrusting project activities to two groups of participating companies. The project is collecting data necessary for the basic design of offshore wind facilities, including information on the sea bottom as well as weather and marine conditions. The researchers will publish their research results to help expand offshore wind power.

METI is sponsoring the Fukushima Floating Offshore Wind Farm Demonstration Project. This project carries out full-scale experimental research with an offshore floating wind power generation system that uses the world's first plural wind turbines (2 MW, 5 MW, and 7 MW), as well as a floater type and floating offshore electrical substations, a measurement platform, and other facilities. The project evaluates safety, reliability, and economic efficiency. An independent committee was established to evaluate the results obtained during the project, and a report providing an evaluation and future issues was published in August 2018.



Figure 3. Offshore floater and turbine system being towed by tugboats

## **Collaborative Research**

Japan participated in the following nine tasks in 2018. Task 40 was started in 2018, and Japan is serving as Operating Agent (OA) and Co-OA.

- Task 11 Base Technology Information Exchange
- Task 25 Design and Operation of Energy Systems with Large Amounts of Variable Generation
- 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 International Wind Farm Flow Modeling
- 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 2018, wind-generated electricity helped reduce about 3.4 million tons of CO<sub>2</sub> equivalent, amounting to 0.26% of Japan's total CO<sub>2</sub> emissions. Japan aims to reduce energy-related CO<sub>2</sub> emissions by 25% from their FY2013 levels by FY 2030. Wind energy will contribute to reaching this target to some extent, but its impact will be limited.

### **Economic Benefits & Industry Development**

Japan's wind energy industry has developed steadily and significantly for the past two decades, mainly due to facility makers and power generation companies. However, it has not contributed much to the domestic economy compared to the energy industries in Europe and the United States.

The impact of the wind energy industry is very limited in Japan. Japanese facility makers have recently begun to cooperate with foreign companies to increase their global competitiveness. Mergers of wind turbine manufacturers are increasing worldwide. Such companies are working on increasing the size of wind turbines, and it is expected that large-scale wind turbine technology will be applied to offshore wind farms.

The value chain of the wind power generation industry includes production of parts, materials, and the main body of wind turbines, assembly, power station construction, operation and maintenance (O&M) after startup, and others. Of the companies involved in the value chain, there are promising Japanese companies with strengths in advanced technologies that manufacture parts and materials for wind power systems. Some companies have a 10% to 20% share of the parts and materials produced worldwide. In contrast, there is only one domestic manufacturer that produces wind turbines, and its market share is less than 1%.

Hitachi, Ltd., Japan's only wind turbine manufacturer, received an order for 21 5.2-MW wind power generation systems for an offshore wind farm project in Taiwan in April 2018. Under the contract with Taiwan Electric Corporation, Hitachi and Jan De Null Group will supply and install the wind turbines and provide five years of O&M.

Japan must reinforce the domestic wind power industry's strength in the value chain if the industry is to progress in the coming years. NEDO will initiate research and development related to O&M from this viewpoint.

## **NEXT TERM**

Several new land-based wind farm projects are in the environmental impact assessment process. These projects are expected to begin operation in a few years, which will significantly increase Japan's total capacity. Additionally, more than 9 GW of offshore wind projects are currently planned. New rules covering general common sea areas will go into effect in April 2019, and they will contribute to the deployment of offshore wind farms in Japan.

### **References**

Opening photo: Floating form wind turbine named *Hibiki* manufactured by Hitachi Zosen Co., Ltd. installed 15 kilometers offshore of Kitakyushu City.  
[1] Japan Wind Power Association (JWPA) annual statistics  
Authors: Yuko Takubo and Yoshitomo Watanabe, New Energy and Industrial Technology Development Organization (NEDO), Japan.



**Table 1. Key Statistics 2018, México**

Total (net) installed wind power capacity	4,908 MW
Total offshore capacity	0 MW
New wind power capacity installed	927 MW
Decommissioned capacity (in 2017)	0 MW
Total electrical energy output from wind	12.44 TWh
Wind-generated electricity as percent of national electricity demand	4.02%
Average national capacity factor	32%
National wind energy R&D budget	1.63 mil USD; 1.42 mil EUR
Target	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 2018 the country had added 927 MW of new installed wind power capacity to the national electricity grid. This brought the total capacity to 4,907.5 MW, which represents about 6.4% of total installed energy capacity [1].

In the next six years, new policies will support an accelerated transition toward the generation, transmission, and use of renewable and clean energy—provided that social inclusion is addressed [2].

México's R&D focus is on medium and small-sized turbines. These efforts include: development of a 1.2-MW scale wind turbine; installation and testing of a 2-MW horizontal wind

turbine with a 100-m concrete tower; development of two prototypes of 30 kW HWT; and innovations in automated blade manufacturing, virtual reality for operations and maintenance 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 2018, CEMIE Eólico continued representing Mexican R & D efforts on the IEA Wind Technology Collaboration Programme (TCP) Executive Committee, and participated actively in Task 11 Base Technology Information Exchange and Task 25 Energy Systems with Large Amounts of Variable Generation.

## MARKET DEVELOPMENT

### National Targets & Policies Supporting Development

México's wind power industry aims to install 8 GW of wind power capacity by the end of 2020, and 11 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.

Targets for percent of electricity generation met by renewable energy sources in México are: 25% by 2018, 30% by 2021, and 35% by 2024 [3]. 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 GW, but only 17 GW of additional installed capacity is required to reach the goal of generating 35% of electricity with clean

technologies by 2024 [3]. México added 927 MW of new wind power capacity to the national electricity grid by the end of 2018, bringing the total capacity to 4,907.5 MW in 52 wind farms [1]. This represents an increase of 18.9% from 2017.

The constitutional framework and public policies for the wind power industry have not experienced any changes with respect to the electricity market and promotions for generating energy through renewable resources.

## **Progress & Operational Details**

Three long-term energy auctions have been called and have proved to be an effective instrument to increase development of wind energy. Wind power accounted for 3,407 MW contracted via the auctions; these projects should be installed before 2021. Investments for new wind energy projects totalled 8.97 billion USD (7.8 billion EUR) [4]. A total of 2,439 land-based turbines have installed as of the end of 2018 [5].

## **Matters Affecting Growth & Work to Remove Barriers**

The following barriers still affect the growth of the wind power industry and need to be addressed for its full deployment:

- Lack of social acceptance in relation to leasing the land and signing contracts;
- Bureaucratic processes for obtaining permits, authorizations, and licenses at the federal, state and municipal levels;

- Low integration of national components in the manufacturing chain value of wind power industry;
- Lack of specialized personnel to participate in designing and installing wind power plants.

The CEMIE Eólico's work includes development of strategic projects to increase the number of specialized personnel able to participate in designing and installing wind power plants, as well as to encourage the fabrication of some principal wind turbine components by Mexican companies. In order to improve social acceptance, the SENER-Conacyt Energy Sustainability Fund is evaluating a new CEMIE Eólico proposal on design, development, implementation, and validation of an innovative methodology of increasing social impact under national and international standards.

## **R,D&D ACTIVITIES**

### **National R,D&D Priorities & Budget**

By the end of 2018, the Energy Sustainability Fund (FSE) had supported the wind energy CEMIE with 1.63 million USD (1.42 million EUR). These funds supported the implementation of technological solutions for the operation and maintenance of wind turbines via strategic projects developed by national experts at research institutes and universities.

### **National Research Initiatives & Results**

The CEMIE-Eólico is a national effort by the Mexican government to encourage collaborative research and technological developments related to the wind power industry. Research topics for members of the CEMIE-Eólico are: aerodynamics and aeroelasticity; medium-capacity wind turbines; small-sized wind turbines; control systems; applications of artificial intelligence and mechatronics; and training of specialized human resources.

Members receive financial support from the Energy Sustainability Fund to build capacity in infrastructure, human resources, instrumentation and equipment, and specialized software. The results of this research and the technological projects of the CEMIE-Eólico initiative have led to the extension of funding for one additional year.

### **Test Facilities & Demonstration Projects**

Demonstration projects and test facilities in operation during 2018 included:

- Laboratory for blade manufacturing up to 12 m long;
- Laboratory for testing small wind turbine blades up to 12 m long (opening photo)
- The installation and testing of a 2-MW horizontal wind turbine with a 100-m concrete tower
- Design, manufacturing, and installation of two 30-kW wind turbine prototypes
- Design, manufacturing, and testing of two AC-DC electrical converters
- Design, manufacturing, and testing of two electrical generators (permanent magnets and double feed)
- Artificial Intelligence systems for diagnostics of wind turbines

- Design, manufacturing, and testing of a control system to reduce loads on blades for small wind turbines
- Design, manufacturing, and testing of vibration
- Design, manufacturing, and testing of a manufacturing cell for automatic laying of small wind turbine blade sections monitoring system for small wind turbine gearboxes

### **Collaborative Research**

In 2018, CEMIE Eólico, led by the Instituto Nacional de Electricidad y Energías Limpias (INEEL), continued representing Mexican R & D efforts as a member of the IEA Wind Technology Collaboration Programme (TCP) Executive Committee, and participated actively in Task 11 Base Technology Information Exchange and Task 25 Energy Systems with Large Amounts of Variable Power. Experts also participated in Topical Expert Meetings (TEM) 91 on blade durability and TEM 93 on wind turbine lifetime extension.

International collaborative research between CEMIE-Eólico members and international institutions continued in 2018. Activities for testing and validation of design and manufacture of blades of 10 kw and 30 kW were carried out by the Centro de Tecnología Avanzada (CIATEQ A.C.) in México and the Centro de Investigaciones Energéticas, Medioambientales y Tecnológicas (CIEMAT) in Spain.

DTU Denmark, INEEL, and UNAM worked together on site characterization through the development of the Global Wind Atlas. Lastly, INAOE collaborated with the National Wind Institute at the University of Arizona (USA), on the design and implementation of artificial intelligence technology to integrate a wind test facility with a smart grid.

# IMPACT OF WIND ENERGY

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## Environmental Impact

The development of 8,000 MW of wind power by 2020 would reduce emissions by more than 13 million tons of CO<sub>2</sub>, equivalent to approximately 10% of the national mitigation target. In addition to the environmental benefits of reducing CO<sub>2</sub> emissions, wind power 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 [6].

## NEXT TERM

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The Mexican wind industry expects to install about 1,176 MW of wind power capacity in 2019 [7]. By 2020, the industry expects to see more than 8,000 MW installed, and up to 11 GW are expected to be installed by the end of 2022 [7].

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Opening photo: Test facility for small turbine blades (Photo credit: INEEL)

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# The Netherlands



**Table 1. Key Statistics 2018, Netherlands**

Total (net) installed wind power capacity	4.3 GW
Total offshore capacity	1 GW
New wind power capacity installed	0.13 GW
Decommissioned capacity (in 2017)	0 GW
Total electrical energy output from wind	9.9 TWh
Wind-generated electricity as percent of national electricity demand	8.3%
Average national capacity factor	26%
National wind energy R&D budget	30 mil EUR; 34 mil USD
Target	14% RES by 2020

## OVERVIEW

The Dutch climate agreement set a 2030 deadline to reduce CO<sub>2</sub> production by 49%, as compared to the 1990 level. All sectors, including power generation, industry, transportation, the built environment, and agriculture must contribute to achieve this goal. Electricity production, in particular, must increase from 17 TWh in 2017 to 84 TWh in 2030. Of this total, 49 TWh will be produced by offshore wind power and 35 TWh by land-based renewable energy sources.

In 2018, total installed wind energy capacity was 4.3 GW. Of this, 1 GW was offshore-based capacity, which is a small increase over the previous year. However, 3.5 GW of offshore capacity and 2.6 GW of land-based capacity is under construction or development. The Ministry of Economic Affairs and Climate is currently developing the second offshore

wind energy roadmap for the North Sea, which will add an additional 6.1 GW by 2030.

In the Netherlands, R&D activities are supported in order to make wind energy cheaper and, ultimately, to realize the 2030 goals. Most of the research subsidy budget (about 30 million EUR; 34.4 million USD) was granted to offshore wind energy developments. The final users of these projects are closely committed to the results, thus guaranteeing practical implementation. Research topics included: new installation methods for monopiles; atmosphere and sea modelling; new wind turbines; new test facilities for wind turbine components; more durable blades; decommissioning of monopiles; flow modelling in wind farms; and more accurate flow measurements in windfarms.

## MARKET DEVELOPMENT

### National Targets & Policies Supporting Development

The 2020 target for land-based installed wind power capacity is 6GW, of which each of the provinces has its own sub-target to meet. This means that each province has to develop its own site planning, environmental impact reports, and permit procedures.

It is an especially complex process to achieve the land-based 2020 wind power targets because so many stakeholders are involved, including provinces, municipalities, residents, wind farm developers, and land owners, each with their own, sometimes conflicting interests. In the north there is heavy protest against some large windfarms, mainly due to lack of involvement of the local residents.

Other issues are industry and housing, military radar, height limits near airports, and turbine lightning. A core team,

consisting of the central government, province governments, and sector organizations, monitors the progress of performance agreements and the solution of bottlenecks.

The development of offshore wind energy is entirely under the direction of the central government in the Netherlands, which makes the process run more smoothly. Two roadmaps for offshore wind power are currently under development.

The first roadmap covers the development of five, 700-MW windfarms (3.5 GW) placed relatively close to the shore by 2023. The second roadmap deals with the development of 6 GW of new installed capacity further offshore by 2030. The central government designates locations and makes data on weather, waves, soil conditions, archeology, and unexploded ordnance (UXO) available for the development of the wind farms.

Additionally, offshore substations and the cables to shore are provided by the central government through the TSO TenneT. This approach has reduced much of the risk and uncertainty of offshore wind energy development and therefore reduced the cost to a level where permits can be granted without subsidy.

### Progress & Operational Details

Due to spatial and social considerations, total land-based wind power is limited to the 2020 target of 6 GW of installed capacity. In 2018, about 3.3 GW of land-based wind power capacity was installed and an additional 2.6 GW was either under construction or the construction was being prepared; this is 0.1 GW and 0.6 GW greater, respectively, than in the previous year, indicating that land-based deployment is picking up speed.

Unfortunately, the real speed of implementation is, in some cases, obstructed by objections and appeals, practical issues, or even by threats against developers, contractors, and land owners.

Currently, approximately 1 GW of wind power capacity is installed in the Dutch part of the North Sea, with an additional 3.5 GW planned prior to 2023 as part of the first roadmap. Three developers already have a permit to build and operate a wind farm. It's likely that in May 2019 the fourth permit will be issued to the winner of the tender for the sites Hollandse Kust Zuid 3 and 4. The tender for the last site of the first roadmap, Hollandse Kust Noord, will be open for application in the first quarter of 2020.

Wind-generated electricity production has gradually increased over the last five years, as can be seen in Figure 2. However, in the last two years the rate of increase has contracted due to a temporary slowdown in the number of installations and installed capacity.

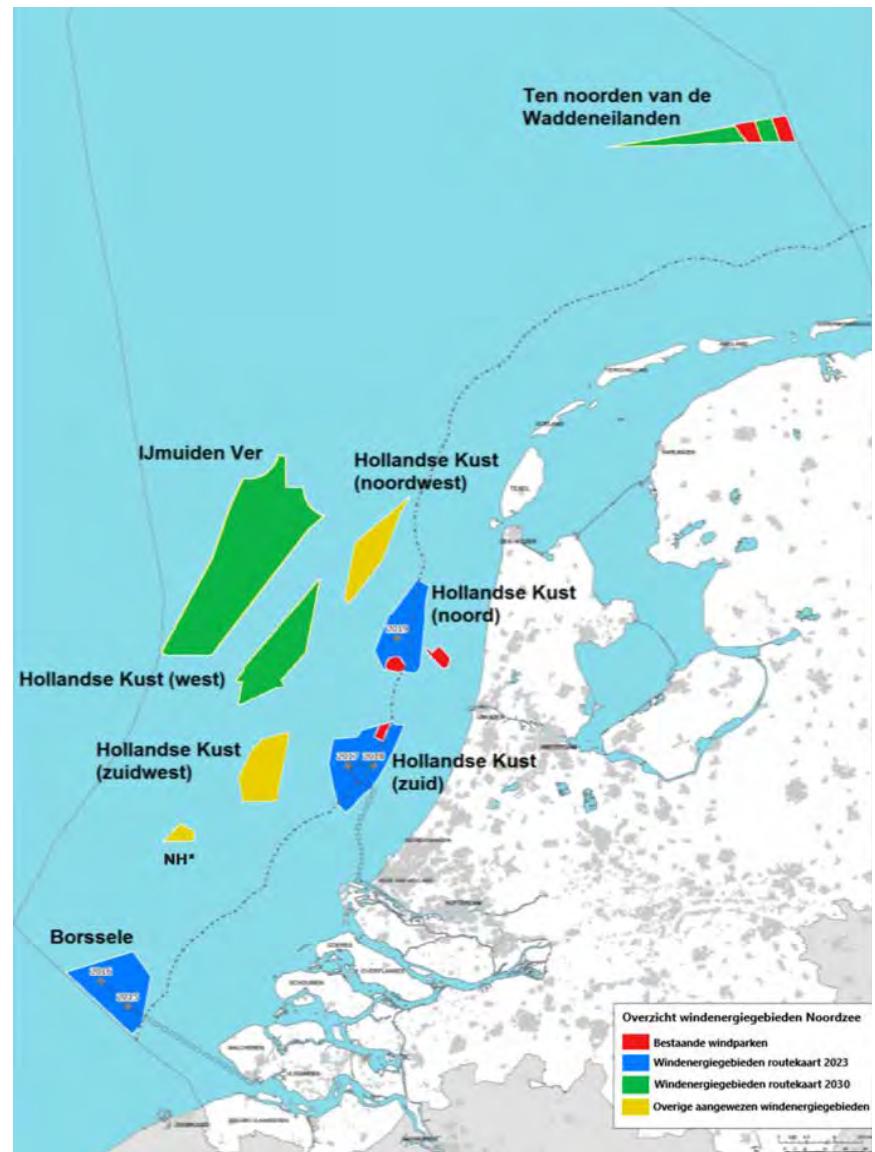


Figure 1. Dutch offshore wind areas. Red denotes existing wind farms (1 GW), blue shows roadmap 2023 (3.5 GW) planned installations, green shows roadmap 2030 (6 GW) planned installations, and yellow covers other assigned areas (Source: RVO)

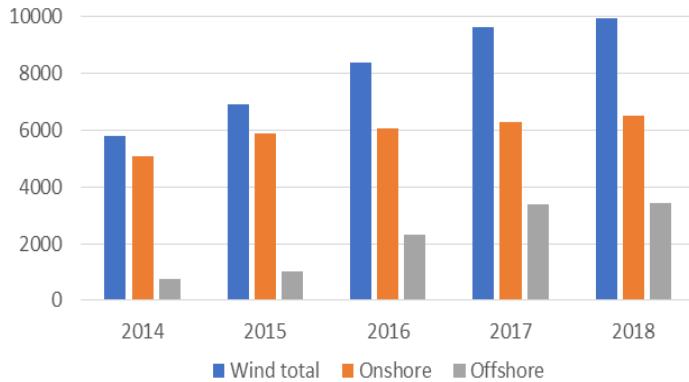


Figure 2. Wind-generated electricity production in the Netherlands (millions kWh)

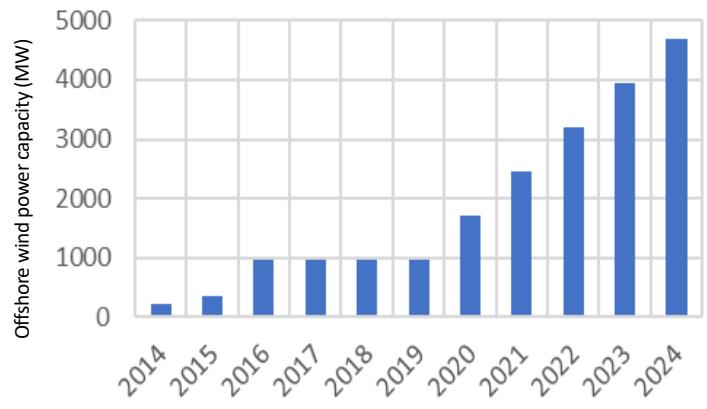


Figure 3. Offshore wind power development (MW). These numbers are expected to grow rapidly through 2023, as the first roadmap's goals are achieved.



Figure . Artist impression 2B1X (PSource: 2B-Energy)

## R,D&D ACTIVITIES

### National R,D&D Priorities & Budget

Dutch R,D&D continues to focus on reducing the costs of renewable energy. In 2018, an R&D tender was dedicated to offshore wind power with a budget of 4.8 million EUR (5.5 million USD) and in 2019 there will be a similar R&D tender of 4.5 million EUR (5.2 million USD).

In these tenders, the projects must fit into one of the following program lines: cost reduction and optimization; integration into the energy system; and offshore wind and the environment. There is also a broader subsidy scheme for which all types of renewable energy R&D projects can apply. In those cases, cost reduction and rate of success in Dutch society are important criteria.

### National Research Initiatives & Results

In 2018, nine renewable energy projects were granted a total of 25 million EUR (29 million USD), and another eight projects were granted 5 million EUR (5.7 million USD) in the offshore wind power R&D tender. Compared to 2018, total granted subsidies increased from 13.4-30 million EUR (15-34 million USD). Projects and achievements in 2018 included:

- **Demonstrator GE Haliade X – 12-MW offshore wind turbine, 220-m rotor** (GE Renewable Holding B.V.). The first prototype of the largest offshore turbine was built in Port of Rotterdam. Testing was completed to: validate aerodynamical models; enable a stable and verified power curve; and to validate design and load models, components functionality, operations and maintenance, and installation procedures.
- **Test of cups and pistons for the Hydraultrans Drive Train** (Hydraultrans B.V.). Geared drive trains are heavy and have high maintenance requirements; direct drive generators are also heavy. Hydraulic drive trains are potentially lighter and more reliable, although not as efficient. Hydraultrans has developed a hydraulic pump and motor based on floating cup technology showing very low friction and absence of wear and tear. The goal is a mechanical-hydraulic drive train for a 12-MW turbine.
- **Step change in turbine capacity to meet 2030 cost reduction** (2-B Energy Holding). The development and demonstration of a 14-MW wind turbine, based on a two-bladed downwind turbine design, on a full jacket support structure and with an integrated helicopter landing platform, will increase the performance of wind turbines and significantly lower the Levelized Cost of Energy (LCOE).
- **Motion Compensated Pile Gripper (MCPG)** (Temporary Works Design B.V.). Installation of monopiles by jack-up barges has several drawbacks, including limited deck space, limited monopile size, time consuming operation, and expense. Although floating ships don't face these challenges, the motion of the ship has to be compensated for during pile upending, lowering, and driving. TWD has now developed and built a full-size prototype of the MCPG.
- **WINDCORE: WIND turbine COntrol strategies to reduce wind turbine blade Rain droplet Erosion** (TNO). This project will develop wind turbine control strategies, based on optimizing rotor speed, to alleviate blade leading-edge rain erosion. The project will investigate correlations between environmental and operational conditions in relation to leading-edge blade erosion.
- **Prefab Modular Rotor Blade Root Bushing** (Tres4 B.V.). Traditional T-bolts for connecting blades to the hub require a lot of space. The main objective of this project is to develop a Prefab Modular Root Bushing which combines several root bushings to make the production of rotor blades with infused bushings easier and the resulting connection cheaper, smaller, more reliable and durable.
- **JIP Cable Lifetime Monitoring** (Deltares). Submarine power cables are less reliable than required. Cable failures will be collected and analyzed, providing the basis for recommendations for better design, manufacturing, installation, testing, and operation of offshore wind farm cables. Measurement techniques for monitoring cable position and health will also be developed.
- **STRETCH: State of art Rotor Extended To Create Higher performance** (LM Wind Power R & D [Holland] B.V.). The goal of STRETCH is to define an innovative design trajectory for ultra-large rotors (220-m and larger) by stretching and improving an existing rotor design (AVATAR). This requires improved modelling and testing of the hub, pitch bearings, blade-hub interface, and blade design. A large hub test facility, including digital twins, will also be developed to reduce testing time.

- **SAWOP: Sensor Assisted Wind farm Optimization** (LM Wind Power R&D (Holland) B.V.). Optimization of offshore wind farm performance relies on monitoring of the wind farm. Therefore, new spinner sensor and nacelle lidar technology for individual wind turbine power performance assessment, as well as for waked turbines, must be developed and implemented to industry standards. The final objective is to develop and further refine optimization strategies, capitalizing particularly on the unique and extensive sensor layout inputs derived from this project.
- **Win-Wind** (Stichting Wageningen Research). This project encourages the multiple uses of offshore wind farms by studying lobster and brown crab fisheries in offshore wind farms. It gives insight into the ecology, economy, and technical risks of combining such activities.
- **JIP ECO-FRIEND** (Stichting Wageningen Research). This project investigates how to restore the almost extinct flat oysters in the North Sea. This research takes place in the Gemini Wind Farm.
- **InLEP** (Universiteit Twente). An integrated leading-edge protection (LEP) is being developed with high durability against rain erosion, using a co-molding technique that enhances the process's reliability and predictability. Integrated LEP will increase asset earning power (AEP) and reduce operating and capital expenses, leading to a 6% LCOE reduction.
- **DCPM:Dynamic Cone Pressure Measurement** (Technische Universiteit Delft). This project aims to develop a new cone penetration measurement technique to acquire better knowledge of monopile soil interaction.
- **HyPE-ST: Hydraulic Pile extraction Scale Tests** (Innogy Renewables Benelux B.V.). This project investigates the complete removal of monopiles by sealing and pressurizing the inside of the monopile to drive it out of the soil.
- **AKKA** (Ampyx Power B.V.). This project consists of research into the dynamic and aerodynamic scaling effects that influence the design of a multi-MW-scale airborne wind energy system's remotely-piloted aircraft. The challenge is to fly tethered aircraft the size of a small commercial airliner as nimbly as a fighter jet.
- **DAEDALUS** (Ampyx Power B.V.). This project explores the design and testing of a tether system for a megawatt-scale airborne wind energy system. The challenge is to reduce wear and tear by acquiring reliable knowledge of lifetime and design parameters of tether.
- **WindTrue** (TNO). This project aims to quantify the uncertainties in the wind turbine rotor aeroelasticity to better predict turbine response and energy production.

### Collaborative Research

In 2018, the Netherlands participated in 10 of the 16 ongoing IEA Wind TCP Tasks, which is one less than in 2017. The Netherlands is also involved in DemoWind, a European Horizon 2020 collaborative research initiative.

## NEXT TERM

The Stimulation of Sustainable Energy Production (SDE+) feed-in support for renewable energy production will probably total 10 billion EUR (11.5 billion USD) in 2019, which is a 2 billion EUR (2.3 billion USD) reduction from the 2018 budget. In the coming years, the scope of the new SDE++ will widen to include new CO<sub>2</sub> reduction techniques.

From 2020 on, subsidized R,D&D projects should also meet a more general mission goal: completely CO<sub>2</sub>-free electricity production by 2050. The intermediate goals for 2030 are 35 TWh of land-based renewable electricity and 50-80 TWh of offshore electricity generation. More specifically, the mission should allow a scale jump from 11.5 GW to 18.6 GW in 2030 and up to 60 GW in 2050.

To meet these targets, cost reductions to 30-40 EUR/MWh (3.34-45.8 USD/MWh), an installation pace of 2-3 GW/year, and the integration of large amounts of electricity into the grid will be required.

The results from the projects Haliade X, MCPG, Windcore, SAWOP and JIP Cable Lifetime as discussed in chapter National Research Initiatives and Results are expected to be implemented within a few years.



### References

Opening photo: Artist impression of the Motion Compensated Pile Gripper (Photo credit: TWD BV)  
Authors: Ruud Oerlemans, Rijksdienst Voor Ondernemend Nederland ([www.RVO.nl](http://www.RVO.nl)), the Netherlands.

Figure 4. Artist impression Haliade X (Source: GE)



**Table 1. Key Statistics 2018, Norway**

Total (net) installed wind power capacity	1,695 MW
Total offshore capacity	2.3 MW
New wind power capacity installed	506 MW
Decommissioned capacity (in 2017)	0 MW
Total electrical energy output from wind	3.87 TWh
Wind-generated electricity as percent of national electricity demand	2.9%
Average national capacity factor	32.8%
National wind energy R&D budget	6.1 mil EUR; 6.9 mil USD

## OVERVIEW

Norway broke all national records for wind power deployment in 2018, installing 506 MW of new wind power. This resulted in a total installed wind power capacity of 1,695 MW by the end of the year. More wind power is under construction, and we expect installed wind power capacity to increase by 1,515 MW during 2019.

In 2018, the wind-based electrical energy increased 36% from the previous year, which resulted in 3,870 GWh of wind-generated electricity. This amounts to 2.6% of the Norwegian electricity production. The decrease in LCOE for wind power projects and the end of the electricity certificate scheme has driven this increase in Norway's wind power deployment.

Researchers at Sintef Ocean have developed coupled models for wave loads and soil response of large monopile wind turbines, which enabled the use of larger diameter monopiles.

The Norwegian Geotechnical Institute (NGI) has developed reliable foundation models for design analyses. The improved reliability in analysis and design make it possible to optimize the structures, leading to more cost-effective designs that then reduce the cost of energy.

Institute for Energy Technology (IFE) has performed research leading to more realistic engineering speed models for waves and wave loads. Increased knowledge about calculated fatigue and extreme loads will lead to lower LCOE for offshore wind.

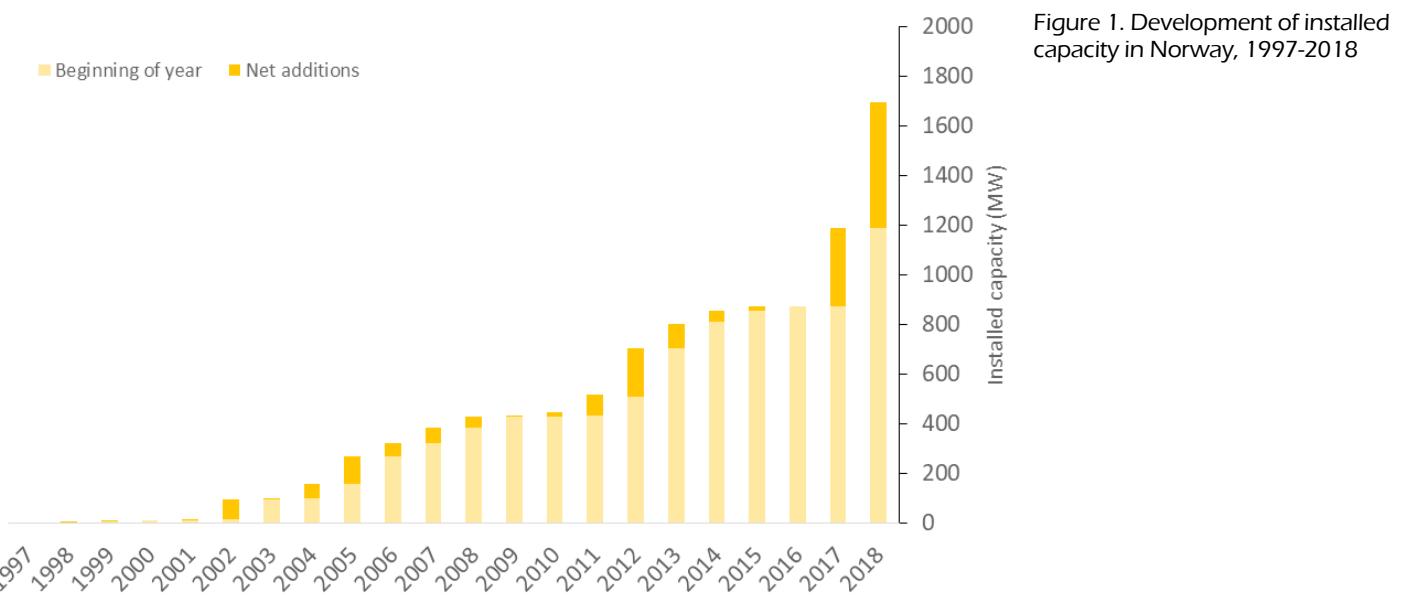
## MARKET DEVELOPMENT

**National Targets & Policies Supporting Development**  
Norway's total electricity production in 2018 was 146.4 TWh. Renewable sources amounted to 97.7% of the national electricity production, and 2.6% of the electricity production was wind-based. With electricity demand in the country totaling 135.4 TWh for the year, there was a net electricity export of 11 TWh.

As a member of the European Economic Area (EEA), Norway was obliged to accept the EU's renewable energy directive in 2011. The target for renewable energy was set to 67.5% of total energy consumption by 2020. Norway plans to meet this target through a combination of energy-efficient measures and increased renewable energy production. The incentive mechanism for increasing renewable energy production in Norway is a joint support scheme with Sweden to finance 28.4 TWh/yr of new renewable energy production by 2020, of which 13.2 TWh is to be financed by Norwegian power

consumers. This market-based electricity certificate scheme is both country- and technology-neutral. The objective is to allow the market to dictate which type of renewable energy production is utilized and where it comes from. In practice, this means that Norway has no explicit wind energy target. However, the electricity certificate scheme has resulted in investment decisions that will lead to considerable new wind energy deployment in Norway by 2020.

The electricity certificate scheme has been the governing supporting policy since 2012. The support lasts for 15 years from commissioning and certificates are awarded for every MWh generated. All electricity users are required to purchase certificates equivalent to a certain proportion of their electricity use, which creates a consistent 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.



Norway will not expand its targets beyond the existing scheme, but the cut-off for Norwegian projects has been extended by one year. This means that wind power in Norway must be commissioned by the end of 2021 to receive support. There is no plan to subsidize new wind power in Norway after 2021, and wind power realized in Norway after 2021 will thus have to be profitable without subsidies.

### Progress & Operational Details

Investment decisions for Norwegian wind power plants increased dramatically in 2016, and investments continue at a high level today. In addition to the record 506 MW commissioned in 2018, over 2,000 MW of wind power capacity was under construction in Norway at the end of the year—1,515 MW of which will be commissioned during 2019.

Eight projects were commissioned in 2018, all of which were land-based. The projects varied in size from two to 71 wind

turbines. Costs for the projects have decreased from previous years, and the weighted average of the LCOE for the eight projects was 31 EUR/MWh (35.5 USD/MWh). Most of the projects are located along the Norwegian coastline. The first inland project in Norway, Raskiftet, is an exception. All the projects use modern turbine technology and have generator capacities between 3.2 MW and 3.6 MW. Rotor diameters varied from 115 m to 126 m, mostly appropriate for IEA Class II wind sites. We expect that the projects built in 2019 will have even higher generator capacities and larger rotors.

Wind resources were slightly below normal in 2018, with a weighted average wind index of 98.8%. This resulted in a production index of 98.4%. The average capacity factor was 32.8%. The capacity factor of wind farms in normal operation varied between 20% and 47%. Annual energy per swept area ranged from 744–1668 kWh/m<sup>2</sup>, with a national average of 1,080 kWh/m<sup>2</sup>.

## 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.

The Norwegian energy agency, Enova, offers capital grants for full-scale demonstration projects for renewable ocean energy production, including offshore wind. While up to 50% of eligible costs can be covered, Enova's funding measured in absolute figures is limited. Innovation Norway runs a program supporting prototypes for environmentally-friendly technology, including wind energy. The program supports developers up to 45% of their eligible costs.

### 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 foundations for both seabed-based and floating turbines and different seabed conditions
- Concepts and systems for reliable electric infrastructure (offshore subsea solutions)
- Cost-effective, time-saving assembly and installation of offshore wind farms
- Efficient concepts for marine logistics (heavy maintenance) and robust solutions for access
- Concepts and systems for reducing 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 budget for the ENERGIX program (see above) in 2018 was 450 million NOK (45.3 million EUR; 52.0 million USD) and the same budget is expected in 2018. In total, the Research Council granted 55 million NOK (5.5 million EUR; 6.4 million USD) to wind energy research in 2018. In January 2019, the ENERGIX program granted funding to the following wind energy R&D projects:

- Advanced Wave and Wind Load Models for Floating Wind Turbine Mooring System Design, Sintef Ocean, (Knowledge building Project for Industry)
- Fibre rope mooring, Aibel AS (Industrial innovation project)
- RedWin 2-REDucing cost on offshore WIND by integrated structural and geotechnical design 2, Equinor ASA, (Industrial innovation project)
- Intelligent Medium Voltage Modular Multi-level Converter for Environmental Energy, THE SWITCH MARINE DRIVES NORWAY AS, (Industrial innovation project)

ENERGIX is currently funding 14 R&D projects which involve 20 industrial companies and five research institutes.

### National Research Initiatives & Results

The ENERGIX program supports several "Knowledge building Projects for Industry" at Norwegian research institutions. These are large research projects with budgets of 20-25 million NOK, which will take place over 4-5 years and include the education of PhD students. These projects are:

**Engineering speed modeling of realistic fatigue for all the individual turbines in wind parks by representative pre-calculations** (NEXTFARM, Institute for Energy Technology, IFE). The objective is to develop tools that are both accurate and fast for simulating the loads and performances of all the individual wind turbines in a farm.

Expected results and industry benefits:

- Design windfarm with lower LCOE
- Improve operation of wind farms by taking into account state, hourly wear, and production of the individual turbines vs. the electricity price at that time
- Get the most out of an existing farm by lifetime extension planning and control

**Wave loads and soil support for extra-large monopiles**" (WAS-XL, Sintef Ocean). The objective: is to produce better hydrodynamic load models improve soil response models for monopile OWTs. Expected results:

- Connect physics from wave and wave loads with structural and soil response of large monopile wind turbines
- Facilitate move towards larger diameter and heavier turbines

**Dimensioning sea loads on offshore wind turbines in shallow to intermediate waters** (DIMSELO, Institute for Energy Technology, IFE). The objective is to compare existing and project-developed wave and wave load models with respect to dimensioning loads for offshore wind turbines.

Expected results:

- Create more realistic engineering speed models for waves and wave loads
- Increase knowledge about how calculated fatigue and extreme loads vary with different allowed models

**REDWIND–Reducing costs of offshore wind by integrated structural and geotechnical design** (NGI). The objective is to develop reliable foundation models for design analyses. Expected results:

- Develop REDWIN models, which report more fundamentally correct behavior than the modeling approaches commonly used today
- Improve reliability in analyses and design, making it possible to optimize the structures and utilize less costly design, thus reducing the cost of energy

## Collaborative research

In 2018, Norway participated in the following IEA Wind Tasks:

- Task 11 Base Technology Information Exchange
- Task 19 Wind Energy in Cold Climates
- Task 25 Energy Systems with Large Amounts of Variable Generation
- Task 26 Cost of Wind Energy
- Task 29 Analysis of Aerodynamic Measurements
- Task 30 Offshore Code Comparison Collaboration Continuation with Correlation (OC5)
- Task 32 Wind Lidar Systems for Wind Energy Deployment
- Task 34 Working Together to Resolve Environmental Effects of Wind Energy (WREN)
- Task 37 Wind Energy Systems Engineering

## IMPACT OF WIND ENERGY

### Environmental Impact

Renewable energy accounts for 97.7% of Norway's national electricity production. Recently, this high ratio of renewable energy production, combined with concerns about wind power development's local environmental impacts, has provided fuel for considerable public debate on the topic of wind power development in Norway.

Authorities have been preparing a national framework for wind power to be released in the spring of 2019. The working process with this framework has triggered broad engagement from the public regarding which areas are most suitable for wind power development.

### Economic Benefits & Industry Development

Development and ownership of wind power projects has traditionally been dispersed among local energy utility companies. Foreign investment is becoming increasingly common in Norwegian wind power projects, and for the projects that are currently operating and under construction, foreign ownership accounts for roughly three quarters of the total ownership in wind power.

Large national energy companies or local energy utilities operate some of these projects on behalf of the owners. Some Norwegian companies, like Fred Olsen Renewables, Statkraft and Equinor, are also engaged in projects in foreign countries, like offshore wind in the United Kingdom.

There is no significant wind turbine manufacturing industry in Norway. But there are several industry initiatives towards offshore wind, especially floating offshore wind. Companies with experience from the offshore oil industry (e.g., OWEC Tower and Aker Solutions) have widened their scope of interest and engaged with the offshore wind industry. These companies offer offshore wind turbine substructure solutions like jacket quatrropods and tripods. Other companies specialize in support systems, anti-corrosion technology or site optimization modeling.

## NEXT TERM

The next term will be dominated by the construction of large amounts of new wind power in Norway. Installed wind power capacity is expected to reach nearly 5 GW by 2021. Norway will not continue with Sweden in the electricity certificate scheme, which means wind power built in Norway after 2020 will need to be profitable without subsidies.

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 toward 2020 and beyond.

## References

Opening photo: Mehuken Wind Farm, Norway (Source: Olav Haaverstad)  
Authors: Ann Myhrer Østenby, Norwegian Water Resources and Energy Directorate, and Harald Rikheim, Research Council of Norway.





**Table 1. Key Statistics 2018, Portugal**

Total (net) installed wind power capacity	5.38 GW
Total offshore capacity	0 GW
New wind power capacity installed	0.067 GW
Decommissioned capacity (in 2017)	0 GW
Total electrical energy output from wind	12.7 TWh
Wind-generated electricity as percent of national electricity demand	24.2%
Average national capacity factor	27.1%
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 during 2018. The country deployed an additional 67 MW of wind power capacity, which brought the nation's total installed wind power capacity to 5,380 MW—38% of Portugal's total renewable operational capacity [1]. In 2018, Portuguese wind farms produced 12.7 TWh and met approximately 24% of the nation's electricity demand with wind energy [1-4].

The electricity production from renewable energy sources in 2018 reached 58% of the national consumption, and for nearly 70 consecutive hours, continental Portugal met 100% of its electricity needs with renewables [2].

Wind energy was crucial for this achievement, as it constituted 65% of the energy produced—the highest share. The high contribution from endogenous resources enabled Portugal to reduce its dependency on foreign energy and exports exceeded imports for the third consecutive year.

Portugal, along with European and North American partners, conducted an important experimental wind campaign in complex terrain at Perdigão in 2017 as part of the ERA-NET+ NEWA collaborative project. Presenting and publishing the results of this campaign was a major part of Portugal's efforts in 2018 [5].

## MARKET DEVELOPMENT

### National Targets & Policies Supporting Development

In April 2013, the Portuguese government established the national renewable energy targets through the National Renewable Energy Action Plan (NREAP) 2013-2020 [6]. This action plan aims for installed wind power capacity to reach 5,300 MW by 2020, of which 27 MW are reserved for offshore wind. The current total land-based installed wind capacity is 5,380 MW—exceeding the 2020 target by 80 MW.

In September 2018, Ordinance 246/2018 was published, which requires the Energy Services Regulatory Agency (ERSE) to consult on authorization procedures regarding the overcapacity of wind farms. The ordinance also defines decision criteria to be adopted, proceeding to the first amendment of Administrative Rule 102/2015, which was published in April 2015 [7].

The RCM (Resolution of the Council of Ministers) also published 12/2018 in February 2018. This set of measures,

which was informed by studies from LNEG (National Laboratory for Energy and Geology), created one pilot zone in the maritime region next to Viana do Castelo, since this area is more suitable for offshore wind exploitation than the previously established region in the coast of São Pedro de Moel [8]. This document also stated, "It is also intended to combine the change of location and the extension of the scope of the Pilot Zone to the project WindFloat, ensuring its compatibility with the Industry for Ocean Renewable Energies (EI-ERO), in the context of policies to foster new activities that maximize the utilization of resources of the Sea."

The NREAP renewable targets have not been adjusted since 2013. Therefore, the renewable targets previously set for 2020 are active and established as:

- 10.0% contribution for the transportation sector
- 35.9% in the heating and cooling sectors
- 59.6% for electricity [6]

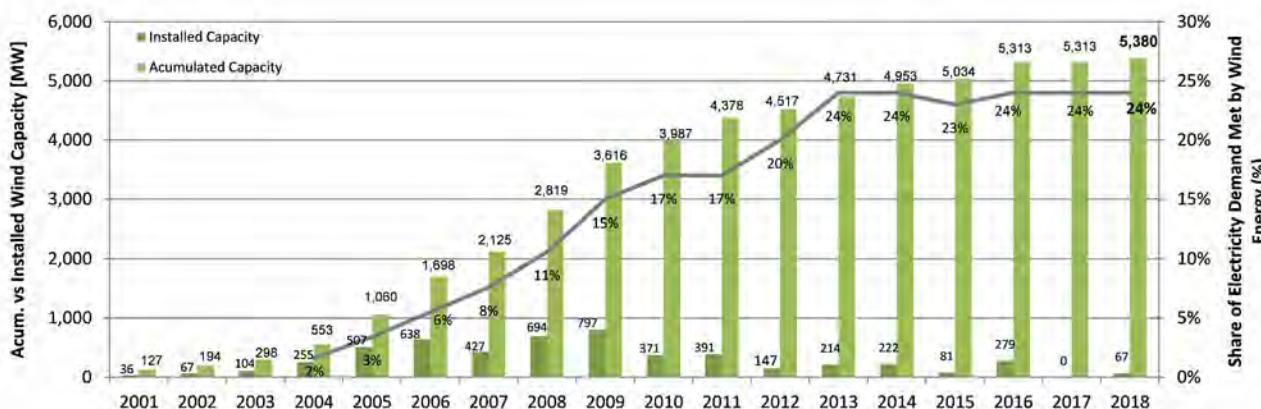


Figure 1. Installed and cumulative wind power capacities and share of electricity demand met by wind energy (Source: DGEG, REN, LNEG)

In 2018, Portugal released draft versions of the National Energy and Climate Plan (PNEC) 2030 and the Roadmap for Carbon Neutrality 2050. These plans ensure the political coherence between the climate and energy areas to decarbonize the economy, taking into account a long-term (2030–2050) perspective. The proposed national renewable energy targets for 2030 are ambitious, and the expected wind power capacity is between 8.0 and 9.2 GW (including overcapacity and repowering procedures). Compared with the current installed capacity, these numbers represent an increase of more than 30%.

The Decree Law 153/2014 maintains and regulates the national incentives for micro- and mini-generation [9]. According to Ordinance 32/2018 issued on 23 January 2018, the feed-in tariffs from 2015 will remain valid for existing installations during the statutory period [10].

### Progress & Operational Details

The additional wind power capacity in 2018 was 67 MW (Figure 1) [1]. Only two new wind farms were connected to the grid in 2018, with a total capacity of 48.5 MW, while the remaining capacity was a result of “overcapacity,” or expanding the capacity of current wind parks. By the end of the year, the cumulative installed capacity was distributed over 259 wind farms, with 2,773 wind turbines operating across the country [1]. The Portuguese wind power fleet generated 12.7 TWh—more than [24]% of electricity demand—for a third consecutive year [1].

The wind share of the total renewable production decreased 9.8% from the previous year to 41.2%. This considerable decrease is due to increased hydropower production (44.2%), which recovered from the dry year of 2017. Still, the average wind power production at full capacity stood at 2,384 hours, indicating a 1.2% increase over 2017 (2,355 hours) [1].

The Portuguese TSO indicated an annual wind generation index of 1.00 [2]. This represents a 4% increase in the index compared to 2017. This slight increase is explained by the high wind generation index observed during the first three months of 2018. Figure 2 depicts the wind generation profiles on:

- The maximum demand day and the respective wind power contribution: The maximum instantaneous demand value (8,794 MW) occurred at 19:45 on 7 February 2018, but wind generation was only 1,1717 MW.
- Maximum daily penetration from the wind and the daily wind contribution: On 11 March 2018, wind power supplied Portugal with 101.1 GWh of electricity, accounting for 77% of the daily demand—the highest in 2018.
- Instantaneous peak wind penetration: The highest instantaneous penetration of wind power in the demand (99%) occurred at 05:00 on 14 October 2018.

Despite the high wind penetration values recorded, the TSO did not report any technical problems during these events. Moreover, during 2018, the TSO also did not report wind energy curtailment occurrences, contrary to 2017, where 0.0116% of the total wind energy was curtailed.

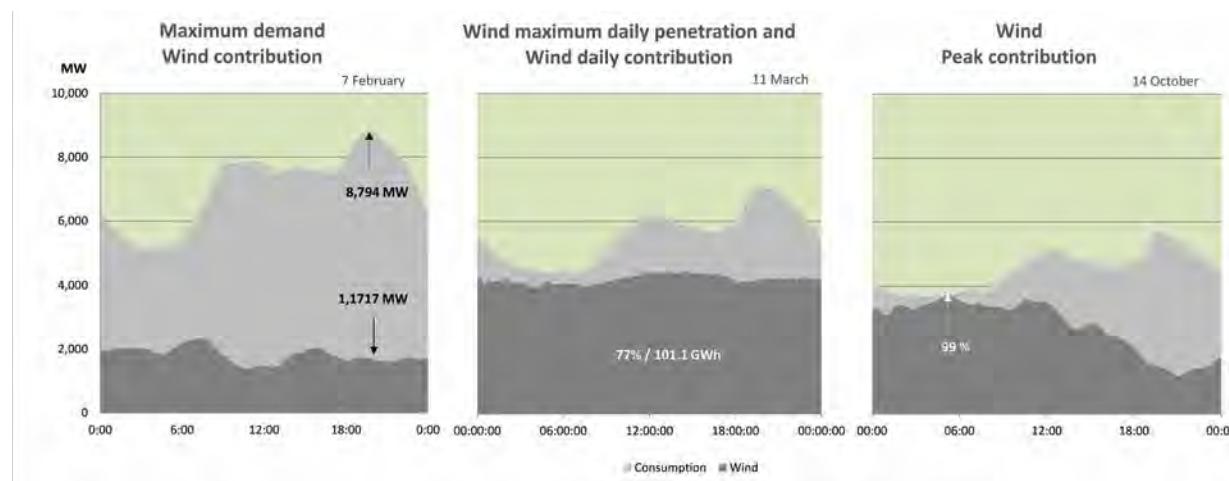


Figure 2. Wind power penetration and energy generation records during 2018 (Source: REN and LNEG)

## Matters Affecting Growth & Work to Remove Barriers

Due to a lack of government support, including the suspension of new grid connection capacity in 2012, and the low competitiveness of wind in the Iberian electricity market compared to other technologies (e.g., solar photovoltaic), Portugal has experienced a strong divestment in the wind

sector. Governmental changes, together with the PNEC 2030 and RNC 2050, have brought about a new expectation for the wind energy sector. This expectation is related to new legislation for new capacity (which will hopefully be based on auction schemes) and overcapacity procedures.

## R,D&D ACTIVITIES

### National R,D&D Priorities & Budget

National R&D efforts during 2018 focused on offshore wind energy, smart-grid facility, and the development of tools and methodologies to maximize the penetration of renewable energy from both a grid security operation point-of-view and a market perspective. Most R&D activities are taking place at the main Portuguese institutes and universities and are funded through national and/or European programs.

The Portuguese Foundation of Science and Technology (FCT) invested nearly 637 million EUR (730 million USD) in science and technology in 2018. Approximately 145 million EUR (166 million USD) was for R,D&D and innovation projects, while 141 million EUR (162 million USD) went towards scientific jobs [11]. These numbers represent a 12% increase in total investment, an 8% increase in R,D&D investment, and a 27% increase in scientific job investment compared to 2017 [12].

### National Research Initiatives & Results

Offshore technologies demonstration projects, such as the new ReaLCoE and DemoWind, were launched to accelerate the implementation of high-performance offshore wind turbines and to create connections between European offshore wind partners who can provide new offshore technologies [13,14].

The DEMOGRAVI3 project, which is financed by Horizon 2020, intends to develop gravity-based foundations for offshore wind turbines [15]. The OffshorePlan project, financed by the POSEUR-P2020 program, also took place in 2018 and developed a set of scenarios for implementing marine renewable energy systems (wind and wave energy converters) along the Portuguese coast, taking into consideration energy resource, socioeconomic aspects and technology characteristics.

### Test Facilities & Demonstration Projects

Portugal's ongoing R&D activities are as follows:

- **ReaLCoE:** an H2020 demonstration project aiming to accelerate a new generation of competitive and subsidy-free clean energy from offshore wind energy converters with a high performance 12+MW demonstration turbine
- **DemoWind:** an H2020-ERA-NET demonstration project enabling industry, through partnership, to connect existing and new European offshore wind demonstration opportunities
- **BestRES:** an H2020 project to bring best practices and innovative business models to renewable energy aggregators
- **DemoWind:** an H2020-ERA-NET collaborative demonstration project to join the offshore wind technology demonstration project through 2019
- **Research Infrastructure (RI) WindScanner.PT:** a project that constitutes the Portuguese node for the European Research Infrastructure WindScanner.EU and 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.

- **DEMOGRAVI3:** an H2020-funded project to demonstrate the GRAVI3 technology, an innovative gravity foundation for offshore wind turbines

### Collaborative Research

Portugal participates in the following IEA Wind TCP Tasks:

- Task 25 Design and Operation of Energy Systems with Large Amounts of Variable Generation
- 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) and Energy Systems Integration (EERA-ESI). During 2018, LNEG also joined the European Sustainable Energy Innovation Alliance (ESEIA).

In Portugal, LNEG and other Portuguese R&D entities are active partners in the following international research efforts:

- **InnoDC:** an H2020 project focused on developing the electricity transmission system and targeting the connection of offshore wind with the existing power system
- **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 facilitates the sustainable integration of wind energy into the EU grids
- **NEWA:** an ERA-NET+ project concerning the development of a new wind atlas for land-based and offshore wind in European countries
- **OffshorePlan project:** a project co-financed by the Operational Program for Sustainability and Efficiency in the Use of Resources (POSEUR) through Portugal 2020 and the Cohesion Fund, which directs the planning of the optimized development of marine renewable energies in Portugal, to account for socio-economic impacts of offshore technology
- **AEOLUS4FUTURE:** an H2020 project to develop efficient and sustainable wind energy systems for various EU needs
- **SWARMS:** an H2020 project to create underwater robots in cooperation meshes to inspect offshore foundations
- **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 the EERA Joint Programme on Wind Energy partners

- **OptiGRID:** a national funded project (Portuguese foundation for Science and Technology – FCT) that demonstrates the Dynamic Line Rating approach to increase the integration of renewables into the electric grid, with particular focus on wind energy systems

- **REGEDIS-CYTED:** The Red de Energía Eólica Para la Generación Distribuida En El Ámbito Urbano conducts studies for the wind energy integration in urban and rural environments, from regulation to technology development

## IMPACT OF WIND ENERGY

### Environmental Impact

In 2018, wind-generated electricity generated 1.155 million EUR (1.323 million USD) for wind power plant developers [16]. This represents an increase of 2.8% compared to the previous year and a savings of about 5.5 million tons of CO<sub>2</sub> emissions (considering a factor of 430 g/kWh). Based on data from the yearly contribution of each technology in the Portuguese energy mix, imports, and the consumption index, Portugal's dependence on fossil fuels generation was calculated at nearly 42%—a significant decrease compared to 2017 (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 decreased the 2018 CO<sub>2</sub> emissions to nearly 15 million tons (MT) in mainland Portugal—a 16% decrease compared to 2017 [3]. Madeira Island also observed an almost 7% decrease in CO<sub>2</sub> emissions, reaching 0.38 MT. For the third year, Portugal's energy exports exceeded imports by nearly 2,656 GWh [2]. This result is particularly relevant, as the country also observed an increase in electricity consumption to 50.9 TWh (Portugal mainland).

### Economic Benefits & Industry Development

The wind industry and deployment activities in Portugal supported approximately 3,250 jobs during 2018. The mean tariff paid to the wind power plants in 2018 increased 2.38 EUR/MWh (2.73 USD/ MWh) from the 2017 rate to 97.40 EUR/MWh (111.58 USD/MWh) [16].

Enercon continues to lead 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 [0.7%] [17].

## NEXT TERM

With the ambitious targets for 2030 regarding the renewable integration into the power system, the government will soon establish a feed-in tariff for overcapacity procedures while researchers continue to analyze the most adequate scheme for supporting new wind farms. It is also expected that in the coming years, repowering will be more expressive in Portugal.

After some issues, the first floating offshore wind park on the Portuguese coast (25.2 MW across three wind turbines with a nominal capacity of 8.4 MW) will be connected to the grid during 2019 with the government's support, as well as support from the NER300 and InnovFin programs.

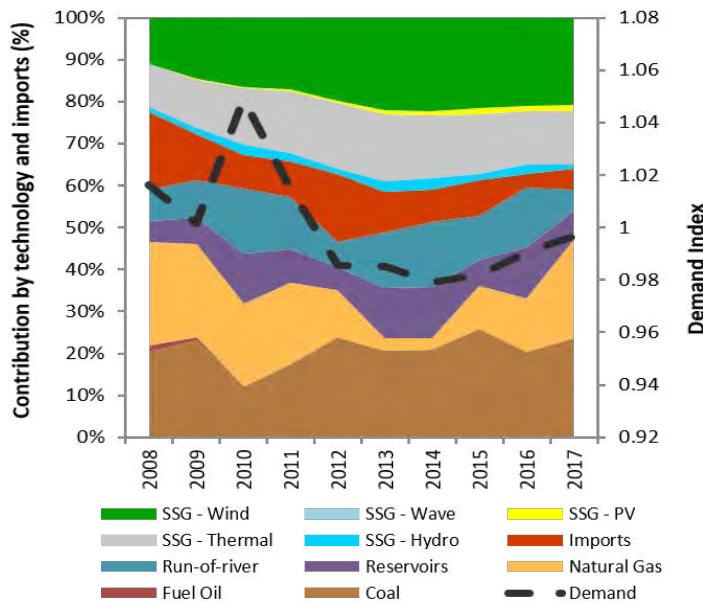


Figure 3. Yearly contribution from each technology and imports to the energy consumption and demand index from 2008-2017 in mainland Portugal (Source: REN and LNEG) [1]

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**Table 1. Key Statistics 2018, Spain**

Total (net) installed wind power capacity	23,484 MW
Total offshore capacity	5 MW
New wind power capacity installed	392 MW
Total electrical energy output from wind	48.9 TWh
Wind-generated electricity as percent of national electricity demand	19%
Average national capacity factor	23.78%
National wind energy R&D budget	14.97 mil EUR; 17.15 mil USD
Target	29.4 GW by 2020

## OVERVIEW

Wind power was the second largest source of electricity generation in Spain for most of 2018. In December, wind power became the largest source, with a share of 24.3%. The Spanish government has committed to installing about 6,400 MW of new wind capacity and investing about 7.5 billion EUR (8.6 billion USD) as part of its energy planning efforts to meet European targets for 2020.

The Spanish wind sector installed only 392 MW of new wind capacity during 2018 [1]. The first auction was carried out in 2016, which allocated for 500 MW of wind power capacity in contracts that offered no subsidy over the market price. A second auction was carried out in May 2017, which awarded 2,979 MW of wind capacity with no subsidy over the market price. The auction led to contracts priced at 42.53 EUR/MWh (48.7 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. The contracts from this auction had a cost of 33.41 EUR/kWh (38.27 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.

By the end of 2018, the Spanish Government issued a draft of the Integrated National Energy and Climate Plan 2021-2030 (NECP 2021-2030), which aims to install 22.3 GW of new wind capacity within this period.

National investments for wind-related R&D totaled 14.97 million EUR (17.15 million USD) in 2018.

## MARKET DEVELOPMENT

### National Targets & Policies Supporting Development

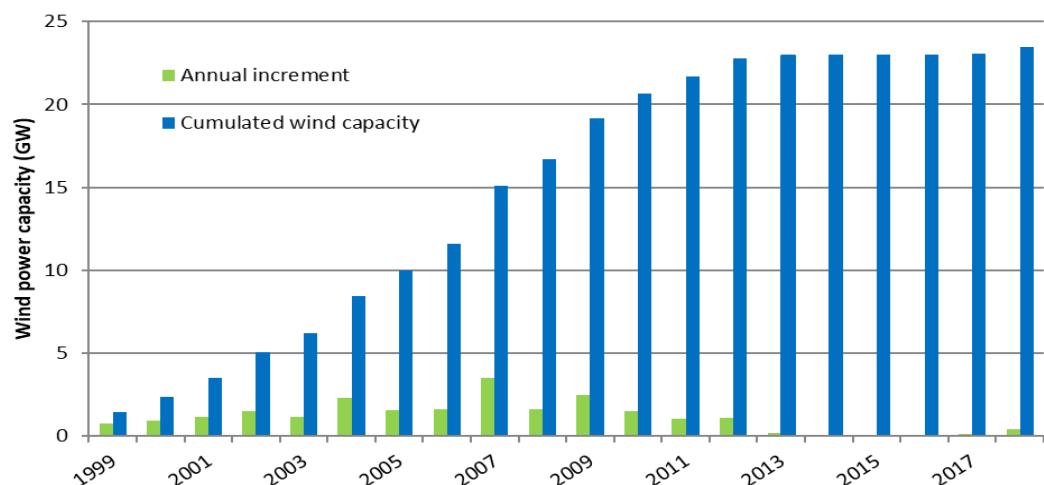
After the 2012 Spanish electricity sector reform, regulatory uncertainty led to a dramatic reduction in new projects until 2016, when the government established auctions based on investments cost discount. The target of the National Renewable Energy Action Plan (NREAP 2011-2020) was 35 GW; so far, 4.6 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.

Figure 1. Annual and cumulative installed wind power capacity in Spain (Source AEE)



The baseline capex amounts to 1.2 million EUR/MW (1.4 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 (28.58 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.

### Progress & Operational Details

Spain installed 392 MW of new wind power capacity in 2018. These installations included 190.1 MW in the Canary Islands, 90.9 MW in Aragón, 68 MW in Galicia, 30 MW in Andalusia, 10.37 MW in Castilla-La Mancha and 2.35 MW in Catalonia.

Land-based wind power capacity increased 392 MW in 2018, bringing the national total to 23,484 MW. Wind-based electricity generation was responsible for 48.9 TWh/yr – 19% of the country’s total electricity generation. Wind-based electrical generation increased 2.9%, becoming the second largest source of electricity generation in Spain (Figure 2).

To achieve the European targets, around 6,473 MW of new wind capacity needs to be installed before 2020; however, no new auctions were developed in 2018.

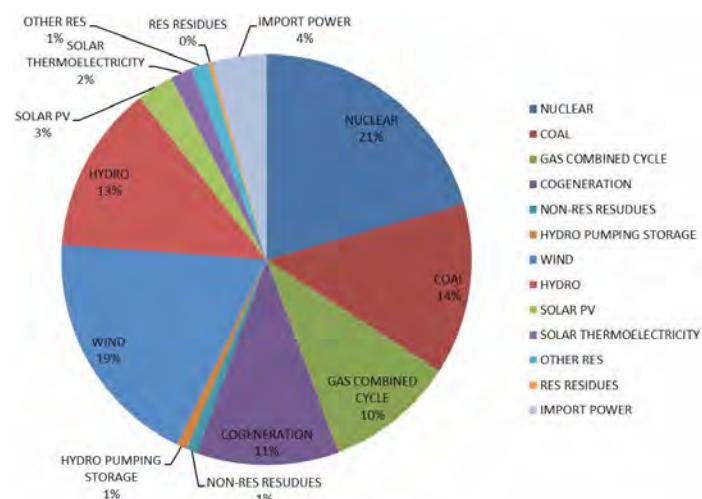


Figure 2. Sources of the 2018 power supply in Spain (Source: REE)

The maximum instantaneous share of wind energy happened on 28 February 2018 at 3:45 a.m., when wind attained a 60.7% share of power demand. During the first 28 days of March 2018, wind power production reached 6,937 GWh – 62.7% higher than the same period last year – and accounted for 32.9% of Spain’s total production. The daily average for 2018 almost reached 250 GWh.

The Spanish wind energy sector developed only a few wind farms in 2018. A 23-year-old, 30-MW wind farm in the coast of Andalusia was repowered in 2018, replacing 90 330-kW Kenetech KVS33 turbines. The new installations—eight 3-MW Nordex/Acciona N100/3000 turbines and four 1.5-MW Nordex Acciona AW70/1500—increased the total energy production by 16% (112 GWh/yr).

Galicia holds the biggest share of Spain’s new wind capacity, with two new wind farms (46-MW and 22-MW, respectively) and a total of 34 2-MW turbines from VESTAS. In Aragón region, a new “100% merchant” 50.4-MW wind farm has been developed with 20 2.5-MW SG 114-2.5 turbines. In the Canary Islands, several small wind farms have been connected to the grid, which amounts to an additional 190-MW. Finally, in Catalonia, the first Spanish community wind initiative has connected to the grid. The installation of a 2.35-MW E103 turbine from Enercon was funded by more than 650 persons or entities.

### Matters Affecting Growth & Work to Remove Barriers

Wind capacity for ancillary services in Spain reached 10,442 MW (46% of total capacity installed) during 2018, and the total energy managed by the Spanish TSO (REE) for power deviation management and tertiary regulation amounted to 307 GWh (5.7% of total energy managed 5.4 TWh).

During 2018, several Operating Procedures regarding Spain’s adaptation to the new EU Grid Code transition (Regulation EU/2016/631) were submitted to public consultation. These procedures are:

- PO 9.0: Information exchanged by the system operator
- PO 12.1: Processing of access, connection and commissioning requests to the transport network
- PO 12.2: Generation and demand facilities: minimum requirements for design, equipment, operation, commissioning and safety



Figure 3. ELISA-ELICAN Project: A 5-MW offshore wind turbine installed in Gran Canaria Island, Spain. Self-installing precast concrete telescopic tower and foundation; the first bottom offshore wind turbine ever installed with no need for heavy-lift vessels. (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, such as increasing O&M cost competitiveness, extension-of-life strategies for wind farms, optimizing manufacturing process, etc. Offshore wind R&D activities are increasing, especially for floating applications. National investments in wind energy R&D amounted to 14.97 million EUR (17.15 million USD) in 2018. This budget is similar to the previous years.

### National Research Initiatives & Results

In 2017, the Spanish government developed the State Plan for Scientific and Technical Research and Innovation 2017–2020, following the 2013–2020 Spanish Strategy for Science and Technology and Innovation [6]. This is the reference strategic framework for the whole country to address research and innovation matters. The plan tries to align the R&D&I priorities with those set in the European Strategic Energy Technology Plan (SETPlan).

The 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 (which addresses clean, efficient, and secure energy topics). R,D&I projects are designed around five main areas:

- Address research challenges
- Address proof of concepts
- Stimulate the collaboration between private companies and research organizations (collaborative research)

- Promote hiring young researchers
- Address international joint programming 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 highlighted here.

#### LCOE Reduction

##### Research Projects

- Study of the behavior against impact and post-impact of wind turbines manufactured with sandwich structures (TRL <6); coordinated by University Carlos III of Madrid
- Advanced models for the evaluation of the resistance and efficiency of blade bearings of wind turbines (TRL <6; coordinated by the University of the Basque Country

#### Collaborative Projects (Industry and academy)

- Development of advanced materials in wind energy. Partners: SGRE Innovation and technology, Clam Desarrollo S.L., Asociación de Investigación en materiales plásticos, University Jaume I de Castello; 2018–2021; Budget: 1.71 million EUR, Grant: 360,000 EUR, Loan: 378,000 EUR

- Innovative development of an on-site construction system for high-rise wind towers, with high-performance concrete reinforced with fibers and without conventional reinforcement. Partners: ATESVI S.L., CALTER INGENIERIA S.L., University of Castilla La Mancha, CSIC; Budget: 1.27 million EUR, Grant: 380,000 EUR, Loan: 722,000 EUR
- Development of a new concept of high-rise concrete tower in situ for high-altitude wind turbines. Partners: DRAGADOS S.A., DRACE Infraestructuras S.A., INGECID investigación y desarrollo de proyectos S.L., Universidad de Cantabria; Duration: 2018-2020; Budget: 700,000 EUR, Grant: 260,000 EUR, Loan: 236,000 EUR

### **Innovation Projects**

- Nucleos project: new electrical components for premium and 4-MW wind turbines
- New family of wind turbines with common partial aerodynamic design and high bushing capacity for locations with low and medium wind
- New technological concepts for more compact and reliable multi-megawatt gears

### **Lifetime Extension of Wind Farms**

#### **Collaborative Projects (Industry and academy)**

- Development of an integrated system for monitoring the structural state of wind turbine blades using distributed fiber optic sensors. – SIAMESE Project. Partners: SGRE Innovation and technology, Uptech sensing S.L. Public University of Navarra; Duration: 2018-2021; Budget: 1.16 milion EUR, Grant: 260,000 EUR, Loan: 300,000 EUR

### **Optimized O&M Procedures for Wind Farms**

#### **Collaborative Projects (Industry and academy)**

- Development of an intelligent engine of wind predictors. Partners: UNATEC ICT SL, Fundación CENER-CIEMAT, University of Salamanca; Duration: 2018-2019; Budget: 509,000 EUR, Grant: 148,000 EUR, Loan: 325,000 EUR

### **Innovation Projects**

- Integrated operation & maintenance ismart safety system for wind turbines
- Tim project: platform for transport, installation and maintenance of offshore structures

### **Power System Integration: Hybrid solutions, Energy storage**

#### **Collaborative Projects (Industry and academy)**

- Solutions to improve the operation of wind turbines in weak networks. Partners: Gamesa Electric S.A (Coord), SGRE Innovation and technology S.L, University of Alcala, Pontificia University of Comillas; Duration: 2018-2020; Budget: 1.18 million EUR, Grant: 320,000 EUR, Loan: 364,000 EUR
- Asset management of the interconnection of wind turbines-GADIA Project. Partners: ORMAZABAL y Cia SLU (Coord), ORMAZABAL Cotradis Transformadores S.L.U, ORMAZABAL Protection Automation SLU, Mondragon Goi Eskola Politeknikoa, Jose Maria Arizmendiarreta S Coop, Asociación Centro Tecnológico CEIT-IK4; Budget: 2.18 million EUR, Grant: 611,000 EUR, Loan: 1.35 million EUR

### **Offshore Wind Technology**

#### **Research Projects**

- Analysis of the dynamic behavior of floating offshore wind platforms for the optimization of the design for deep waters (TRL <6); coordinated by the Fundacion Instituto de Hidraulica Ambiental de Cantabria
- Development and validation of intelligent monitoring systems, pitch control strategies and structural damping for floating offshore wind turbines (TRL <6); coordinated by IKERLAN S.Coop
- Influence of the phenomena of soil-structure interaction in the seismic response of offshore wind turbines (TRL<6); coordinated by the University of Las Palmas de Gran Canaria (Canary Islands)
- Development and validation of intelligent monitoring systems, pitch control strategies and structural damping for floating offshore wind turbines (TRL <6); coordinated by the Technical University of Catalonia

#### **Collaborative Projects (Industry and academy):**

- Standardization of floating structures for offshore wind applicable at low and high depths. ISOBATA Project. Partners: ESTEYCO SAP (Coord), COBRA Instalaciones y Servicios, Fundación Instituto de Hidraulica Ambiental de Cantabria; Duration: 2018-2019; Budget: 596,000 EUR. Grant: 219,000 EUR, Loan: 313,000 EUR.

### **Test Facilities & Demonstration Projects**

The Canary Islands Oceanic Platform (PLOCAN) is a floating laboratory 2.5 km from shore, which allows 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.

WINDBOX initiative new infrastructure dedicated to integrating and validating the different subsystems used in wind energy in order to optimize their design, improve manufacturing processes, and increase their reliability. WINDBOX is composed of nine private companies (subsystem suppliers) and one laboratory (IK4-TEKNIKER) and 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 International Wind Farm Flow Modeling. Spain also participates in:

- Task 11 Base Technology Information Exchange
- Task 25 Energy Systems with Large Amounts of Variable Generation
- 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 Turbine Technologies

## IMPACT OF WIND ENERGY

According to AEE reports, the reduction effect of wind energy in the Spanish power market in 2018 was 8.83 EUR/MWh (10.12 USD/MWh) – clearly lower than in 2017 (20 EUR/MWh; 23 USD/MWh). This decrease was due to a greater interconnection with France and the increase in the price of fossil fuels and CO<sub>2</sub> emissions.

### Environmental Impact

AEE reports state that wind energy in Spain avoided about 25 million tons of CO<sub>2</sub> emissions during 2018. According to REE reports, the nation's electrical power demand increased by 0.4% during 2018; however, the domestic power generation decreased by 0.5%, mainly because a reduction of coal (-15%) and natural gas (-20%) use.

Therefore, total CO<sub>2</sub> emissions from the Spanish power generation sector decreased by 2.2%. In 2018, 48.9 TWh of wind-generated electricity prevented approximately 11.83 million tons of CO<sub>2</sub>, reducing the energy-related annual CO<sub>2</sub> emissions in Spain by 2%. A 395-MW Combined Cycle Power Plant was decommissioned in 2018.

### Economic Benefits & Industry Development

The Spanish wind sector employs 22,578 people annually. More than 207 companies work in Spain, often focusing on exports due to a lack of national deployment. The sector accounted for 1% of Spain's total exports in 2018, totaling around 2.391 billion EUR (2.740 billion USD). Wind energy directly and indirectly contributes 3.394 billion EUR (3.889 billion USD) to the GDP, which represents 0.31%.

## NEXT TERM

The domestic market for land-based wind energy is expected to be the most exciting in Europe in 2019. Previous successful auctions awarded a total wind capacity of 4,607 MW in Spain, which must be in operation by the end of December 2019. The government's commitment to the ambitious Integrated National Energy and Climate Plan (NECP 2021-2030) will add at least 3 GW of new capacity per year.

The progressive drop in the cost of energy produced by land-based wind farms will allow Spain to promote viable 100% merchant wind farms in windy areas in Spain. On the other hand, offshore wind deployment will continue to

Most of the new wind turbines currently under installation in Spain utilize big rotor diameters (from 114 to 136 meters) to increase the capacity factor as much as possible. Siemens Gamesa Renewable Energy is supplying the Model SG 3.4-132 Class IEC II A and Model SG 2.6-114 Class IEC IA/IIA. The new Model SG 4.2-145 Class IEC II A will get the Type Certificate in early 2019. Spain's wind sector also frequently uses the model V136 3.45 Class IEC IIIA/IIB turbine from Vestas Windpower and GE 3.4-130 Class IEC IIB turbine from GEWind.

While Spain has installed only one 5-MW offshore wind turbine to date, there is a very active industrial offshore wind sector. Offshore technology developments include:

- 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 demonstrating the ELISA-ELICAN project, the world's first ground-based, 5-MW offshore platform with a telescopic tower configuration, which allows for both self-transportation and self-installation of the complete wind turbine – at the PLOCAN Test Facilities in the Canary Islands (Figure 3).

Additionally, the joint venture Navantia-Windar built five spar-type floating foundations for the 30-MW 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).

decrease (except for some singular demonstration projects located in Canary Islands) because of the high cost of energy generated in those islands.

The Integrated National Energy and Climate Plan 2021-2030 will establish a promising R&D dimension, with more funds to facilitate an energy de-carbonization transition that is completely aligned with the EU Energy Union strategy. It is expected that next State Plan for Scientific and Technical Research and Innovation 2021–2027 will facilitate an increasing number of calls for proposals, and that a greater number of innovative projects will begin.

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**Table 1. Key Statistics 2018, Sweden**

Total (net) installed wind power capacity	7.406 GW
Total offshore capacity	0.200 GW
New wind power capacity installed	0.716 GW
Decommissioned capacity (in 2018)	0.001 GW
Total electrical energy output from wind	16.4 TWh
Wind-generated electricity as percent of national electricity demand	10.9%
Average national capacity factor	26.6%
National wind energy R&D budget	60 mil SEK; 5.9 mil EUR; 6.8 mil USD

## OVERVIEW

In 2018, Sweden installed 716 MW of new wind energy capacity (199 MW were installed in 2017). At the end of the year, the country's total installed capacity was 7,406 MW from 3,659 wind turbines.

Through the EU burden-sharing agreement, Sweden aims to cover at least 50% of total energy use with renewable energy by 2020. In 2016, the government announced a new, ambitious targets of 100% renewable electricity production by 2040. The Swedish Energy Agency estimates that the country will need to install an additional 2.5-6 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 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 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

The EU burden-sharing agreement requires Sweden 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 nation's 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, which is called the electricity certificate. The electricity certificate scheme was implemented in 2003 with the intention to increase renewable electricity production and decrease production costs. The scheme also contributes to work that assesses areas of national interest for wind power, which can be considered a "soft incentive."

In the electricity certificate scheme, the government awards electricity producers a certificate for each MWh of renewable energy. 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.

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 in Sweden 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 produce 26.4 TWh of renewable electricity 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 2018 resulted in 716 MW of new capacity. At the end of 2018, Sweden's total installed capacity was 7,406 MW from 3,659 wind turbines. The total electrical energy output from wind was 16.4 TWh.

Interest is gaining around Northern Sweden, as the region exhibits many areas with high potential for wind power. However, 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 a risk of falling ice.

Wind turbines in these areas must be equipped with special cold climate packages, which include tower and nacelle structures with special steel qualities, special types of oil and grease, and (in some cases) de-icing or anti-icing equipment. Because many challenges remain, the Swedish Energy Agency considers wind power in cold climates an R,D&D priority.

## 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 2018: Vindforsk, Vindval, Swedish Wind Power Technology Centre (SWPTC), and VindEL [5]. The Swedish Energy Agency supervised all four programs [2-5].

Vindforsk finalized its fourth period during 2018. It started operations in 2013 with a total budget of 60 million SEK (6.2 million EUR; 6.6 million USD). The program was financed by the Swedish Energy Agency (50%) and industry (50%).

### 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 sites (which are almost exclusively land-based) are considered for new wind farms today.

During 2017, the government commissioned the Swedish Energy Agency to investigate potential ways to eliminate grid-connection costs for offshore wind power. The Swedish Energy Agency suggested two different models, and while government has invited different organizations to review the report during 2018, there has yet not been any decision regarding the two models.

In 2018, the Swedish Environmental Protection Agency and Swedish Energy Agency took the initiative to prepare a common strategy for sustainable wind power expansion in Sweden. The goal is to produce a roadmap for wind power expansion that facilitates municipal planning as well as local and regional permit processes, while also contributing to increased predictability for all stakeholders involved. This roadmap will provide guidelines on how consideration should be given to different stakeholders for a more efficient permitting process.

Vindforsk was organized in three research topics:

- Wind resource assessment and installation
- Operation and maintenance
- Grid integration

In total, the program has produced over 20 reports since 2013. Vindval is a research 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 third phase of the program had a budget of 27 million SEK (2.8 million EUR; 3.0 million USD) and ended in June 2018. The agency has allocated a total of 20 million SEK (2.0 EUR; 2.3 USD) to implement the fourth phase of Vindval, which will focus on wind power and spatial planning. The program extends through December 2021.

The SWPTC has been extended and will run from 2019-2022. The program is commonly financed by industry, universities, and the Swedish Energy Agency, with a total budget of 48 million SEK (4.7 million EUR; 5.4 million USD). The center focuses on optimizing wind turbine design by considering the interactions 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 will run from 2017-2021. It is financed by the Swedish Energy Agency and has a total budget of 133 million SEK (13 million EUR; 15 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 2018 wind energy projects:

**Wind turbines under harsh operation conditions:** focused on the harsh operational conditions that sometimes lead to gearbox and bearing failures before their expected lifespan has been reached. Researchers developed methods for determining the operational severity from data acquired during operation, which can help obtain relevant operational severity indices.

The results showed that complex terrain increased the fatigue on the gearbox shaft. Additionally, the wind direction in complex terrain fluctuates at a much higher rate than on the flat terrain, resulting in more destructive fatigue loads. Project simulations also showed that de-rating a wind turbine had a significant impact on the loads in the drive train, but it had no significant impact on the fatigue loads on the nacelle.

**Wind power in forest – the effects of clearings:** investigated how forest clearings impact the wind conditions in a wind farm. The wind flow over forested terrain is characterized by a slowdown in wind speeds, higher wind shear, and increased turbulence. These are factors that increase turbine fatigue loads, and most wind turbines today are not designed for these loads. This project aimed to learn more about the effects of clearing forests around a wind turbine to increase production and minimize loads.

**Optimal maintenance of wind power plants:** developed a new optimization model for the short-time maintenance schedule. The model uses maintenance data (corrective maintenance costs, preventive maintenance costs, survival functions, logistic costs, etc.) as input, and generates a short-term maintenance schedule that will indicate to the maintenance staff, who are on site, which components have the highest probabilities of failing within a short time span.

This method can also be used to look at other kinds of data, such as the gearbox bearing temperature and gearbox oil temperature. By analyzing this data, operators can better estimate a component's survival function and generate a better maintenance schedule.

## 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 2018.

## Collaborative Research

In 2018, 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 Energy Systems with Large Amounts of Variable Generation
- Task 29 Mexnext: Analysis of Wind Tunnel Measurements and Improvement of Aerodynamic Models
- Task 31 International Wind Farm Flow Modeling
- Task 34 Working Together to Resolve Environmental Effects of Wind Energy (WREN)
- Task 36 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 also maintaining security of supply. This can be achieved with an active energy policy, incentives, and research funding. Currently, CO<sub>2</sub> 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 2019.

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Opening photo: Wind turbine supplying electricity to Sweden (Credit: Lars Johansson, Mostphotos)

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Author: Andreas Gustafsson and Pierre-Jean Rigole, Swedish Energy Agency, Sweden.



**Table 1. Key Statistics 2018, 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	0.12 TWh
Wind-generated electricity as percent of national electricity demand	0.2%
Average national capacity factor	18.6%
National wind energy R&D budget	1.4 mil EUR; 1.6 mil USD
Target	4.3 TWh/yr

## OVERVIEW

By the end of 2018, Switzerland had 37 large wind turbines in operation with a total capacity of 75 MW. These turbines produced 122 GWh of electricity in 2018. No new turbines were installed in 2018 but the construction of a new wind farm with a capacity of 12 MW is planned for 2019, which will increase the total wind power capacity by 15%.

A cost-covering feed-in tariff (FIT) for renewable energy in Switzerland has been in place since 2009 [1]. This policy promotes wind energy and has led to an increase in new wind energy projects.

Financing is currently requested for an additional 3.4 TWh under the FIT scheme. In addition, implementation of the Energy Strategy 2050 began in 2018 with a new legislative package encouraging renewable energies and energy efficiency [2].

Internationally cross-linked research activities in 2018 focused on cold climates, turbulent and remote sites, and social acceptance of wind power.

## MARKET DEVELOPMENT

### National Targets & Policies Supporting Development

The new Energy Strategy foresees an additional 22.6 TWh/yr from renewable energy by 2050. 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, a total of 89 GW of wind power capacity is in operation and being supported under the scheme; additional projects with a potential energy yield of 1,741 GWh have been registered, and 1,536 GWh are on the waiting list. Since the beginning of 2018, wind projects with an electricity production of 23.5 GWh are being supported using direct market subsidies.

The Energy Strategy 2050 that was approved by the Swiss population in 2017 entered into force at the beginning of 2018. The new legislative package increases the budget for Switzerland's cost-covering feed-in tariff for renewable energy.

Renewable resources include hydropower (up to 10 MW), photovoltaics, wind energy, geothermal energy, and biomass. The cost of the FIT is financed by a levy on electricity consumption. The new law increased the maximum levy from 14 CHF/MWh (12.4 EUR/MWh; 14.2 USD/MWh) to 23 CHF/MWh (20.4 EUR/MWh; 23.4 USD/MWh).

Under the new law, the FIT for newly installed wind turbines in 2018 was 230 CHF/MWh (204 EUR/MWh; 234 USD/MWh) [3]. Wind turbines built on locations at or above 1,700 m above sea level received an additional altitude bonus of 22.2 EUR/MWh (25.4 USD/MWh).

The payment period has also been shortened from 20 to 15 years and, after a transition period lasting until 2020, the payment scheme will change from feed-in tariffs to a direct commercialization scheme. At that time, wind turbine operators will be required to sell the generated electricity on the market and will receive an additional market premium from the supporting scheme.

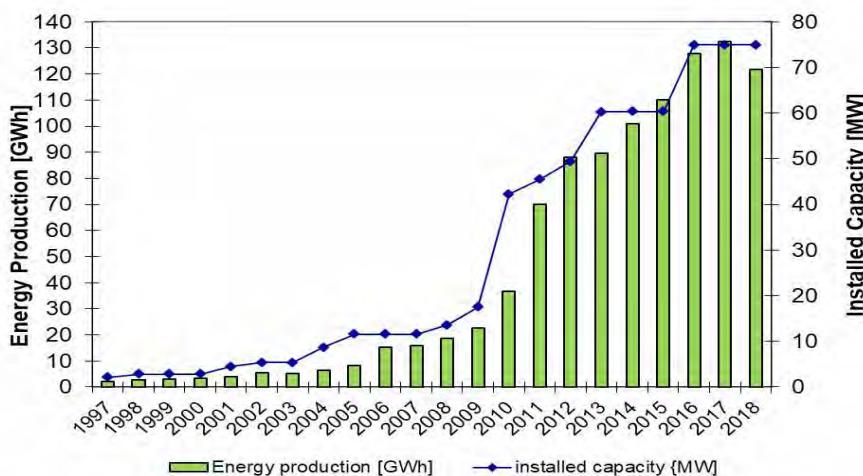


Figure 1. 20 years of wind energy power generation in Switzerland. Source: SuisseEole

The Wind Energy Conception adopted in 2017 by the Swiss Federal Council is also in effect [4]. This document defines how the interests of the State should be taken into consideration during wind project planning processes and indicates the areas particularly suitable for harnessing wind energy.

For each canton with wind power generation potential, it sets a non-binding target that the cantonal department of energy should take into consideration in its energy plan.

### Progress & Operational Details

Approximately 59% of Switzerland's overall electricity production comes from renewable sources, with hydropower by far the biggest contributor (95%). Wind power generation currently provides 0.2% of Swiss electricity consumption.

In 2018, no new turbines were installed, keeping the amount of wind-generated electricity at 132 GWh. Future projects that are already in advanced planning stages 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, and specific projects must also be approved by voters in the local population.

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 discussions on very specific topics, which slows down the planning procedures.

The new energy law that entered into force in 2018 helped ease planning procedures in two main ways. First, wind farms expected to produce more than 20 GWh/year are now considered to be of national interest. This contributes to more court decisions in favor of wind power deployment.

Three wind projects have already benefited from this in 2018 [5]. Second, the role of the cantonal authorities in the planning process is now better defined and they are more able to assist project developers and communes with a project on their territory. A central office (Guichet Unique) at the state level was created to help coordinate the different procedures.

## R,D&D ACTIVITIES

### National R,D&D Priorities & Budget

The priorities of the research term 2017 to 2022 remain valid for 2018 [6]. These priorities are:

- Performance optimization per turbine and farm via turbine optimization, control optimization, and wind farm design;
- Reduction of turbine downtimes through technical optimization, icing protection, wind forecasts, and understanding of avifauna behavior; and
- Acceptance of wind power. This includes accelerating research between wind power and other fields (such as ornithology or noise research) and promoting stronger cooperation between federal offices and institutes.

In 2018, the budget for wind energy related R&D and demonstration projects from the Swiss Federal Office of Energy was approximately 750,000 CHF (666,000 EUR; 762,710 USD).

Within the national Swiss Energy program, approximately 0.8 million CHF (0.7 million EUR; 0.8 million USD) were allocated to the wind energy sector for information activities, quality assurance measures, and for the support of regional and communal planning authorities [6].

### National Research Initiative & Results

Due to Switzerland's topography, one important topic is the optimization of wind farms in complex terrain. Prof Porté-Agel and his team from the Wind Engineering and Renewable Energies Laboratory (WiRE) at the EPFL have been working for several years on a virtual wind simulator. The simulator predicts turbulent wind over complex terrain and its interactions with wind turbines and wind farms. It was developed based on a unique combination of computer simulations, wind-tunnel experiments and field experiments.



Figure 2. Radio link testbed near a wind turbine in Jura (Photo credit: Matthieu Ducret, 2018))

The numerical simulations focus on two wind farm performance issues that are receiving increased levels of attention in the wind energy community: the potential of using selective turbine downregulation as a strategy to mitigate the power losses associated with wind turbine wakes in wind farms (thus improving wind farm performance); and the effects of atmospheric turbulent flow on the wind distribution inside and around (upwind and downwind of) wind farms.

The wind-tunnel experiments use a miniature wind turbine which allows researchers to control the yaw angle and electrical loading of multiple wind turbines in wind farm configurations. The flow around a single wind turbine has been further characterized, with emphasis on the effect of atmospheric boundary-layer turbulence on wind turbine wake.

Field experiments took place in the U.S. in Cedar Rapids, Iowa. Researchers studied wind turbine wake flows using two EPFL laser-based scanning wind lidars mounted on the nacelle of a wind turbine. This unique experimental setup allowed researchers to simultaneously measure the turbulent incoming flow and the wake flow. These measurements provided unique new insights on how wind turbine wake flows are affected by the incoming atmospheric flow as well as valuable datasets for the validation of the numerical models.

Due to Swiss regulations, telecommunication networks are very dense in Switzerland. Therefore, the probability of having wind energy farm developments close to telecommunication facilities is high. Radio links are widely used and operators need to maintain high quality standards. Lack of knowledge concerning interferences on radio links caused by wind turbines, and particularly their order of magnitude, led to the use of conservative assumptions in risk assessment calculations.

Given the need to know the interferences' order of magnitude for telecommunication operators and wind energy developers, a measurement campaign was carried out in the Jura region through autumn of 2018. Thanks to this campaign, the order of magnitude is better known and the excessively conservative assumptions can be discarded, although further measures with different turbine models, layouts and terrain types are needed. Some findings are transferable to radar impact assessment as well.

### 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 (with particularly active participation in Meteotest )
- Task 26 Cost of Wind Energy
- Task 28 Social Acceptance of Wind Energy Projects
- Task 31 International Wind Farm Flow Modeling
- Task 34 Working Together to Resolve Environmental Effects of Wind Energy (WREN)
- Task 39 Quiet Wind Technologies

## IMPACT OF WIND ENERGY

### Environmental Impact

Since Switzerland's electricity generation mix is almost completely carbon neutral, increasing wind-generated electricity doesn't contribute to carbon emission reduction targets. However, wind power generation, combined with solar power, is expected to replace power generated at nuclear power plants which are expected to be shut down at the end of their lifetime.

### Economic Benefits & Industry Development

A study estimated that the total turnover in wind energy in Switzerland in 2010 was about 38.9 million EUR (44.5 million USD) and that the wind industry employed about 290 people [7]. Another study from 2009 estimated the worldwide turnover of Swiss companies in wind energy will be 8.6 billion EUR (9.9 billion USD) by 2020, and that the wind power industry will employ 32,000 employees worldwide [8].

The Swiss industry is active in several wind energy fields:

- Development and production of chemical products for rotor blades, such as 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

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Numerous Swiss wind farm projects are on hold because of avifauna considerations. The current approach is to conduct a study on the potential impact to all bird species (migratory or local) for each new wind farm project. In 2018, a study taking a more systemic approach started with the aim to identify key areas for specific species. This study, led by the University of Bern, focusses on big alpine raptors. Initial results will be available in 2019.

Furthermore, a study proposed by the ETH Zürich from the Department of Environmental Systems Science was launched which will assess the complementarity of the wind power regimes within Switzerland as well as comparing Switzerland to neighboring countries with quickly developing wind industries. The final aim is to assess the market value of wind energy produced in Switzerland based on potentially complementary wind regimes.

In terms of deployment, in 2018, one wind farm project was approved by all planning bodies. Its construction will start in 2019 and should add 12 MW to total capacity.

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Opening photo: Telecommunication antenna neighboring a wind turbine in Jura (Photo credit: Matthieu Ducret, 2018)

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# United Kingdom



**Table 1. Key Statistics 2018, U.K.**

Total (net) installed wind power capacity	21.74 GW
Total offshore capacity	8.21 GW
New wind power capacity installed	1.96 GW
Decommissioned capacity (in 2018)	0 GW
Total electrical energy output from wind	57.12 TWh
Wind-generated electricity as percent of national electricity demand	16.1%
Average national capacity factor	30%
Target	30 GW offshore by 2020

## OVERVIEW

Last year, the renewable energy share of electricity generation in the United Kingdom climbed to 33.3%; the share was even higher, at 37.1%, in the last quarter [1]. Wind power was the largest contributor of all renewable energy sources due to increased installed capacity and relatively high winds.

Offshore wind power added more than 1.2 GW of capacity, maintaining the U.K.'s leading position in the global market. On the other hand, land-based wind power installations plummeted by nearly 80%; this drop reflects a lack of visibility in policy support and signals that more low-carbon energy is needed to keep the U.K. on track toward its carbon goals [2].

More focus on the long-term renewable energy strategy and the terms which will define the U.K.-EU relationship can increase the investment attractiveness of the sector.

The U.K. continues to focus on realising the aims of the Clean Growth and Industrial Strategy by placing offshore wind power at the top of the agenda. Several R&D programs aspire to bring together members of academia and the wind power industry to seek solutions to challenging industry problems including biofouling, heavy lifting, and subsea inspection, as well as creating research hubs and supporting small and medium-sized enterprises (SMEs) in demonstrating their technologies.

## MARKET DEVELOPMENT

### National Targets & Policies Supporting Development

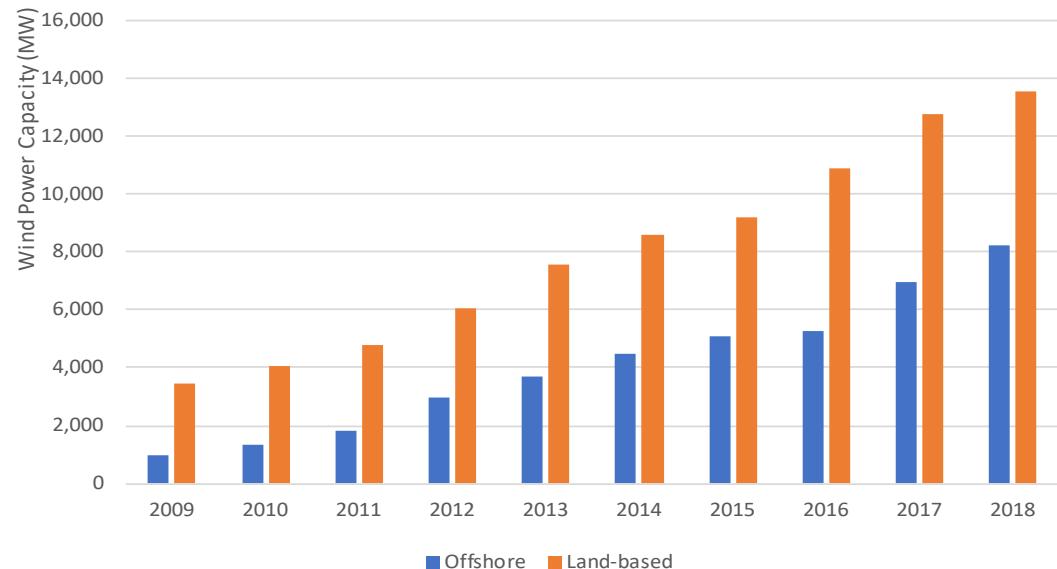
The U.K. drafted its 10-year National Energy and Climate Plan (NECP) for the period from 2021 to 2030 in December 2018, as required for all Member States following the EU's new energy and climate 2030 targets [3]. A final NECP is due to be submitted to the Commission by 31 December 2019 [4].

In July 2018, the U.K. government announced that it will distribute up to 557 million GBP (620 EUR; 711 USD) in subsidies for less-established renewable energy sources (Pot 2) through auctions that will take place every two years beginning in mid-2019 [5]. The next Contract for Difference (CfD) auction is planned for May 2019 and is expected to contract a significant amount of capacity from offshore wind power. During this CfD, developers will be able to bid for contracts in the remote islands for the first time.

Further tenders are expected to follow throughout the 2020s. BEIS announced a draft budget of 60 million GBP (66.8 EUR; 76.6 USD) for the third (2019) CfD auction and set a preliminary capacity cap of 6 GW for projects to be delivered in 2023-2024 and 2024-2025 [6].

The U.K. offshore wind power industry has committed to work with the U.K. government on a transformative Sector Deal which aims to increase skilled jobs by the thousands in coastal areas and support export opportunities [7].

Figure 1. Installed wind power capacity in the UK, 2009-2018  
(Source: BEIS)



## Progress & Operational Details

Wind-generated electricity met approximately 16% of the U.K.'s electricity demand, which remained stable at 354 TWh. This was nearly 2% higher than 2017. However, total indigenous electricity production declined from 339 TWh to 334 TWh in 2018 due to the shift from coal to renewable energy (Figure 1) [8].

In 2018, additional installed capacity and higher wind speeds increased offshore wind power by 28%--from 20.9 TWh in 2017 to 26.7 TWh. [1]. New wind power capacity of 2,121 MW in eight offshore wind farms became operational, while the size of installed wind turbines continued growing. [9] The total offshore wind power capacity was 8.2 GW and the average capacity factor was estimated at 37.1% (Figure 1).

Land-based wind-generated electricity comprised 9.1% of total electricity production, an increase of 4.6% (from 29.1 TWh in 2017 to 30.4 TWh in 2018). This highlights the government's decision to allow onshore wind power companies to bid in the first CfD auction in 2015 while also terminating the Renewable Obligation Certificate (ROC) scheme in 2017, which led to a rush to commission projects in 2017 [1]. The total land-based wind power capacity reached 13.5 GW and the average capacity factor was estimated at 25.7%.

In September 2018, the world's largest operational offshore wind farm (the Walney Extension, developed by Orsted, PKA, and PFA) opened off the coast of Cumbria. At 659 MW, it surpasses the capacity of the 630 MW London Array (Figure 2) [10]. The 11 most powerful wind turbines were commercially deployed at the European Offshore Wind Deployment Centre (EOWDC) off of the Aberdeen Coast. [11].

## Matters Affecting Growth & Work to Remove Barriers

The Carbon Price Support (CPS) encourages investment in low-carbon energy in the U.K. (excluding Northern Ireland) and has been a key factor in driving coal off the U.K. grid. The government set a Total Carbon Price target (comprised of the CPS plus the price of EU Emissions Trading System [EU ETS] permits) of 24 GBP (27 EUR; 31 USD) per tCO<sub>2</sub>e. This significantly lowers the target from the current 35 GBP (39 EUR; 45 USD) per tCO<sub>2</sub>e.

Although there was no announcement on whether the U.K. would remain in the EU ETS after 2020 if a deal on leaving is reached, the Autumn Budget stated that the U.K. government would introduce a Carbon Emissions Tax to replicate the ETS component if the U.K. leaves the EU and its ETS in 2019 [13-14].

Although the U.K. government committed to accelerating the development of offshore wind power in last year's Sector Deal discussions, new onshore wind installations slowed in 2018. This is likely the result of blocking access to renewable energy support schemes [15]. And while onshore wind power projects over 5 MW in remote islands will be allowed to compete for revenue support in the next CfD auctions, the ability of these projects to compete against offshore wind power and biomass energy is still debatable [8].



Figure 2. Walney Extension (Siemens Gamesa 7-MW turbines)  
(Source: Orsted) [12]

# R,D&D ACTIVITIES

## National R,D&D Priorities & Budget

The U.K. Government has announced an additional 7 billion GBP (7.8 EUR; 8.9 USD) investment in R&D from 2017-2018 to 2021-2022 which will be allocated to BEIS as part of the National Productivity Investment Fund.U.K.[16].

Additionally, the R&D grant increased by 1.6 billion GBP (1.8 billion EUR; 2 billion USD) in the Budget 2018. Both investments will serve to strengthen the U.K.'s global leadership in science and innovation while driving productivity and growth [17].

The United Kingdom Research and Innovation (UKRI), a new Non-Departmental Public Body (NDPB), came into operation on 1 April 2018. UKRI brings together Research Councils, Innovate U.K., and the Research and Knowledge Exchange functions of the Higher Education Funding Council for England (HEFCE) into one organization. [16]

## National Research Initiatives & Results

The Offshore Wind Innovation Hub (OWIH) developed a suite of technical roadmaps for offshore wind energy. These are now complete, with industry and academia participants actively engaged and supportive of the trajectory of technologies across the industry.

Five innovation challenges were launched as part of OWIH, including: removal of biofouling from offshore structures; heavy lifting of electrical equipment in dynamic offshore weather conditions; improving data collection for subsea inspection; and connected data for improved efficiency of bolt-torqueing operations offshore.

The Supergen Wind Hub (2014-2019) is an ongoing 2.9 million GBP (3.2 EUR; 3.7 USD) project funded by the Engineering and Physical Sciences Research Council (EPSRC) which brings together leading U.K. wind-energy academic research groups to form the technology strategy for driving forward U.K. wind energy research [18]. In 2018, deliverables included a roadmap of U.K.-based test facilities for wind technologies, and a report on offshore wind farm maintenance scheduling algorithms based on climate data and damage model predictions [19].

A program of demonstration projects gave SMEs access to the ORE Catapult's Levenmouth Demonstration Offshore Wind Turbine (LDT) during 2018. The University of Strathclyde was engaged to support research in the development of innovative products.

Eight SME technologies were successfully demonstrated at LDT and two PhD projects were supported. This activity supports SMEs in commercializing their products, securing work, and growing their businesses. ORE Catapult also developed a robust process for assessing an SME's readiness for demonstration of their technology.

## Test Facilities & Demonstration Projects

Vattenfall's 300 million GBP (334 EUR; 383 USD) European Offshore Wind Deployment Centre (EOWDC) officially opened in 2018. At 93.2 MW, it is Scotland's largest offshore wind power testing and demonstration facility. Two V164-8.8MW turbines and nine V164-8.4MW turbines, the most powerful in the market, were installed with suction-bucket jacket foundations. The EOWDC has been awarded up to 40 million EUR (45 GBP; 51 USD) in funding from the EU and is supported by Aberdeen Renewable Energy Group (AREG) [20].

The eGrid facility installed at ORE Catapult is one of the world's most advanced grid emulation systems. The 18-MVA system allows clients to simultaneously test mechanical and electrical systems to evaluate electrical performance, gain critical performance data, and achieve grid-compliant assurance. eGrid replicates AC grid voltage, current, frequency, and power balance, allowing the simulation of abnormal conditions that wind and tidal turbines might experience in the field. The system provides a platform for electrical power-quality research and testing in a controlled environment.

GE Renewable Energy and ORE Catapult signed a five-year research and development agreement to test and develop next-generation offshore wind technologies. Haliade-X 12 MW OWT and existing Haliade 150-6MW will undergo advanced test and demonstration programs that accurately replicate real-world operational conditions to enhance performance and reliability (Figure 3). Testing will take place at ORE Catapult's 15-MW power train test facility in Blyth, Northumberland.

## Collaborative Research

The NeSSIE project (2017-2019) seeks to deliver new business and investment opportunities in corrosion solutions and new materials for offshore energy installations in the North Sea. Eight partners from five countries participated in the 860,000 GBP (958,000 EUR; 1,097,000 USD) project, which resulted in two reports and a roadmap.

Participants investigated the economic potential of anticorrosion solutions, the state of the art of the development of new materials in the offshore renewables market, and the development of high-value manufacturing opportunities for anti-corrosion solutions. The consortium also launched three stages of competitions to connect project developers with innovative supply-chain companies in the offshore wind energy sector across Europe. The NeSSIE project is co-funded by the European Maritime and Fisheries Fund (EMFF) [21].

U.K. engagement in IEA Wind TCP tasks includes: Task 11 Base Technology Exchange; Task 25 Design and Operation of Energy Systems with Large amounts of Variable Power; Task 26 Cost of Wind Energy; Task 30 Offshore Code Comparison Collaboration Continued, with Correlation; Task 32 Wind Lidar Systems for Wind Energy Deployment; Task 34 Working Together to Resolve Environmental Effects of Wind Energy (WREN); Task 36 Forecasting for Wind Energy; and Task 37 Wind Energy Systems Engineering: Integrated Research, Design and Development [22].

## IMPACT OF WIND ENERGY

### Environmental Impact

In 2018, electricity consumption remained stable (at 301 TWh) as compared to the previous year, maintaining the 56 TWh reduction since its peak in 2005 [23]. The U.K. showed the highest reduction of electricity consumption in west Europe since 2010 [24]. In addition, U.K. statistics reveal that total electricity production reached a 25-year low last year (at 334 TWh) mainly due to economic restructuring and improved energy efficiency [25].

Renewable energy supplied 33% of electricity, while coal provided just 5% of total U.K. power. Installed renewable energy capacity surpassed 44 GW, marking a new green milestone [1]. The annual average share of wind energy was 51.4% of all renewable energy generation, with a high share of 61.3% in the first quarter of 2018.

There was a 3% reduction in the total U.K. carbon emissions last year; 10% of the reduction from the power sector was driven by the gradual closing of coal-fired plants [26]. Overall, U.K. CO<sub>2</sub> emissions were 38% lower than 1990 levels [27]. The annual emissions savings attributed to wind energy are estimated at approximately 24.6 million tons of CO<sub>2</sub>.

### Economic Benefits & Industry Development

Offshore and land-based wind power contributed 42% to the renewable energy turnover in 2017. Offshore wind was the bigger contributor with 7,200 employees and a turnover of 3.6 billion GBP (4 billion EUR; 4.6 billion USD), which has increased by 35.9% since 2016.

Similarly, land-based wind power accounted for 5,300 employees and 2.8 billion GBP (3.1 billion EUR; 3.6 billion USD) turnover, dropping by 15.1% in 2017. This was driven primarily by a decrease in the turnover of manufacturing and construction industries, including decreasing installation of wind turbines and the cut in the Feed-in Tariffs (FITs) scheme. Wind exports showed an increase reaching 524 million GBP (584 million EUR; 669 million USD) in 2017 which is attributed to the fast-growing offshore wind sector [28].

## NEXT TERM

The offshore wind Sector Deal published in March 2019 places offshore wind power at the heart of the U.K.'s future clean-energy strategy, providing industry with the long-term confidence to invest 48 billion GBP (53.5 billion EUR; 61.2 billion USD) in infrastructure and deliver one third of the U.K.'s electricity needs by 2030 [29].

A 100 million GBP (111 million EUR; 128 million USD) investment in a new industry program, the Offshore Wind Growth Partnership (OWGP), will help U.K. companies seeking

to grow their business in the global offshore wind energy market, as well as more broadly encourage the development of skills for the sector. [29]

Lastly, 26.6 million GBP (29.6 million EUR; 33.9 million USD) will be invested in 15 projects aimed at developing robots for a variety of industrial purposes, including maintenance of offshore wind power farms and repairing underground pipe networks [30].



Figure 3. GE's Haliade 150-6 MW nacelle arrives in ORE Catapult's Blyth facility (Source: ORE Catapult)

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# United States



**Table 1. Key Statistics 2018, U.S.**

Total (net) installed wind power capacity	96,433 MW
Total offshore capacity	30 MW
New wind power capacity installed	7,588 MW
Decommissioned capacity (in 2018)	127 MW
Total electrical energy output from wind	275 TWh
Wind-generated electricity as percent of national electricity demand	6.6%
Average national capacity factor	33.9%
National wind energy R&D budget	92 mil USD; 80 mil EUR
Target	Land-based: Reduce LCOE to 0.06 USD/kWh (0.057 EUR/kWh) without incentives by 2030 Offshore: Reduce LCOE to 0.10 USD/kWh (0.095 EUR/kWh) by 2030

## OVERVIEW

In 2018, wind energy grew 8% and provided 6.6% of U.S. annual net energy generation [1, 2]. Low cost wind energy was delivered to regions of the country with very good wind resources and transmission access—in some cases under 0.02 USD/kWh (0.017 EUR/kWh) with the Production Tax Credit (PTC) incentive. More than 96 GW of land-based wind power capacity is deployed across 41 states, Guam, and Puerto Rico, supporting more than 114,000 U.S. jobs and providing enough electricity to power roughly 30 million U.S. homes [1].

The United States is a global leader in distributed wind power capacity and has more than 83,000 distributed wind turbines

deployed across all 50 states, Guam, Puerto Rico, the U.S. Virgin Islands, and Washington, D.C. [3]. A record volume of power purchase agreements (PPAs) were signed in 2018, driven by brand-name corporations and nonutilities, such as AT&T, Facebook, Royal Caribbean, T-Mobile, and Walmart [1].

Offshore wind took a large leap forward, driven by falling offshore wind turbine prices in the United States, accelerated federal offshore wind lease auctions, and state procurement mechanisms [4]. Continued wind energy science and technology innovation offers the potential for wind energy to add substantially more value nationwide.

## MARKET DEVELOPMENT

### National Targets & Policies Supporting Development

In 2018, the remaining federal Investment Tax Credit (ITC) policy, as well as state procurement policies, drove interest in offshore wind energy investment. States with stronger standards tended to have more renewable energy development [5].

In April, the U.S. Department of the Interior's Bureau of Ocean Energy Management (BOEM) announced the sale of three offshore wind lease areas near Massachusetts; in December, the competitive auction to lease these areas generated 135 million USD (118 million EUR) each—far surpassing the previous lease record of 42.5 million USD (37.1 mil EUR) [6, 7].

### Progress & Operational Details

Transmission expansion was a key topic for the U.S. wind power industry as demand from corporate buyers, such as Google, GM, and Nike, increased significantly. A record volume of PPAs—4,203 MW—were signed in 2018, driven by these nonutility buyers [8].

Another trend in the U.S. wind power industry was increased height. Taller hub heights and increased rotor diameters allow turbines to reach stronger, steadier winds, making them more productive while reducing project costs [9]. Applications filed with the U.S. Federal Aviation Administration (FAA) in the last two years indicate a trend toward taller tip heights, surpassing the 500-ft (152-m) "soft cap." Over 40% of FAA applications filed in 2018 were for tip heights taller than 500 feet [10].

A 2018 report from the Pacific Northwest National Laboratory (PNNL) was the first of its kind to benchmark costs for distributed wind projects installed in the United States. The research team found that the average cost of a representative residential system in its sample was 11,953 USD/kW (10,434 EUR/kW), whereas a commercial system cost, on average, 7,389 USD/kW (6,450 EUR/kW) [11].

## Matters Affecting Growth & Work to Remove Barriers

Investment in U.S. wind energy has totaled more than 142 billion USD (124 billion EUR) since 2006, demonstrating wind energy's increasing role in the U.S. electricity generation portfolio [1]. However, in 2018, some investors still considered wind energy risky. To address this, the National Renewable Energy Laboratory (NREL) led a DOE-funded effort called Performance, Risk, Uncertainty, and Finance (PRUF), which focused on the mitigation of risk related to the investment in and financing of wind energy projects. Through activities such as PRUF, a broad and widely understood assessment of wind energy project risk among developers, investors, and policymakers can help to expand the potential pool of industry investors and drive down the cost of capital for the wind energy industry [12].

The U.S. offshore wind industry faces unique challenges:

- Varying U.S. conditions on the seabed and deeper waters could be better suited to jacket, suction-bucket, and floating foundation types [13].
- The 15-GW pipeline of projects taking shape on the U.S. East Coast will require developing a robust, competitive, local supply chain [14].
- Federal laws restrict the use of foreign vessels in U.S. waters. In particular, the Merchant Marine Act of 1920, commonly referred to as the Jones Act, generally requires that all vessels transporting "merchandise" between two points in the United States be U.S. built, U.S. flagged, U.S. owned, and predominantly crewed by U.S. citizens or residents. In 2018, there were no American vessels capable of installing offshore wind turbines [15].

## R,D&D ACTIVITIES

### National R,D&D Priorities & Budget

DOE's Wind Energy Technologies Office (WETO) invests in energy science research and development activities that enable the innovations needed to advance U.S. wind power systems, reduce the cost of electricity, and accelerate the deployment of wind power.

In 2018, WETO focused its 92 million USD (80 million EUR) budget on these key areas [16]:

- Improving the performance and reliability of next-generation wind plants by investigating systems-level interactions influenced by atmospheric conditions, variable terrain, and machine-to-machine wake interactions
- Lowering wind energy costs and improving performance through fundamental R&D in controls, sensors, algorithms, materials, and manufacturing
- Developing solutions to key barriers to wind siting and development—resolving grid integration, radar interference, and environmental challenges
- Educating and training a 21st-century workforce by focusing on science, technology, engineering, and math activities that support development of a robust domestic wind energy industry
- Managing and modernizing R&D infrastructure by maintaining, operating, and upgrading the National Wind Technology Center (NWTC) and Scaled Wind Farm Technology facilities

Priority R,D&D projects funded in 2018 included:

- Releasing a competitive solicitation to develop a lightweight drivetrain that contributes to turbine scaling beyond 10 MW [17]
- Creating the Big Adaptive Rotor initiative to develop rotors with larger swept area and improved energy capture for tall wind applications
- Releasing a competitive solicitation to conduct advanced wind R&D to reduce costs and environmental impacts
- Forming a consortium to fund offshore wind research and technology to address unique U.S. challenges [18]

### National Research Initiatives & Results

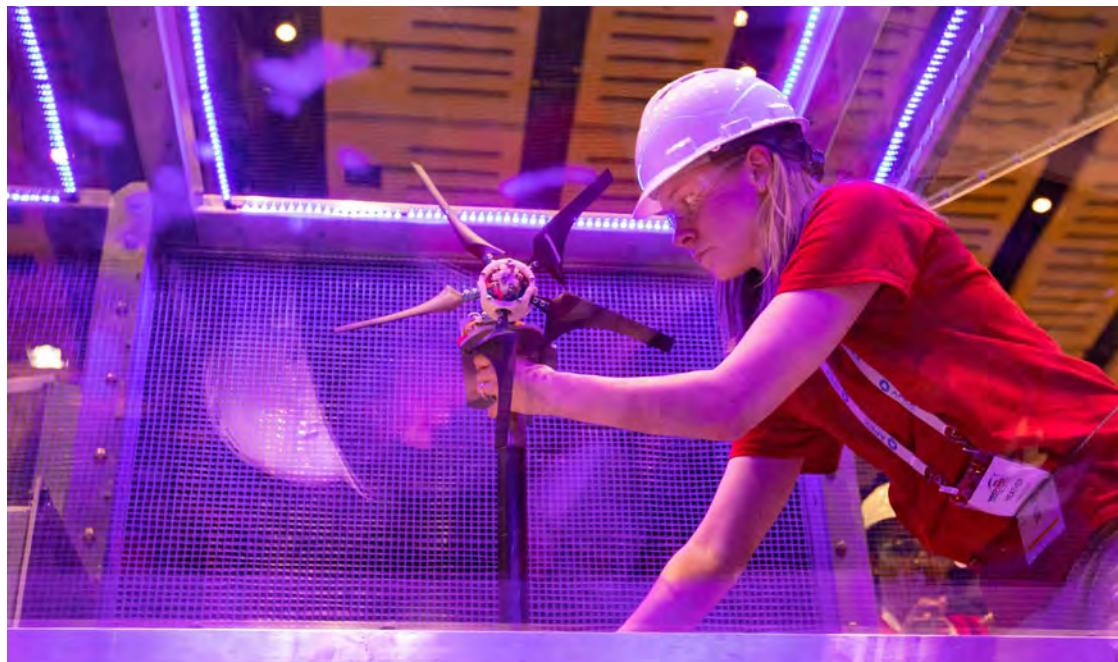
DOE's Lawrence Berkeley National Laboratory, the U.S. Geological Survey (USGS), and the American Wind Energy Association (AWEA) released the United States Wind Turbine Database (USWTDB) and, to access the public data set, the USWTDB Viewer [19]. These tools allow federal agencies to share data to properly develop and plan around wind projects, including the potential impacts on defense and civilian radar systems [20].

In partnership with the National Oceanic and Atmospheric Administration (NOAA), DOE's second Wind Forecast Improvement Project generated one of the most comprehensive meteorological data sets collected in complex terrain [21].

Figure 1. Two cameras equipped with ThermalTracker software designed to capture the flight patterns of birds and bats and provide more accurate data about their behavior around offshore wind turbines. (Photo courtesy of PNNL)



Figure 2. A student conducts turbine performance testing at the DOE Collegiate Wind Competition 2018. (Photo by Werner Slocum/NREL)



The collaborative team developed physical modeling methods and atmospheric theories that will improve forecasts in areas of complex terrain, where wind circulation and flow make predictability challenging, and enhance the fundamental capabilities of NOAA models for weather prediction throughout the United States.

### Test Facilities & Demonstration Projects

To improve the reliability of wind power, NREL developed an advanced validation and demonstration platform using the laboratory's Controllable Grid Interface. This new platform will:

- Further real-time control of wind power, energy storage, and solar photovoltaic
- Enhance local and wide-area systems stability
- Give grid operators the information they need to integrate large amounts of variable wind- and solar-generated electricity into power systems while simultaneously providing the essential reliability of services that enable a more robust power system

Two offshore wind power advanced-technology demonstration projects continued to develop in 2018. The Lake Erie Energy Development Corporation's Icebreaker Project plans to install six, 3.45-MW, direct-drive turbines on mono-bucket foundations off the coast of Cleveland, Ohio, becoming the first freshwater offshore wind project in North America [22, 23]. DOE initiated the National Environmental Policy Act process for this project in 2016 and published the Final Environmental Assessment in 2018.

The New England Aqua Ventus I project, led by the University of Maine, will be a floating offshore wind plant using concrete, semisubmersible foundations in deep waters off Monhegan Island, Maine [22, 24]. DOE initiated the Environmental Assessment scoping process in 2017.

At NWTC, the USGS began field research on two projects. One explores whether illuminating a turbine with dim ultraviolet light will prevent bats from mistaking it as a potential food source or place to roost. Another leverages an existing U.S. weather radar network to provide wind power plant operators with information to reduce impacts on wildlife [25].

### Collaborative Research

Through DOE's Atmosphere to Electrons initiative, NREL partnered with NextEra to validate the Wind-Plant Integrated System Design and Engineering Model (WISDEM™) and FLOW Redirection and Induction in Steady State (FLORIS) design tools, which provide a detailed simulation environment for wind power plant operations and optimize collective turbine-steering of wakes within a wind power plant.

NREL also supported collaboration, innovation, and product certification within the distributed wind energy industry through the implementation of DOE's Competitiveness Improvement Project. The project is designed to reduce the levelized cost of energy, increase the fleetwide capacity of distributed wind turbines, increase predictability of energy production, and to certify these technologies. It seeks to reduce the installed cost of distributed wind technologies while increasing each turbine's energy capture [26].

University and laboratory researchers completed and began testing the Segmented Ultralight Morphing Rotor (SUMR) 50-MW offshore wind turbine. The turbine's segmented blades fold together in strong winds, much as the fronds of palm trees bend and yield to the direction of the wind to withstand hurricanes. The research team includes researchers from the University of Virginia (lead), University of Illinois, University of Colorado, Colorado School of Mines, NREL, and Sandia National Laboratories [10, 27].

U.S. representatives participated in research for 14 of the International Energy Agency (IEA) Wind TCP tasks in 2018. Key among these are Task 30 Offshore Code Comparison Collaboration, Continued, with Correlation (OC5); and Task 34 Working Together to Resolve Environmental Effects of Wind Energy (WREN). U.S. wind energy stakeholders collaborated with many domestic departments and agencies, and engaged with international stakeholders through the IEA Wind TCP, the International Electrotechnical Commission, and other partnerships.

## IMPACT OF WIND ENERGY

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### Environmental Impact

U.S. national laboratories and industry partners continued their research on wind energy impacts in 2018. PNNL researchers devised a novel way to integrate stereo vision into software to better “see” the flight patterns of birds and bats. This new 3-D flight tracking in real-time capability (called ThermalTracker) will enable scientists to better identify animal species and flight patterns around offshore wind turbines [28].

More than 25 U.S. wind industry companies backed a new fund to facilitate research that speeds development and deployment of innovative solutions related to wind and wildlife. The Wind Wildlife Research Fund will be housed within the American Wind Wildlife Institute, an independent nonprofit created by stakeholders in the wind energy industry, conservation, and science communities to better understand wind energy’s risks to wildlife and to create solutions [29].

In 2018, 275 million MWh of wind-generated electricity represented 6.6% of total U.S. net electricity generation, exceeded in the renewables sector only by conventional hydroelectric generation [30]. This displaced approximately 386 million pounds of sulfur dioxide and 258 million pounds of nitrogen oxide emissions. Wind power also saved approximately 100 billion gallons of water that would otherwise have been used to cool thermal power plants [1].

### Economic Benefits & Industry Development

The U.S. wind industry invested 12 billion USD (10.5 billion EUR) in new wind projects, provided more than 1 billion USD (0.87 billion EUR) in tax and lease payments to state and local governments and landowners, and employed more than 114,000 workers in 2018 [1, 31].

In 2018, the U.S. offshore wind power industry took a large leap forward as commercial-scale projects were competitively selected in three East Coast states, primarily driven by state procurement mechanisms and competitive solicitations [4]. A 2018 report by Lawrence Berkeley National Laboratory found that increasing penetrations of variable renewable energy (VRE) can affect wholesale electricity price patterns and make them meaningfully different from past, traditional price patterns. This research qualitatively describes how various decisions may change with higher shares of VRE and outlines an analytical framework for quantitatively evaluating the impacts of VRE on long-lasting decisions [32].

DOE helped grow the future wind industry workforce and supported wind energy education. The Collegiate Wind Competition provides university students with real-world experience as they prepare to enter the wind industry [33]. In 2018, DOE announced a partnership with REpowering Schools to expand science, technology, engineering, and math curricula and to help students explore careers in renewable energy [34].

## NEXT TERM

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As projects continue taking advantage of the Production Tax Credit before it expires, 2019 is expected to be a big year for the U.S. wind energy industry [35]. Offshore wind energy has momentum, with 25.5 GW of planned capacity in the development pipeline at the end of 2018 [1]. Significant untapped wind potential exists in every region of the nation, exceeding total U.S. electricity needs.

As part of an “all-of-the-above” national energy strategy, and building on current U.S. wind industry success, federal government R&D investment in opportunities such as offshore and tall wind power could drive U.S. wind technology and siting costs even lower.

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# Appendix A

## IEA WIND TCP EXECUTIVE COMMITTEE 2018

These are the members who served The IEA Wind TCP Executive Committee in 2018. Serving members change occasionally. For the current membership and contact information, visit [www.ieawind.org](http://www.ieawind.org) and select IEA Wind TCP Members.

### 2018 LEADERSHIP

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# Appendix B

## CURRENCY CONVERSION RATES

Country	Currency	1 EUR	1 USD
Austria	EUR	1.000	1.146
Belgium	EUR	1.000	1.146
Canada	CAD	0.640	0.733
China	CNY	0.127	0.145
Denmark	DKK	0.134	0.153
Finland	EUR	1.000	1.146
France	EUR	1.000	1.146
Germany	EUR	1.000	1.146
Greece	EUR	1.000	1.146
Ireland	EUR	1.000	1.146
Italy	EUR	1.000	1.146
Japan	JPY	0.008	0.009
Korea	KRW	0.001	0.001
México	MXP	0.044	0.051
Netherlands	EUR	1.000	1.146
Norway	NOK	0.101	0.116
Portugal	EUR	1.000	1.146
Spain	EUR	1.000	1.146
Sweden	SEK	0.098	0.113
Switzerland	CHF	0.888	1.017
United Kingdom	GBP	1.114	1.276
United States	USD	0.873	1.000

Source: Federal Reserve Bank of New York ([www.x-rates.com](http://www.x-rates.com)) 31-Dec-18

# 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<sub>2</sub>e:** carbon dioxide equivalent

**COE:** cost of energy

**CSP:** concentrating solar power

**DFIG:** doubly-fed induction generator

**DSM:** demand side management

**EC:** European Commission

**EIA:** environmental impact assessment

**ENARD:** Electricity Networks Analysis, Research and Development (an IEA Implementing Agreement)

**EU:** European Union

**ExCo:** Executive Committee (of IEA Wind)

**Feed-in tariffs (FIT):** mandates for utilities to buy the electricity fed into the grid by system owners at a fixed price over the long term. The cost is then redistributed over all electricity customers.

**Flicker:** when the operating turbine blades cast shadows on the observer

**Full load hours:** the (calculated) amount of time the generators would have run at full capacity to produce the electricity they actually generated in the year. A year has 365 days, hence 8,760 potential full load hours.

**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 m<sup>2</sup>)

**tCO<sub>2</sub>-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 of Wind Energy Systems—also known as the IEA Wind Technology Collaboration Programme (IEA Wind TCP)—operates under the auspices of the International Energy Agency (IEA). It is a collaborative venture among 26 contracting parties from 21 Member Countries, the Chinese Wind Energy Association (CWEA), the European Commission, and WindEurope (formerly the European Wind Energy Association) (Table 1) [1].

National governments and international organizations agree to participate in the IEA Wind TCP (formerly referred to as the IEA Wind Implementing Agreement) [2]. Since it began in 1977, participants have developed and deployed wind

energy technology through vigorous national programs and 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 they can participate in the IEA Wind TCP research tasks. The most current contact list of IEA Wind TCP members is available at [community.ieawind.org](http://community.ieawind.org).

**Table 1. Contracting Parties to the IEA Wind TCP in 2018**

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
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 Energia Eólica (CEMIE Eólico)
Netherlands	The Netherlands Enterprise Agency
Norway	1) The Norwegian Water Resources and Energy Directorate (NVE) 2) Research Council of Norway
Portugal	National Laboratory of Energy and Geology (LNEG)
Spain	Energetica Medioambiental y Tecnologica (CIEMAT)
Sweden	Swedish Energy Agency
Switzerland	Swiss Federal Office of Energy
United Kingdom	Offshore Renewable Energy Catapult
United States	US Department of Energy
WindEurope	WindEurope

## THE EXECUTIVE COMMITTEE (EXCO)

The Executive Committee (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. 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&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 2018, Ignacio Martí (Denmark) served as Chair; Stephan Barth (Germany), John Mc Cann (Ireland), Brian Smith (United States), and Jose Manuel Franco-Nava (México) served as Vice Chairs. For 2019, John Mc Cann was elected to serve as Chair; all current Vice Chairs were re-elected, with the addition of Ignacio Cruz (Spain).

**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; 2019-2021)	11
25	Design and Operation of Energy Systems with Large Amounts of Variable Generation	Technical Research Centre of Finland (VTT), Finland (2005-2011; 2012-2014; 2015-2017; 2018-2020)	18
26	Cost of Wind Energy	National Renewable Energy Laboratory (NREL), United States (2008-2011; 2013-2015; 2015-2018; 2018-2021)	9
27	Small Wind Turbines in High Turbulence Sites	CIEMAT, Spain (2012-2017; 2017-2018)	8
28	Social Acceptance of Wind Energy Projects	ENCO Energie-Consulting AG, Switzerland (2007-2011; 2012-2015); IPC, Ireland (2016-2019)	8
29	Analysis of Aerodynamic Measurements	TNO, the Netherlands (2012-2014; 2015-2017; 2017-2020)	9
30	Offshore Code Comparison Collaborative, Continuation with Correlation and unCertainty (OC6)	NREL, United States, and Fraunhofer Institute for Wind Energy and Energy System Technology (IWES), Germany (2010-2013; 2014-2017; 2019-2022)	13
31	International Wind Farm Flow Modeling	CENER, Spain, and NREL, United States (2011-2014; 2015-2017; 2018-2020)	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; 2019-2021)	12
34	Working Together to Resolve Environmental Effects of Wind Energy (WREN)	NREL, United States (2013-2016; 2016-2020)	12
36	Forecasting for Wind Energy	DTU Wind Energy, Denmark (2015-2018; 2019-2021)	13
37	Wind Energy Systems Engineering: Integrated Research, Design, and Development	NREL, the United States (2015-2019)	8
39	Quiet Wind Turbine Technology	DTU Wind Energy, Denmark (2018-2020)	1
40	Downwind Turbine Technologies	Kushyu University, Japan and Wind Energy Institute of Tokyo, Japan (2018-2021)	4
41	Distributed Wind	NREL, United States and Pacific Northwest National Laboratory (PNNL), United States (2019-2023)	10

## Participants

In 2018, there were several personnel changes among the members and alternate members representing their organizations (See Appendix A: IEA Wind TCP Executive Committee 2018). For the latest and most complete ExCo member contact information, visit [community.ieawind.org](http://community.ieawind.org).

All countries with active interest in wind energy are welcome to contact the Chair or Secretary by email at [secretariat@ieawind.org](mailto:secretariat@ieawind.org) and explore participation options.

## Meetings

The ExCo met twice in 2018 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 81<sup>st</sup> ExCo meeting was hosted by the Government of Belgium's Directorate General for Energy. The meeting was held in Ostend, Belgium, from May 14–17, 2018. The 38 participants included ExCo members or alternates from 20 participating countries and sponsor members and observers from Belgium, the Netherlands, and the IEA.

Presentations were given about all 15 active research tasks. The Common Fund audit report for 2017 was approved. The meeting included a technical tour of the offshore-installation construction facilities at the Port of Ostend..

The 82<sup>nd</sup> ExCo meeting was hosted by the U.S. Department of Energy, Wind Energy Technologies Office. The meeting was held in Washington, D.C., United States, on October 15–18, 2018. The 46 participants included ExCo Members or Alternates from 18 participating countries and sponsors; observers from China, Norway, and the United States also participated.

The Common Fund budget for 2019 was approved at the 82<sup>nd</sup> ExCo, with the addition of \$25,000 under special projects to provide funds for overlap and training of the new Secretary. The hosts sponsored a technical tour of the AWEA Offshore Windpower conferences, the offshore wind industry's premiere event hosted by the American Wind Energy Association (AWEA), as well as a tour of the U.S. Capitol.

## Decisions, Publications, and Outreach

In 2018, the IEA Wind TCP ExCo approved one new research task, Task 41 Enabling Wind to Contribute to a Distributed Energy Future, which will formally begin in 2019. Task 27 Small Wind Turbines in High Turbulence Sites concluded at the end of 2018 and the final technical report is expected in 2019.

The ExCo approved extending Task 19 Wind Energy in Cold Climates, Task 26 Cost of Wind Energy, Task 31 International Wind Farm Flow Modeling, Task 32 Wind Lidar Systems, and Task 36 Forecasting for Wind Energy for new three-year terms.

The ExCo also approved Task 30 Offshore Code Comparison Collaboration, Continuation, with Correlation, and unCertainty (OC6) for a four-year term extension and approved Task 37 Wind Energy Systems Engineering for a six-month, no-cost extension.

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 IEA Renewable Energy Working Party (REWP) meetings in March and October 2018. ExCo members presented the IEA Wind TCP's Strategic Communications Plan at the spring REWP meetings and a request for extension for a new five-year term at the fall meeting.

## 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 2017 Annual Report* was published in September 2018 and 1,100 copies of the 2018 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 41<sup>st</sup> IEA Wind TCP annual report, lists accomplishments by the close of 2018. The IEA Wind TCP 2018 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 16 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 2018 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](http://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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## IN MEMORIAM



**Cheolwan Kim**

IEA Wind TCP Executive Committee Alternate Member  
from the Korea Aerospace Research Institute  
on behalf of the Government of Korea from 2010 to 2019





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**Front cover:** Heavy seas engulf the Block Island Wind Farm—the first U.S. offshore wind farm. A project of Deepwater Wind, the 30-MW wind farm located 3.8 miles (6.1 km) from Block Island, Rhode Island in the Atlantic Ocean, came online in December 2016. (Photo by Dennis Schroeder/NREL)

**Inside cover:** Offshore wind farm on the Belgian coast (Photo courtesy of the Government of Belgium)

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# IEA Wind TCP

# 2018 Annual Report

The IEA Wind Technology Collaboration Programme (TCP) is the leading international organization for wind energy research cooperation. For more than 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.

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 2018 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.



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