Technology Collaboration Programme
by iea

IEA Wind TCP

Annual Report

2019

Message from the Chair

JOHN MC CANN

Dear reader,

2019 was a landmark year for environmental activism globally. The school strike for climate movement brought into sharp focus the threat of greenhouse gas emissions, by an age cohort who are increasingly likely to suffer their adverse effects. It provided a lesson, to those who are older and supposedly wiser, that we cannot be complacent about our rate of response to the scientific evidence and put the welfare of future generations at risk. UNESCO summed this up in 2018 in quoting the Indian proverb "We do not inherit the Earth from our ancestors, we borrow it from our children."

2019 was also a year in which many countries reviewed their climate, emissions and renewable energy policies and finalised new post-2020 goals. Along with medium-term 2030 targets, many countries identified a target year by which their economies must become climate neutral. The latter will be extremely challenging and will involve, along with other measures, deploying modern renewable energy technologies, including wind energy, at an unprecedented rate.

> New wind farms now have a lower levelised cost of energy than any form of new fossil fired plant

It is, therefore, good news that the wind energy industry is ready to rise to this challenge. Wind energy is no longer a marginal new entrant in the electricity sector—in the leading countries wind is fast becoming their main source of electricity. New wind farms now have a lower levelised cost of energy than any form of new fossil fired plant. Zero-bid prices, or zero net subsidy, emerged in renewable electricity support schemes a number of years ago for onshore wind and, more recently, for offshore wind. Corporate power purchases agreements with wind farms are also becoming more commonplace. All of these provide evidence of the increasing competitiveness of wind energy, both onshore and offshore.

While a new industry could normally be satisfied with such progress, with the threat of irrevocable environmental damage, we must accelerate the deployment of wind energy beyond limits being experienced in the current market paradigm. This will require technology advances both to continue to reduce the cost of wind energy and to enhance the value of wind energy in the electricity system. Where these goals are met, wind energy can play a role in decarbonising the heat, transport and industrial sectors through electrification.

The IEA Wind Technology Collaboration Programme (IEA Wind TCP) is a uniquely international forum for wind energy research collaboration. Our research collaborations, or "Tasks," have advanced wind energy science, not only in the core wind power technology, but also in related fields such as power systems analysis, ecological impact and sociology. In 2019 we continued to grow our portfolio of Tasks, involving new experts, from diverse disciplines, to identify and address the research challenges to wind energy playing the leading role in the future sustainable power system. We also reached out to wind energy research organisations in new countries to become involved in the IEA Wind TCP collaborative.

2019 was also the first year of a new term for the IEA Wind TCP, with refocused strategic priorities and research areas. We also looked inward to examine our own capability to organise and resource the growing scope of IEA research collaborations in delivering the IEA Wind TCP strategy. We initiated the process of putting in place new Executive Committee structures that will give better direction in implementing our strategy. This will position IEA Wind TCP to continue to deliver high-quality research collaboration and results into the next decade.

Our 2019 annual report provides an overview of our current research collaboration activities and of the status of wind energy policies, deployment and R,D&D in our member countries. In this it is a unique international source of insights and data. I hope that reading it will whet your appetite for becoming involved with our research collaborations.

Yours Sincerely,

John Mc Cann
Chair IEA Wind

PHOTO: COLOURBOX

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2019 IEA Wind Overview

2019 was a good year for wind power. Global wind power installed capacity increased by 60 GW to 650.1 GW. This growth represents a 10% increase in cumulative capacity and 19% increase in yearly added new capacity [1]. Land-based wind power surpassed 600 GW, and, representing a more than 30% increase in annual numbers, a record 6 GW of new offshore wind power brought the cumulative offshore capacity close to 30 GW. Subsidy-free wind power and cost reductions in auctions are increasingly reported. New targets set for 2030 and beyond ensure continued market growth in years to come.

Within IEA Wind member countries, 550 GW of operational wind power capacity generated 1,168 TWh in 2019, meeting 7% of the total electricity demand. Nearly 84% of the world's wind generating capacity—and all offshore capacity—resides in countries participating in IEA Wind. These countries added about 52 GW of capacity in 2019, accounting for more than 85% of worldwide market growth.

Governments continue to set targets for renewable energy sources (RES) and wind energy. To reach these targets, they design market mechanisms and energy policies as well as fund research. In 2019, several countries declared ambitious post-2020 targets, in many cases doubling the wind power capacity from current numbers. Some countries set targets that increase the total capacity fourfold to tenfold, mostly for offshore wind power production. To achieve these new, challenging wind energy targets by 2030, several countries are simplifying authorisation procedures in order to reduce the time it takes to obtain permits for new sites.

2019 also continued the trend of moving from old subsidy schemes to auctions for both land-based and offshore capacity. Performance gains and cost reductions have enabled the construction of new subsidy-free wind power plants. Corporate funding via PPAs (Power Purchase Agreements) for wind energy projects outside of subsidy schemes were reported in Spain, Denmark, and Finland. In Europe, 44% of all PPAs ever in renewable energy, mainly wind, were announced in 2019. China, the Netherlands, the United States, and Norway aim to move to subsidy-free deployment of wind plants after their current subsidy schemes end in 2020 and 2021.

Wind energy installations contributed to a growing industry with benefits for the economy, industry revenues, and direct and indirect job creation. The sector is well-positioned to deliver on its potential in the short term, with green recovery programmes that will boost economies, the industry, and green sector jobs.

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Renewable energy R,D&D public funding constituted only 15% of the 21 billion USD (18.7 billion EUR) in total public energy R,D&D spending. This 15% includes wind energy R,D&D funding, which experienced a small decrease compared to the year before.

The following summary of the Annual Report 2019 presents highlights and trends in deployment and R,D&D wind energy activities from 22 countries as well as the European Union and WindEurope. Data reported in previous IEA Wind TCP documents (1995-2018) are included as background for the evolution of trends. The annual report is freely downloadable at community.ieawind.org

Table 1. Key Statistics of Wind Energy 2019

	IEA Wind Member Countries	Global Statistics
Total installed capacity (land-based and offshore)	549.1 GW	650.1 GW
Total offshore wind power capacity	29 GW	29 GW
Total new wind power capacity installed	51.7 GW	60.4 GW
Total annual output from wind	1,168.4 TWh	1,597.4 TWh
Wind-generated electricity as a % of electric demand	7.1 %	5.9 %

INSTALLATION OF SIEMENS GAMESA 7MW TURBINE AT HORNSEA ONE (PHOTO: ØRSTED)

Progress toward Policy Targets

The 2020 wind deployment targets are nearly fulfilled in most countries, and new targets for renewable energy, including wind power, are being set to meet energy and climate targets for 2030 and beyond.

Record year in wind energy for many countries

All countries reported either increasing deployment numbers or anticipation of more deployment after 2019 (see Appendix Table 4 for additions in 2019, and Table 5 for anticipated build-out).

Wind power capacity installed in 2019 represented 10% of the global cumulative installed wind power capacity [1]. The rate of growth for annual installations increased in 2019, following a couple of steady years. The cumulative 60.1 GW installed globally represented a 19% increase compared to 2018 (Figure 1). China, the United States, and Germany continue to lead in cumulative wind power capacity. As in 2018, China installed more than 40% of the installed capacity of the global wind energy market in 2019, followed by the United States, the United Kingdom, and India. Spain and Germany added more than 2 GW each while Sweden, France, and México each installed more than 1 GW.

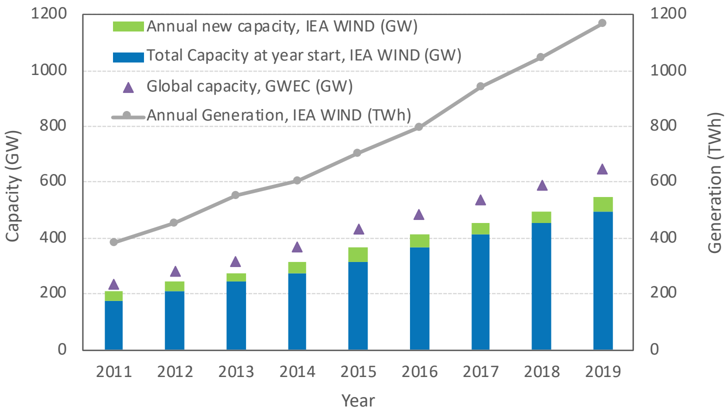


FIGURE 1. ANNUAL NET, NEW, AND CUMULATIVE WIND POWER CAPACITY AND ELECTRICITY PRODUCTION FOR MEMBER COUNTRIES. THE CUMULATIVE GLOBAL CAPACITY IS SHOWN WITH MARKERS.

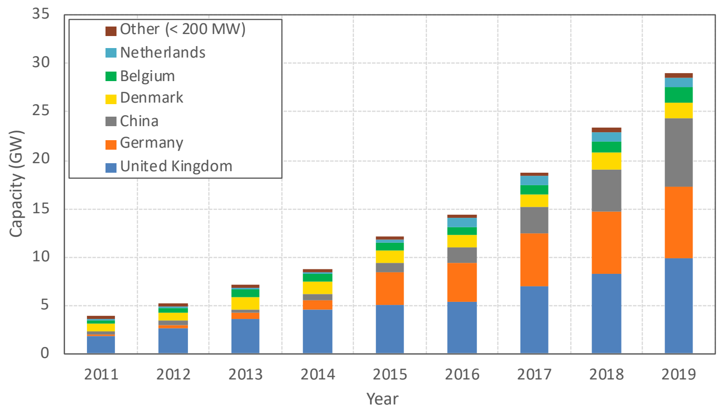


FIGURE 2. THE EVOLUTION OF OFFSHORE WIND POWER INSTALLED CAPACITY.

Key deployment milestones in 2019:

- New records in annual installations were set in China (>26 GW), the United States (>9 GW), Sweden (1.5 GW), México (>1.2 GW), and in Norway and Greece (>0.7 GW).

- For cumulative capacity, China is at 236 GW (of which 210 GW is grid-connected), while Europe and the United States surpassed landmarks of 200 GW and 100 GW, respectively. Ten countries have 10 GW or more of installed wind power capacity (eight IEA Wind TCP members plus India and Brazil). Norway increased the cumulative capacity again by more than 40%, while México, Greece, and Sweden saw increases of 20% or more in 2019 (see Table 2, or the full ranking in appendix Table 6).

- Landmarks in wind-generated electricity were surpassed in China and the European Union (>400 TWh), the United States (>300 TWh), Germany (>125 TWh), Spain (>50 TWh), France (>30 TWh), Sweden (>20 TWh), Italy (>20 TWh), and the Netherlands (10 TWh).

Offshore wind power shows increasing momentum

Offshore wind power installations continued a high growth rate of more than 30% in 2019. Globally, a record of 6.1 GW of new capacity was added, representing 10% of the annual global market and a record 24% of the European market. Cumulative capacity reached a total of 29 GW (Figure 2).

China, the United Kingdom, and Germany led new offshore installations in 2019 (2.5 GW, 1.7 GW, and 1.1 GW, respectively). China, the United Kingdom, and Belgium set new records for annual installed offshore capacity. The United Kingdom, Germany, and Belgium installed more offshore than land-based capacity in 2019.

The United Kingdom leads in cumulative offshore capacity with close to 10 GW installed. Six countries have close to or more than 1 GW of offshore installed wind power capacity (see Figure 2).

New records were also set in offshore power plant size. The United Kingdom's Hornsea One 1.2-GW plant started operation in 2019 and will be fully commissioned in 2020. The average size of newly installed offshore turbines increased to 5.1 MW in 2019, up from 4.9 MW in 2018 (in Europe the average grew to 7.2 MW, up from 6.8 MW the year before).

Floating offshore wind farms continue to advance toward commercial maturity and gain importance in deployment plans. In Portugal, the V164 8.4-MW turbine was used at the Windfloat Atlantic floating wind farm, where the first three-turbine floating wind farm will be commissioned in 2020. The United Kingdom announced a 10 GW floating wind power target in addition to the 30 GW offshore wind power goal in 2030.

> In 2019, wind power produced 7% of the total electricity supply in IEA Wind TCP member countries

Wind power continues to grow in the electricity mix

Wind power continues to steadily increase its share of the electricity mix. In 2019, wind power produced 7% of the total electricity supply in IEA Wind TCP member countries, up from 6.4% in 2018 (Table1). Wind-generated electricity met almost 6% of the world's electricity demand in 2019 (Figure 3).

Key deployment figures for the share of wind power in the electricity mix include:

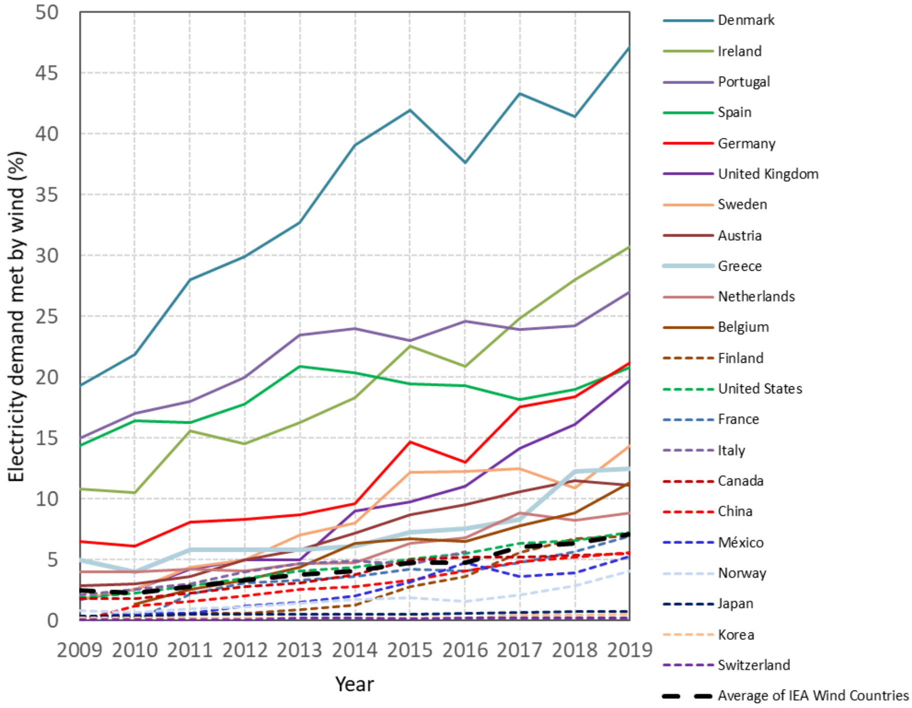


FIGURE 3. NATIONAL ELECTRICITY DEMAND MET BY WIND-GENERATED ELECTRICITY (2019 FIGURES IN APPENDIX TABLE 4).

- Six countries now meet more than 20% of their electricity demand with wind power, and ten countries meet more than 10%. The EU is approaching a 15% share of its electricity demand, with ten Member States achieving wind power shares above 10%
- The highest share, and a new record, was set by Denmark where 47% of the electricity demand in 2019 was met by wind energy, followed by Ireland at 32%, and Portugal at 27%.
- In 2019, Germany, Spain, and the United Kingdom passed, or were close to, the 20% landmark, while Belgium passed the 10% landmark.
- The highest wind shares in one hour, setting new records, were reached in Denmark (160%), Portugal (106%), Spain (76%), and Ireland (close to 70%).
- The highest wind shares in one day were recorded in Denmark (>100%), Portugal (76%), and Spain (48%).

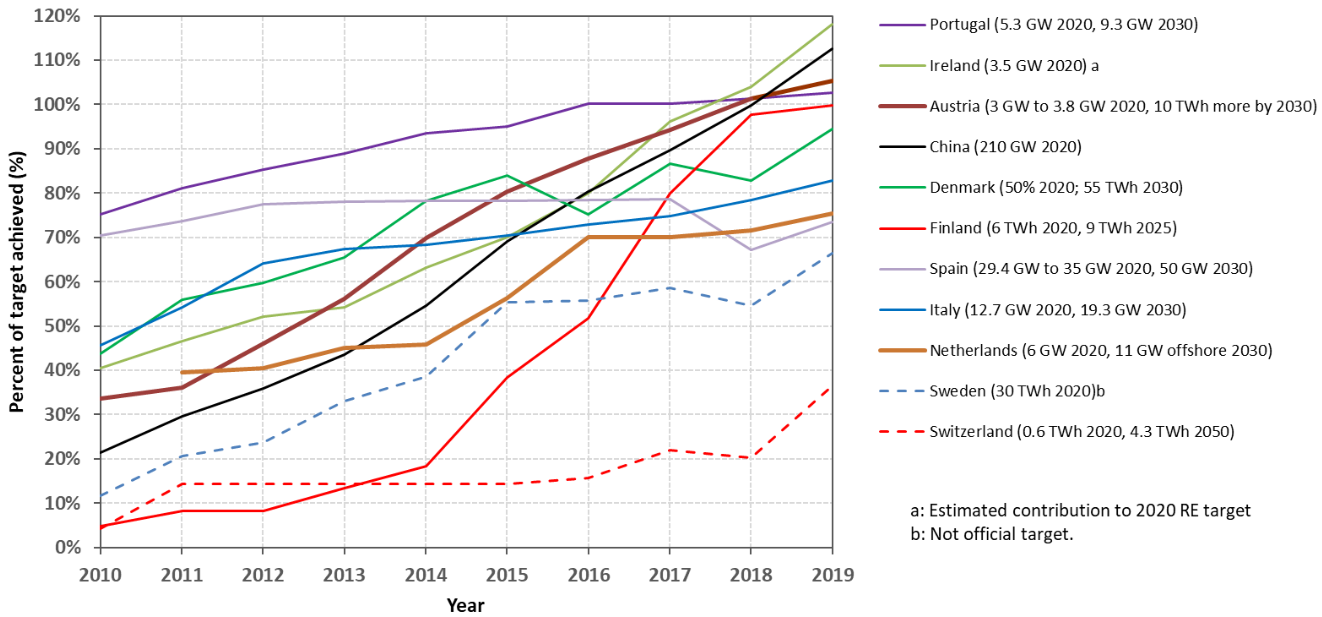


FIGURE 4. PROGRESS IN REACHING 2020 WIND ENERGY TARGETS AND PERCENT OF TARGET REACHED, EXPRESSED IN GW, TWH, OR SHARE OF ELECTRICITY (SEE TABLE 7 FOR TARGETS BEYOND 2020).

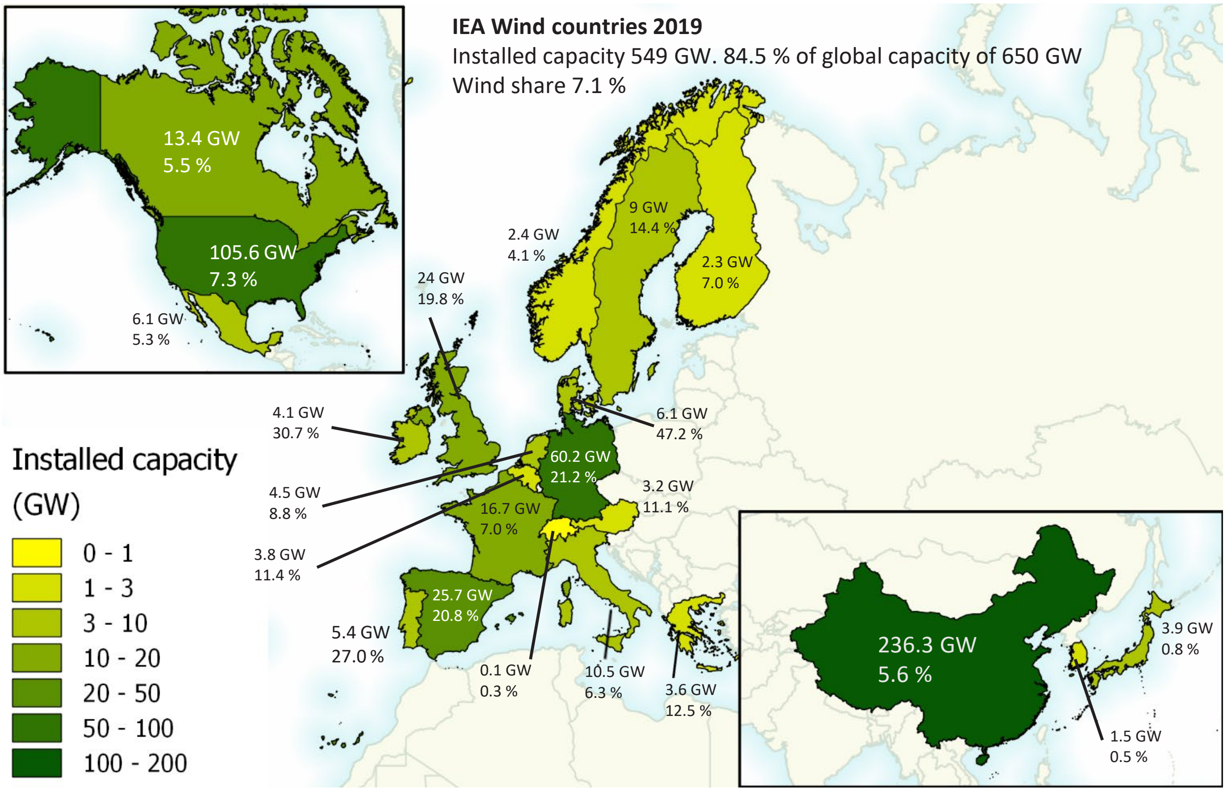


FIGURE 5. TOTAL INSTALLED WIND POWER CAPACITY .

New ambitious policy targets – doubling wind power capacity by 2030

Wind energy is a key contributor to the coming energy transformation, reducing CO_2 emissions significantly. Most IEA Wind TCP member countries are progressing toward their 2020 wind power deployment targets as expected. On average, countries had fulfilled 80% of their targets by 2019 (Figure 4).

In Europe, National Energy and Climate Plans (NECP) for 2021 to 2030 are required in order to meet the EU's new energy and climate targets for 2030. These targets include reaching a 32% RES share of total energy consumption. Several countries have set detailed new targets for wind energy. These goals will double the current land-based wind power capacity by 2030 in Austria, Greece, Italy, Spain, and Portugal. For the first time in Italy, the NECP published in 2019 includes offshore wind power plants to reach the 2030 power capacity.

> In Europe, National Energy and Climate Plans (NECP) for 2021 to 2030 are required in order to meet the EU's new energy and climate targets for 2030

In Denmark, France, and Ireland, this land-based wind power target is exceeded by even higher targets for offshore wind power capacity: in Denmark the new goals include a fivefold increase of offshore wind power capacity while France set a target of 2.4 GW by 2023 and 5.2-6.2 GW by 2028, and Ireland set a first target of 3.5 GW. In the United Kingdom, the new target of 40 GW of offshore wind power capacity equals a fourfold increase while the Netherlands' offshore target is tenfold the current capacity. In Germany, targets to increase offshore wind power capacity to 20 GW by 2030 and 40 GW by 2040 is expected to be approved soon.

Countries in Asia are also targeting significant offshore wind power capacity growth. Korea announced ambitious offshore wind power targets equal to tenfold the current capacity. In Japan, the offshore planning process is advancing, increasing available sites and revealing huge potential with more than 12 GW in offshore wind projects planned for the near future. In the United States, more than 21 GW of offshore wind power is in various stages of development off the East Coast and in the Great Lakes regions. The current national targets established by IEA Wind member governments for renewable energy and wind energy are listed at the end of this chapter in Table 7.

Beyond 2030, policy discussions focus on net-zero emission energy systems with deep de-carbonisation through electrification. In 2019, Europe adopted a new growth strategy, outlined in the European Green Deal, which includes a long-term vision of climate neutrality by 2050. Some countries have announced even more ambitious timetables: Austria aims to achieve carbon-neutral energy systems by 2040, Finland by 2035, and Sweden by 2045. Austria has also set a 100% renewable electricity target for 2030, and Sweden for 2040.

Performance Gains from Wind Technology Improvements

Wind power technology trends toward larger turbines, increased capacity factors, and cost reductions continued in 2019. The average installed capacity of new turbines in IEA Wind TCP member countries surpassed 3 MW. In offshore applications, 7- to 8-MW turbines are increasingly common. Wind Power is increasing its contribution to grid support services.

Turbines continue to increase in size

Wind turbines continue to increase in both height and capacity in reporting countries. According to GWEC numbers, the average rated capacity for new turbines installed in 2019 surpassed 2.75 MW. In the past ten years, the average rated capacity has grown by 1.2 MW—a 72% increase [7].

Table 2 (next page) shows wind power rankings for both new capacity and total capacity in reporting countries. The rated capacity of new turbines in member countries reporting shows the trend toward increasing size (Figure 6). In Finland, the average size of all new turbines in 2019 was a record 4.3 MW. Belgium and Norway also reached an average size of more than 4 MW. Offshore turbine sizes are increasing even more than land-based ones: the United Kingdom reports that most offshore wind power plants used 7-MW turbines in 2019, while Belgium reached an average of 8.4 MW for offshore turbines (Appendix Table 8).

Turbine towers reaching greater heights are also able to access better wind resources. In Finland, 175-m towers were deployed in one wind farm erected in 2019.

Improved technical performance leads to higher capacity factors

Technology advancement with higher turbines and longer blades drives the long-term trend of improved performance. Task chapters related to technological advancements include: chapter 29 on aerodynamics; chapters 30, 32, and 37 on model tool development; and chapter 43 on digitalisation.

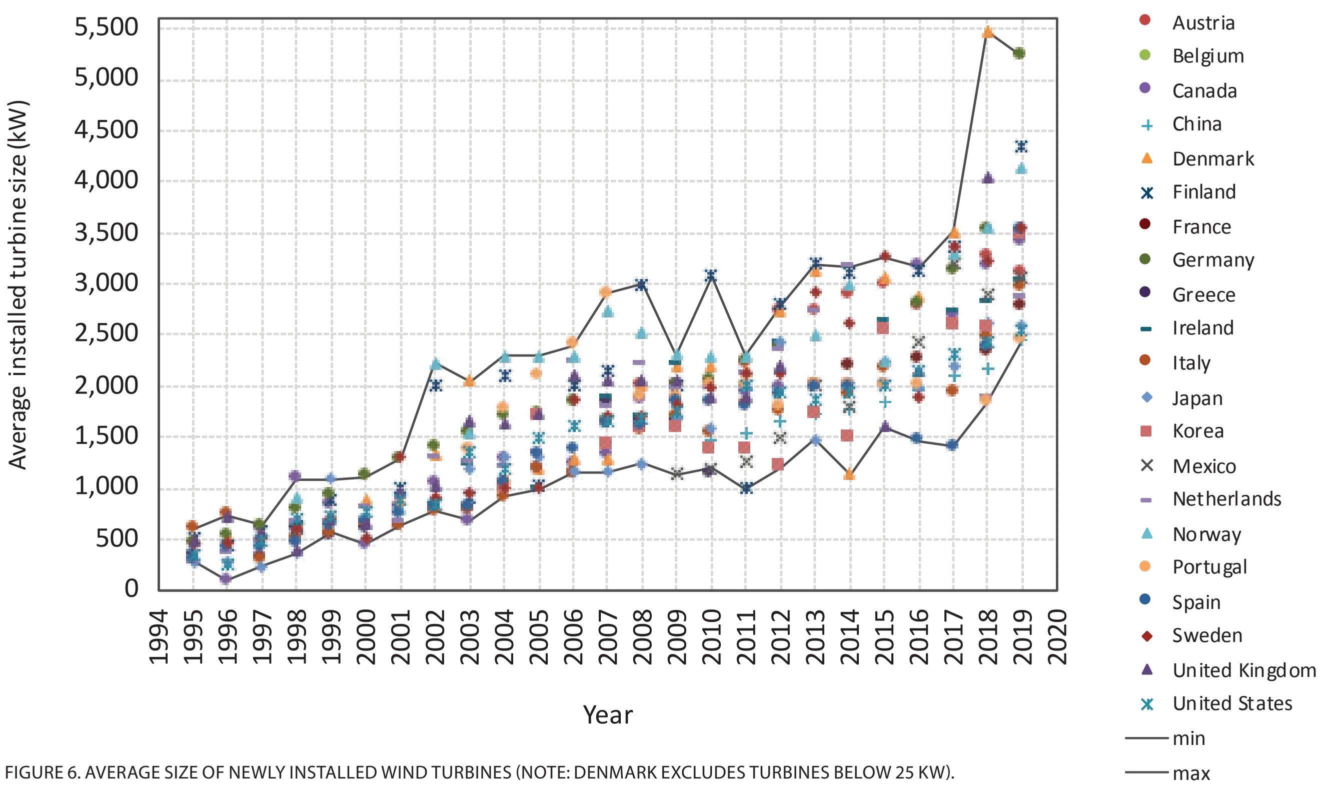


FIGURE 6. AVERAGE SIZE OF NEWLY INSTALLED WIND TURBINES (NOTE: DENMARK EXCLUDES TURBINES BELOW 25 KW).

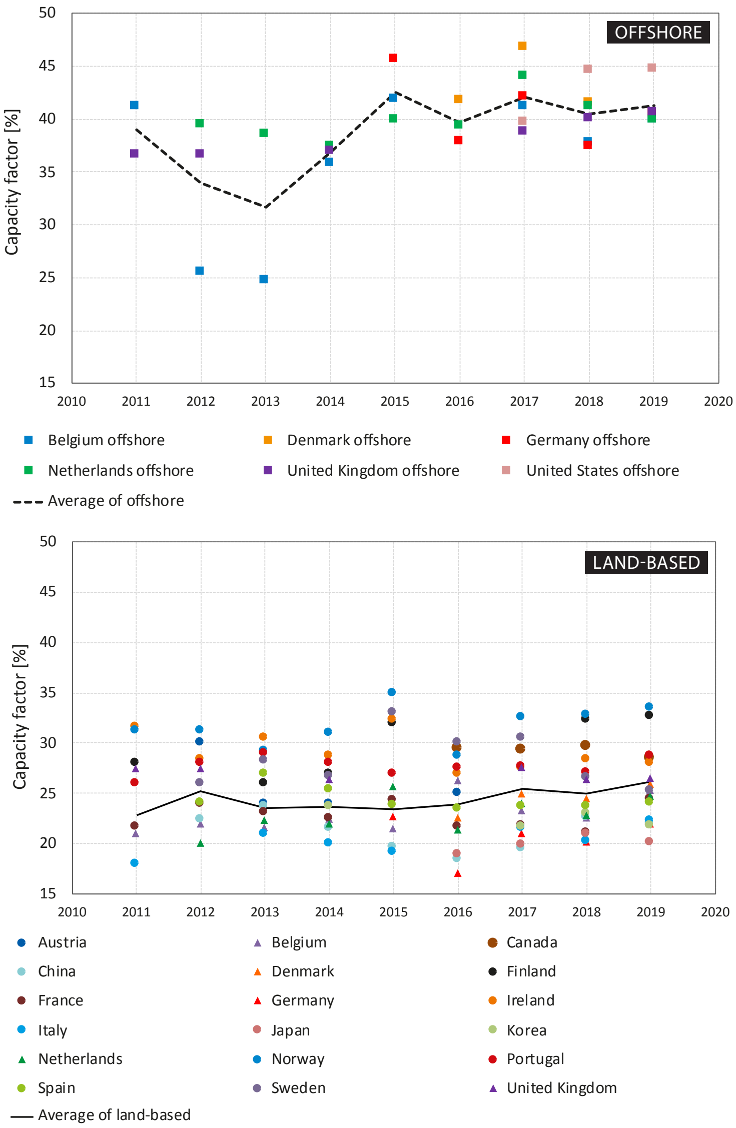


FIGURE 7. REPORTED CAPACITY FACTORS (AVERAGE WIND POWER OUTPUT) BY COUNTRY FOR OFFSHORE AND LAND-BASED WIND POWER GENERATION. THESE FIGURES INCLUDE ESTIMATED DATA FOR 2017-2019 FOR THE COUNTRIES THAT DO NOT REPORT THE CAPACITY FACTORS AS THE TOTAL WIND POWER GENERATION DIVIDED BY THE AVERAGE INSTALLED CAPACITY OF THE YEAR'S BEGINNING AND END.

On average, land-based wind power capacity factors increased slightly as compared to previous years (Figure 7). The highest capacity factors in 2019 were reached in México (35%) and the United States (34%), with Norway, Finland, Belgium, Denmark, and the United Kingdom at more than 30% average capacity factor for their wind power fleet generation. Offshore wind power capacity factors show a good performance of 40-45%, with fluctuations following the pattern reported in the wind resource yearly wind index. The 2019 wind power index showed close to average wind resources for North Europe and above average in Portugal (Figure 8).

Progress toward cost reduction targets

The wind power industry continues to improve its competitiveness. In Norway, the levelized cost of energy (LCOE) of wind energy in 2019 reached an average record low of 31.8 EUR/MWh (35.7 USD/MWh). The average cost of land-based projects reported from IEA Wind member countries was 1,181 EUR/kW (1,326 USD/

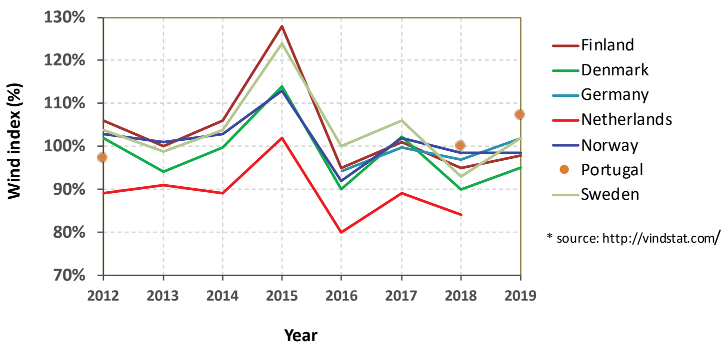


FIGURE 8. WIND RESOURCES REPORTED AS WIND (PRODUCTION) INDEX, OR A MEASURE OF HOW MUCH THE WIND HAD BLOWN MORE OR LESS THAN EXPECTED OVER A GIVEN PERIOD.

Table 2. Top Ten Wind Power Capacity Rankings: Capacity, Percent Increase, Relative to Country Size and Average Turbine Size

	Cumulative Capacity (end of 2019)		New Capacity (2019)		Increase in Cumulative Capacity (2019)		Capacity Relative to Country Size		Average Capacity New Land-based Turbines		Average Capacity All Turbines	
	Country	MW	Country	MW	Country	%	Country	kW/km²	Country	MW	Country	MW
1	China	236,320	China	26,785	Norway	45%	Germany	170	Finland	4.34	Norway	3.06
2	US	105,591	US	9,137	México	26%	Denmark	140	Norway	4.13	Finland	3.03
3	Germany	60,840	Spain	2,243	Greece	25%	Belgium	125	Sweden	3.55	Austria	2.36
4	Spain	25,704	UK	2,205	Sweden	21%	Netherlands	109	Spain	3.54	Sweden	2.19
5	UK	23,975	Germany	2,092	Belgium	16%	UK	99	Korea	3.47	Korea	2.16
6	France	16,654	Sweden	1,588	Korea	15%	Portugal	59	Canada	3.41	México	2.14
7	Canada	13,413	France	1,419	Ireland	14%	Ireland	59	Germany	3.32	France	2.09
8	Italy	10,513	México	1,281	China	13%	Spain	51	Austria	3.10	Switzerland	2.03
9	Sweden	8,984	Norway	785	Finland	12%	Austria	38	México	3.06	Canada	1.98
10	México	6,125	Greece	725	UK	10%	Italy	35	Ireland	3.05	Netherlands	1.96

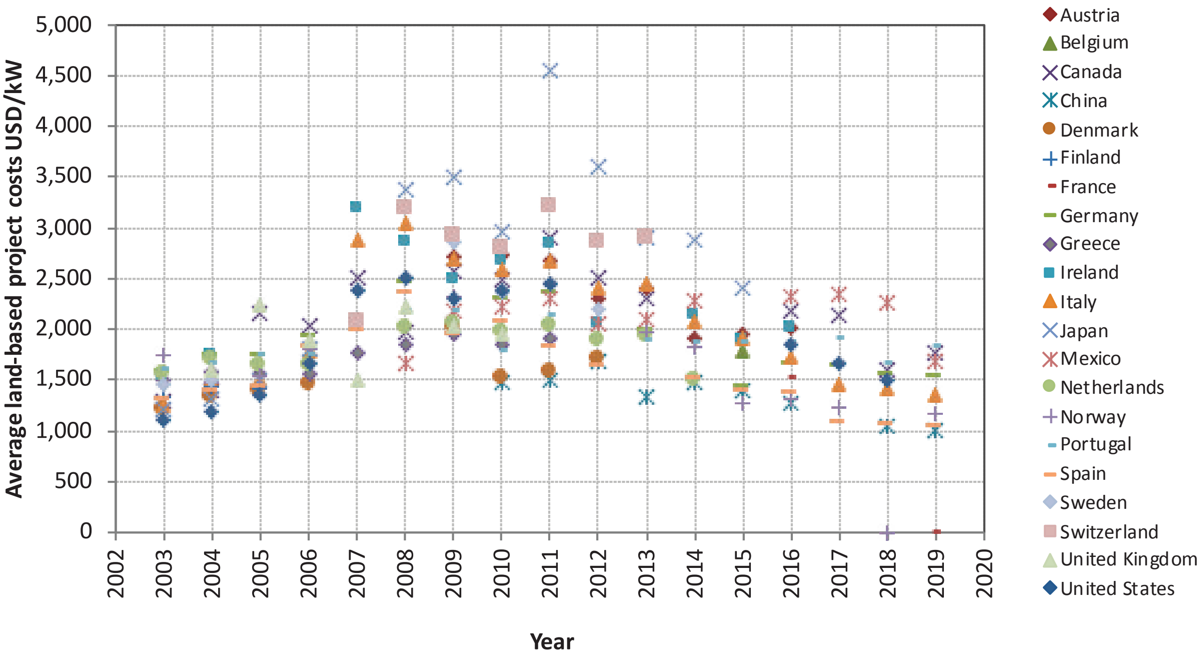


FIGURE 9. LAND-BASED WIND POWER PROJECT COST HISTORY FROM REPORTING IEA WIND TCP COUNTRIES

kW) in 2019 (Figure 9, and Appendix Table 9). Project costs have decreased by 36% since their peak in 2011 (Task 26 Phase 3 Final Technical Report, April 2019).

The shift from fixed guaranteed price support to tendering has prompted increasingly competitive prices for wind energy. Decreasing auction prices have been reported across IEA Wind member countries since 2017, when México and Canada reached record-low prices of 14.2 EUR/MWh (16.3 USD/MWh) and 23 EUR/MWh (26 USD/MWh), respectively.

> The shift from fixed guaranteed price support to tendering has prompted increasingly competitive prices for wind energy

In Spain, bids have been as low as 33 EUR/MWh (38 USD/MWh), the minimum allowed under the Spanish system. In Germany, the record low bid was 39.6 EUR/MWh (45 USD/MWh). In 2019, all Finnish technology-neutral tender winners were wind power plants with average subsidy of 2.5 EUR/MWh EUR/MWh, payable only when the spot price is less than 30 EUR/MWh. In Greece, the auction prices decreased from 69.53 EUR/MWh (78.08 USD/MWh) (July 2018) to 57.74 EUR/MWh (68.84 USD/MWh) (Dec. 2019, lowest bid 55.8 EUR/MWh (62.22 USD/MWh)). This is lower than the wholesale price of electricity in Greece, which was 63 EUR/MWh (40.4 USD/MWh) in 2019.

In France, for the three land-based wind tenders in 2019 which totalled nearly 1200 MW, average prices were 65.4 EUR/MWh (73.4 USD/MWh), 66.9 EUR/MWh (75.1 USD/MWh) and 63 EUR/MWh (70.7 USD/MWh). This is a more than 20% price drop compared to previously awarded feed-in tariffs. The first technology-neutral auctions in Italy (500 MW) were 99% won by wind power bids.

In Greece, there will be three auctions from 2018 through 2020 for a total of 950 MW, while in Italy, another six auctions remain until the end of 2021. In Ireland, the first auction will be in 2020. However, in México and in the province of Alberta in Canada, the auctions were suspended at the end of 2019, and in Spain no auctions have yet been announced.

Austria and Italy are reducing the tariffs paid for wind energy in their FIT subsidies, and Switzerland is moving to a guaranteed price scheme in which wind power producers will receive part of their income from the electricity markets.

Offshore wind power has also seen a dramatic price reduction in the tendering process. In the United Kingdom, the average price of 40.63 GBP/MWh (46.16 EUR/MWh / 51.84 USD/MWh), including grid-connection, reached a tipping point in which no subsidised offshore commercial projects are starting if left out of the auction. In France, the Dunkerque 600-MW tender had a record low price of less than 50 EUR/MWh (56.15 USD/MWh), excluding grid connection. In Germany and the Netherlands, offshore bids have already been awarded at zero premium (over and above the wholesale electricity price, excluding grid connection) In Belgium, the federal government decided that three planned offshore wind farms should be built at 79 EUR/MWh (88.7 USD/MWh).

The success of cost reductions has also brought about corporate PPA-funding of wind power projects outside of subsidy schemes. This had previously been reported in the United States and in Europe. In 2019, record numbers of PPAs were contracted in Europe, equal to 44% of total PPA funding to-date. Additionally, in 2019 Denmark saw its first non-subsidy project; a total of 543MW in merchant projects were installed in Spain; and in Finland all 243 MW of new capacity was without subsidy.

Opportunities for repowering

An increasing proportion of installed capacity will reach its end of life between 2020 and 2030. A regulatory framework for repowering is urgently needed – especially in Europe. To address this challenge, the IEA Wind TCP started a new task, Task 42 on lifetime extension, in 2019.

By 2030, 50% of the current installed capacity in Europe will have reached the end of its operational life. For example, more than 30% of Denmark's installed capacity will be more than 20 years old in 2020. Spain is anticipating 10-15 GW of repowering in the next decade.

Italy and Portugal report repowering as a way to meet future targets for wind energy. In Italy, repowering is included in the auctioning system. The United Kingdom reports that gains from land-based wind are expected from increased performance from repowering with new controls originally developed for offshore plants to extract more energy from the land-based sites.

An example of repowering was reported from Spain where a 22-year-old, 24-MW wind farm on the coast of Galicia was repowered in 2019, replacing 80 300-kW DESA A-30 turbines. The new installation of ten 2.6-MW Siemens-Gamesa SG-114 turbines (limited to 2.4-MW rated power) increased the total energy production by 16% (100 GWh/year).

OFFSHORE WIND TURBINE IN BELGIUM (PHOTO: JAN HENSMANS)

Overcoming Policy and Development Barriers

Member countries work together in the context of the IEA Wind to tackle deployment constraints because many countries experience similar growth impediments. In many cases, policy actions can help overcome or even remove these barriers. The main barriers reported in 2019 include long permitting procedures, regulatory changes, and an increasing number of legal disputes and citizen protests.

Seeking ways to improve public acceptance

Social acceptance continues to be a key constraint on the development of wind energy projects, and thus increasing public acceptance will help member countries meet their renewable energy obligations. Several factors relevant to wind project acceptance are included in this year's IEA Wind country reports, including high-density populations (Belgium, Germany, Italy, the Netherlands), tourism and landscape impacts (Italy), and noise (Finland, Ireland).

Wind energy generally shows a high public acceptance rate in surveys. For example, in 2019, over 80% of the Austrian population supported further wind power expansion – a continuing trend since 2011. However, in many countries local opposition still exists for any new wind power plant proposal, even if the general public supports wind energy. Local opposition from many ongoing projects around the countries shows that the public opinion against wind power has grown stronger, as has been reported from Norway in 2019. This was also seen in Finland in previous years. However, in 2019 after research on noise concerns from large (more than 3 MW) turbines did not find any health impacts on people living nearby. Previous health impact studies, for example from Canada, were of turbines of less than 3 MW.

> Wind energy generally shows a high public acceptance rate in surveys

In Switzerland, renewable energy targets were adapted to a more local level by declaring that the interests of the state should be taken into consideration in the local wind project planning processes at the canton (province) level. This has already helped several project rulings in 2019. These efforts have led to stronger cooperation between federal offices and institutes. The regional cantons have received (non-binding) targets to take into consideration in their energy plans.

Some governments have been working to support public acceptance of wind power by funding research on wind power, community engagement, ornithology, and noise (Finland, Switzerland, and Ireland). Other methods of improving social acceptance reported by IEA Wind member countries include using early stakeholder engagement and incentivising local communities, including community ownership or participation. In 2019, a new project to improve social acceptance was proposed in Mexico on design, development, implementation, and validation of an innovative methodology of increasing social impact under national and international standards. In Ireland the new Renewable Electricity Support Scheme reserves capacity for community owned projects and mandates a €2/MWh community benefit payment.

IEA Wind Task 28 focuses on social acceptance of wind energy.

Mitigating administrative barriers

Wind energy deployment can be hindered by lengthy permitting procedures and appeal processes. For example, in Austria complex and lengthy environmental impact assessment (EIA) procedures have resulted in an extra step of redesigning the wind farm while still waiting for funds to get approved for the FIT system. In Korea, there are many authorities involved, especially regarding environmental aspects. Task 34 addresses this barrier by providing information from studies conducted on environmental impacts in several countries. (Ref. Task 34 Risk-Based Management White Paper of December 2019.)

Many countries have undertaken efforts to simplify permitting processes. Belgium, Greece, Italy, and México report that streamlined authorisation procedures are expected in order to achieve the new, challenging wind energy targets for 2030. Germany has in 2019 focused on ways to simplify and

YEONG-GWANG TEST BED, JELLANAM-DO, KOREA, UNISON 4.3MW WTG (PHOTO: UNISON CO., LTD.)

accelerate permitting procedures, to increase social acceptance and to improve synchronisation with grid development.

A "one-stop-shop" aimed at simplifying and speeding up licensing procedures has mitigated the complexity of permitting procedures in Sweden and France. In 2019, a similar procedure was adopted in Belgium. In the Netherlands, collaboration of authorities overseeing the permitting is required. Lastly, Korea announced the establishment of a new public organisation which will provide consultation and advice to each land-based project from the initial development stage through operation. Regulations regarding Korea's mountain areas will also be re-examined and clarified.

> Harmonised technical requirements across countries would reduce risks

Harmonised technical requirements across countries would reduce risks while speeding up permitting procedures, operations, and the overall industry's path to cost reductions. This includes requirements for site investigation, park layout, health and safety, aviation lighting and marking, and vessels/crew requirements.

Increased demand for large offshore areas might create conflicts with other sea users. In Europe, the lack of common guidance for opening future offshore wind farms to other users and uses creates uncertainties in terms of safety, security, liability, and potential for conflicts with other sectors. In 2019, Japan enacted new rules covering general common sea areas which will promote the deployment of offshore wind farms.

Restrictions related to the defence sector may conflict with wind power deployment, mainly due to interference with communications, navigation, and surveillance (CNS) systems. Mitigation solutions are being developed alongside the next generation of larger and more efficient wind turbines and wind farm projects. Research into radar interference is reported from Switzerland and Germany, where new distance regulation recommendations for German authorities would possibly increase the number of land-based sites according to new scientific validation methods, while height limits near airports and turbine lightning are reported from the Netherlands. In Denmark, the 150-m limit on tip height was removed in 2019, as part of a move from a large number of land-based turbines (>4,300) to fewer, larger-sized turbines (<2,000).

Spatial planning limitations and lack of sufficient eligible wind zones are reported from Austria, Belgium and the Netherlands. To overcome this barrier, Korea has developed national wind maps containing information needed for permitting (for instance, delineating areas prohibited for wind energy).

Supporting further cost reductions and competitiveness in electricity markets

Considerable reductions in LCOE have made wind power one of the cheapest power-generation options.

The shift from feed-in tariffs to tender-based support schemes have prompted increasingly competitive prices for wind energy. In Norway and Sweden, both electricity markets and green certificate prices have been low, resulting in very low income for wind power producers. Incentivising wind power investment has been a major strategy in increasing deployment. Table 10 provides an overview of the subsidy systems and other tools employed by member countries to increase wind power deployment.

> Considerable reductions in LCOE have made wind power one of the cheapest power-generation options.

Encouraging industrial consumers to procure their wind energy needs directly through power purchase agreements (PPAs) is one way of securing long-term income for wind power producers. Asset owners also benefit from PPAs by reducing their risk exposure and ensuring a predictable income flow.

Building energy markets that support the long-term sustainability of wind power and other renewable energy industries will be important. Electrification trends will help the wind energy deployment, as new loads to capture the times when the electricity prices are low are introduced to avoid prices dropping to zero when surplus of wind- and solar power occur. Hybrid solutions combining wind- and solar power with storage will also open new opportunities for the sector to thrive in electricity market environments. Ireland saw the first grid-connected commercial hybrid wind-battery project in 2019. This project was comprised of 13 GE 2.85-MW wind turbines, with a maximum export capacity of 37 MW, each of which was paired with a 69-kWh lithium-ion battery.

More information is available in Task 36, on the development of short-term forecasting for electricity markets.

Reducing wind power curtailment

Research from the IEA Wind Task 25 on grid integration shows that high rates of curtailment are a signal of integration challenges.

In China, a series of policies and regulations to reduce wind curtailment in 2018, combined with large transmission upgrades, have successfully reduced the curtailed energy to less than 17 TWh in 2019 (nearing

WIND TURBINES IN LISTA, NORWAY.
(PHOTO: CAMILLA ORTEN (NVE))

to 4%), compared to 41.9 TWh in 2018 (over 7%). In Italy and Ireland, curtailments have increased to 2.5% and 7%, respectively, and in Germany close to 5% of wind power was curtailed in 2019.

system operators in several countries have achieved high instantaneous shares of wind without technical problems.

However, system operators in several countries have achieved high instantaneous shares of wind without technical problems. In Denmark and Spain, wind power plants are providing balancing energy by controlled curtailing. This market-based use of wind power's flexibility provides additional income to wind power plant operators.

Integrating high shares of wind to power and energy systems

Grid connection opportunities are crucial to enable development of both land-based and offshore wind sectors to meet 2030 targets. In 2019, the Irish TSO Eirgrid identified opportunities to add generation of up to 800 MW, without significant network upgrades, on the east coast of Ireland, facilitating the development of offshore wind.

Higher shares of wind and solar energy will impact the electricity markets as well as power and energy system operation and design. Electrification efforts and energy system coupling will provide options for managing future energy systems in which the majority of electricity is supplied by renewable energy sources. Examples of energy system coupling include using electricity and gas in transport, manufacturing, as well as heating and cooling. These future energy systems, which are already being studied in Denmark, the Netherlands, and the United Kingdom, where large shares of wind power are anticipated, require new demands on Power-to-X (i.e., to heat, syngas and hydrogen, transportation, manufacturing, etc.) as well as to storage. Task 25 on grid integration is also supporting these efforts to understand and improve the design and operation of power systems will large amounts of renewable energy.

Allowing wind power plants to access markets for grid support will help the balancing task of system operators. This is increasingly happening in Europe and the United States. For example, in Spain 54% of wind power plants are participating in markets providing down- and up-regulation.

Transition toward new regulatory frameworks

Despite cost reduction achievements, market uncertainty in terms of demand and availability of financing still impact the future of wind power. The ambitious targets for 2030 and beyond also require new regulatory frameworks. Long-term visibility and stable regulatory frameworks will continue to be crucial for wind energy deployment.

The shift from 2020 targets to longer-term targets has caused some policy uncertainty, especially as policies to increase wind power deployment coincide with a major shift from feed-in-tariffs to tender-based support schemes. Gaps in regulatory programmes and regulatory changes have been mentioned as reasons for growth rates lower than expected in some countries, in addition to permitting process challenges and issues with public acceptance. For example in Germany, a shift from feed-in-tariffs to auctions has caused changes affecting growth, and changes in the offshore auction system are also expected to create a gap in new offshore wind power auctions and installations in 2020.

> policies to increase wind power deployment coincide with a major shift from feed-in-tariffs to tender-based support schemes

Current delays are seen in: Austria (waiting for new legislation to get the project queue funded); Portugal (waiting for auctions for wind power); and México (waiting for new auctions that were suspended in December 2019). In the United Kingdom, the government has been reluctant to continue further land-based deployment, but there are discussions about including support other than for repowering. In Greece, it is anticipated that the ban on offshore wind power projects will be lifted. In Sweden, a decision to remove the grid connection cost from projects to compensate for offshore costs being higher than land-based is expected. In Italy, a new implementing decree was published in 2019. This decree sets an auction for 500 MW for both PV and wind power plants in 2019 and other six auctions until the end of 2021. Only land-based wind power plants are allowed to participate in these auctions, which include revamping and repowering.

Tender-based support schemes have prompted increasingly competitive prices for wind energy. However, many countries have struggled to design a tender-based support scheme in the context of permitting issues and an increasing number of court appeals against wind farms. With a lower number of permitted projects and increased uncertainty due to such appeals, the number of projects that are able to compete in an auction can be significantly reduced. This leads to undersubscribed auctions, as has been the case in Germany and Greece. In Germany, five out of six auctions for land based projects have been undersubscribed, bringing only 1.8 GW from the 3.7 GW target. The impact of undersubscribed auctions can be seen in tender prices, which reached ceiling values because of the lack of competition in Germany and France.

> The impact of undersubscribed auctions can be seen in tender prices, which reached ceiling values because of the lack of competition in Germany and France

Another concern for competition is the challenge of receiving prices too low to enable the projects to secure public acceptance, environmental compatibility, as well as sourcing locally manufactured components to benefit national industry and economy. The United Kingdom is experimenting with soft measures to increase local acceptance of the offshore sector.

In the Netherlands, Norway, and the United States, wind power will be subsidy-free and competing in electricity markets when current subsidy schemes end in 2020 and 2021. In China, wind power tariffs will be aligned with coal tariffs after 2020.In Norway, the green certificates income has been low due to oversuuply of certificates, and the LCOE of wind power is now on a level that does not require subsidies. The Netherlands recently published the rules for how future energy generation will be subsidised based on their CO_2 reductions. This is a major shift in the subsidy framework.

A new strategy of economic re-boost after Covid-19 in Korea, the Green New Deal, will include offshore wind projects that can be good role models for local/rural communities. In Europe, wind energy—particularly offshore wind—plays a pivotal role in the EU Green Deal, striving for carbon neutrality by 2050. Training and reskilling will also need special attention to promote a just transition and provide the skilled workforce needed for the increased deployment and operation of wind farms. Capacity building for design and installation of wind power plants is mentioned as a required mitigation action in Mexico.

The role of governments is more important than ever after Covid-19. They can ensure policy certainty, keep ambitious targets and improve investor confidence in order to accelerate growth beyond 2021. Including wind power in economic stimulus packages is justified by the structural benefits they can bring in job creation, economic development and innovation while reducing emissions [4].

WIND FARM IN CHINA (PHOTO : CWEA)

Societal Benefits of Wind Energy Development

Wind energy offers many benefits to society. With the cost competitiveness of wind energy compared to conventional energy, the wind industry has developed into a thriving global industry with increasing numbers of direct and indirect jobs. This creates a positive economic impact on the Gross Domestic Product (GDP), not least in times of economic crisis. Wind energy is an abundant resource around the world and contributes to reduce CO_2 emissions and local air pollution. Like any other large infrastructure, it has mixed impact on the environment.

Economic impact, industry revenues and jobs

Wind energy installations grew rapidly in 2019, especially in the two largest onshore markets – China and the United States – while European markets experienced mixed results, all of which had impact on the overall economy, industry, and job creation.

Employment is generated throughout the lifetime of the wind power plant. Employment effects are most intensive during manufacturing of the wind turbines, but they continue during planning, construction, operations and maintenance, and decommissioning.

In China, it is estimated that more than 800,000 people will be employed in the wind power industry 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 (76.8 billion EUR; 92.4 billion USD). The top five manufacturers' market share in China increased from 54.1% in 2013 to 73.4% in 2019, and the top ten manufacturers' market share increased from 90% in 2017 to 92.1% in 2019.

The European Commission reported that the wind energy industry employed – directly and indirectly - about 366,000 persons in the EU-28. As an example, the Belgian offshore wind industry generates about 16,000 jobs (including export activities, construction, and operations and maintenance). In Denmark, the wind energy industry employed 32,744 people in 2018. In France and Spain, the wind energy sector employs 18,200 and 24,000 people, respectively (Appendix Table

11). Meanwhile, the United States reported that nearly 115,000 Americans are directly employed by the wind industry.

The European Commission reported that financial activity in the wind energy industry was 44.1 billion EUR (49.5 billion USD) in 2019; new asset financing remained the biggest investment. European wind energy companies have a commercial presence (including manufacturing sites) in more than 80 countries outside Europe. The industry remains a global net exporter with a 2.4 billion EUR (2.7 billion USD) positive trade balance in products and services. The United Kingdom, for example, reported that the wind sector was estimated to be 7.4 billion GBP (8.7 billion EUR / 9.8 billion USD), evenly split between land-based and offshore. However, the export market is dominated by the offshore sector with 489 million GBP (578 million EUR / 649 million USD) compared to 67 million GBP (79.2 million EUR / 89 million USD) for land-based.

Emission reduction

Several member countries calculated the avoided CO_2 emissions (million tons/year) attributable to wind energy deployment. In many countries, wind energy is the largest renewable contributor to emission savings (Austria, Belgium, Denmark, Ireland, Spain, and the United Kingdom).

A 2019 Irish Wind Energy Association-funded study by independent consultants found that wind energy would displace 33 million tonnes of power-sector CO_2 emissions from 2000 to 2020, equivalent to almost three years of total carbon emissions in the power sector today.

Table 3. Top Ten Wind Turbine Suppliers, 2019 [5]

Rank	Company	Percent of Market
1	Vestas*	18.0%
2	Siemens Gamesa Renewable Energy	15.7%
3	Goldwind	13.2%
4	GE Renewable energy	11.6%
5	ENVISION	8.6%
6	Mingyang	5.7%
7	Nordex Acciona	4.9%
8	Enercon	3.0%
9	Windey	2.5%
10	Dongfang	2.1%

*MHI Vestas capacity not attributed to Vestas as organisations must own more than 50% of a subsidiary to receive credit.

In 2019, Japanese wind-generated electricity contributed to a reduction of about 3.5 million tonnes of CO_2 equivalent, amounting to 0.30% of Japan's total CO_2 emissions. Japan aims to reduce CO_2 emissions of energy origin by 25% from their FY2013 levels by FY2030.

In México, the development of 8,000 MW of wind power by 2020 is estimated to reduce emissions by more than 13 million tons of CO_2, equivalent to approximately 10%of the national mitigation target.

The United Kingdom estimated a 3.6% reduction in the total greenhouse gas emissions from 2018 and 45.2% lower than 1990 levels. Emissions from power stations dropped by 13.2%, mainly due to a shift away from coal-fired power generation to renewables. In 2019, Italy's wind-generated electricity reduced CO_2 emissions with approximately 10.8 million tonnes.

In China, wind-generated electricity totalled 405.7 billion kWh, which saved about 144.7 million tonnes of standard coal per year and reduced emissions by 307 million tonnes of CO_2, 1.05 million tonnes of SO_2 and 0.89 million tonnes of NOx and thus plays an important role in reducing air pollution and emissions.

Other environmental impacts and benefits

Large scale use of wind energy may impact wildlife and thus challenge wind energy deployment. Many countries have invested in research and strategies to understand potential environmental impacts and benefits to make informed decisions that balance the need for renewable energy with the need to sustain and protect local wildlife. Examples of studies are presented below, and more information is available in Task 34 on environmental impacts of wind energy.

In Belgium, offshore wind energy developments have been found to increase biodiversity, specifically organisms such as corals and sea 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.

The United States reported that the 2019 launch of the Wind Wildlife Research Fund pooled industry resources to research critical wind-wildlife issues, bringing 30 companies together on seven research projects to reduce collision risks and other potential negative effects on wildlife.

The German project, WEA-Akzeptanz, studies acoustic noise of wind turbines in terms of the chain from the source of sound up to the psychoacoustic evaluation.

Value of Research, Development, and Innovation

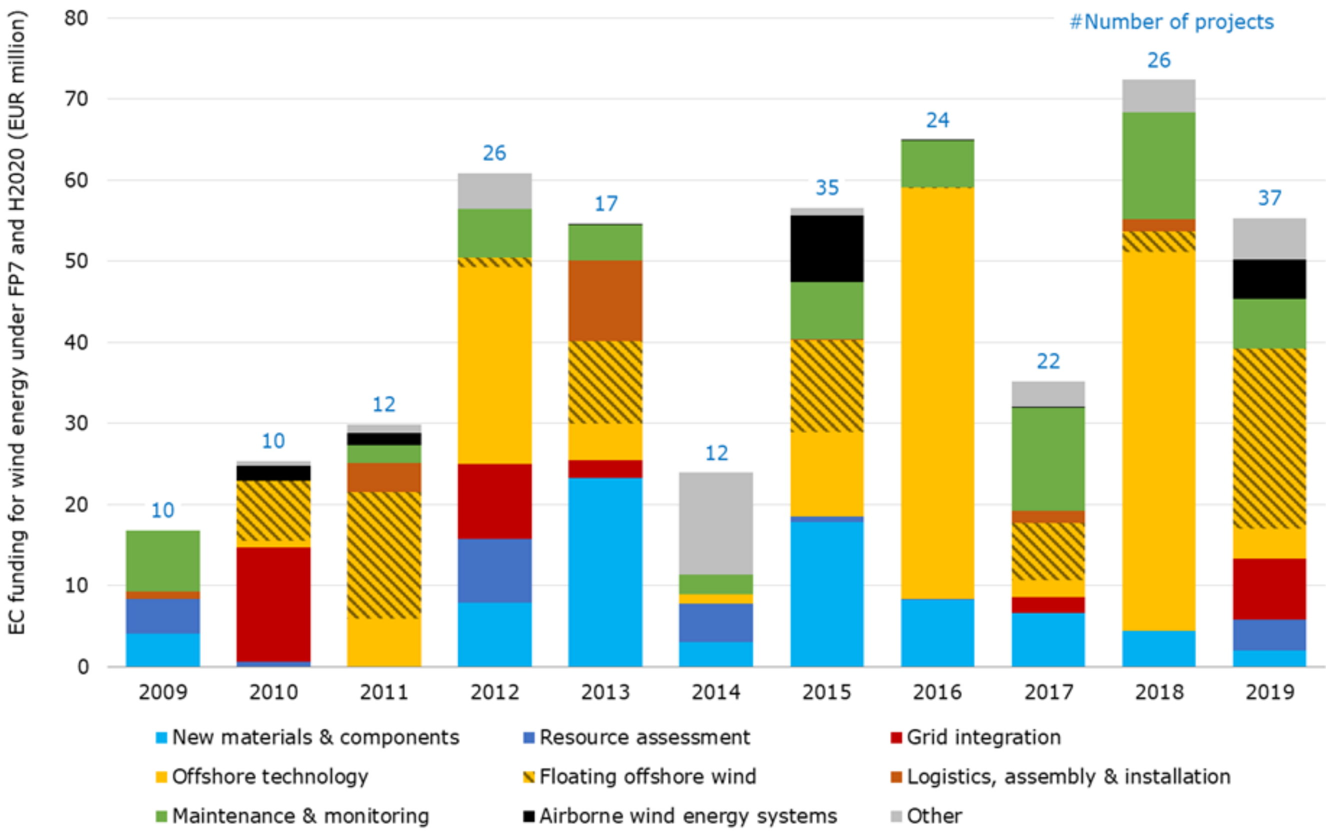
National R,D&D efforts throughout member countries continue to build expertise and a ccelerate technology innovation as a means to drive down the cost of wind energy. Moreover, efforts are also addressing non-technical aspects such as public acceptance.

National R,D&D funding and priorities

Wind energy R,D&D funding decreased slightly in 2019 at both the country level and globally. Of the 16 countries reporting R&D budgets in 2019, only four reported a small increase from 2018 (Canada, the Netherlands, Spain, and Switzerland). However, public R,D&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. It should be noted that renewable energy R,D&D constitutes only 15%, or 3 billion USD (2.6 billion EUR), of the global public energy R,D&D expenditures of 21 billion USD (18.5 billion EUR). In comparison, nuclear energy constitutes 21% and fossil fuels 9% of total expenditures [6]. National budgets for public wind R,D&D from 2010–2019 are shown in Appendix Table 12.

In Europe, the majority of R,D&D takes place at the national level, but a variety of coordination mechanisms aim at aligning activities across EU Member States. Most important is the Strategic Energy Technology (SET) Plan which is the European Commission's effort to support Member States, industry, and the research community in cooperating and better aligning their Research and Innovation (R&I) priorities and funding. The public-private 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) are important R,D&D platforms within the SET-Plan community.

Horizon 2020 – the EU Research and Innovation Programme 2014 to 2020 – continued to fund a substantial number of wind energy projects (37) with



EVOLUTION OF EU R&I FUNDING CATEGORISED BY R&I PRIORITIES FOR WIND ENERGY UNDER FP7 (2009-2013) AND H2020 (2014 2019) PROGRAMS AND THE NUMBER OF PROJECTS FUNDED IN THE PERIOD 2009-2019 [REF. T. TELSNIG (2020). TECHNOLOGY DEVELOPMENT REPORT – WIND ENERGY. EUROPEAN COMMISSION.].

a cumulative investment of 55.3 million EUR (62.1 million USD). Almost 47% of European Commission's funding granted to wind energy projects starting in 2019 focused on bottom-fixed and floating offshore technology concepts. In addition to the EU, interest in floating offshore wind was also reported by the United Kingdom, Italy, Greece, France, Ireland, Japan, Norway, and Portugal.

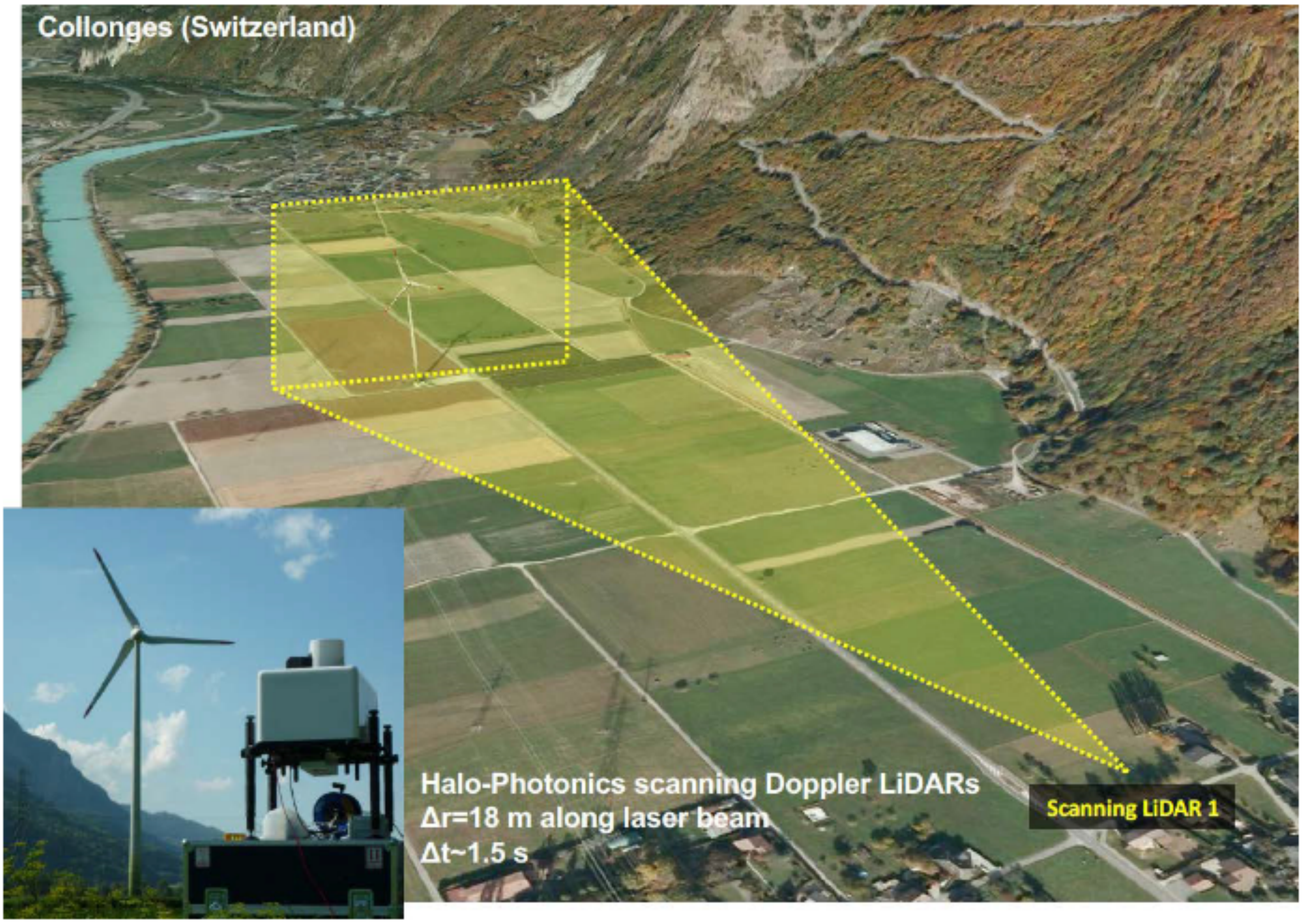
In 2019, the U.S. Department of Energy's Wind Energy Technologies Office (WETO) focused its 92 million USD (82 million EUR) budget on key areas such as improving the performance and reliability of next-generation wind power plants, reducing the cost of land-based wind power, and improving performance through fundamental R&D. The latter included research on controls, algorithms, and materials, and developing solutions to key barriers to wind siting and development such as grid integration, radar interference, and environmental challenges. Funding also supported efforts to manage and modernise R&D infrastructure at the National Renewable Energy Laboratory's (NREL's) Flatirons Campus and at the Scaled Wind Farm Technology (SWiFT) facility at Sandia National Laboratories (Sandia).

The Ministry of Science and Technology of the People's Republic of China launched the National Key Research Program of renewable and hydrogen energy with a total budget of approximately 438 million CNY (56.1 million EUR; 63.1 million USD) in 2019. The budget for wind power is around 65 million CNY (8.32 million EUR; 9.36 million USD).

Research Initiatives & Results

Member countries highlighted key topics driving ongoing and future R,D&D activities, many of which have been identified as national priorities. The highlights of national and cooperative projects below show the variety in R,D&D priorities. The priorities are grouped here according to the four IEA Wind strategic areas:

- Wind resource and site characteristics
- Advanced technology
- Energy systems with high amount of wind
- Social, environmental, and economic impact



VIEW OF THE EXPERIMENTAL SITE WITH THE SAMPLING VOLUME (IN YELLOW) OBTAINED WITH ONE OF THE THREE LIDARS. BOTTOM LEFT: PICTURE OF THE LIDAR AND THE WIND TURBINE IN THE BACKGROUND [PHOTO: EPFL-WIRE]

MODEL FROM DUTCH TIADE (TURBINE IMPROVEMENTS FOR ADDITIONAL ENERGY) PROJECT (PHOTO: TNO, GE POWER THE NETHERLANDS AND LM WIND POWER)

Wind resource and site characteristics

- In Italy, the RSE is working on an update to the Italian Wind Atlas (ATLAEOLICO http://atlanteeolico.rse-web.it/) within the "National Fund for Electric System Research" (RdS) project promoted by the Ministry of Economic Development (MISE). The goal is to create a competitive and innovative product compared to the best atlases currently available for Italy, using the most advanced meteorological modelling tools.

- The optimisation of wind park design in complex terrain is an important topic in Switzerland due to its topography. An integrated approach was used to develop a Virtual Wind Simulator. It predicts turbulent wind over complex terrain and its interactions with wind turbines and wind farms, based on a unique combination of computer simulations, wind-tunnel experiments, and field experiments in Collonges (Switzerland), Iowa, and Colorado (United States). These helped validate the new tool for both topography and active yaw control.

Advanced technology - Components

- BLEEP is a collaborative research programme led by ORE Catapult with two universities, Bristol and Strathclyde, and two coatings manufacturers, Jotun and AkzoNobel. The programme assesses the coating degradation process during combined rain erosion and weathering, using realistic offshore accelerated weathering cycles. A realistic offshore rain test method was developed to predict LEP lifetime and measure viscoelastic properties at very high rain impact strain rates.

- In the United States, Sandia developed and patented a wind turbine blade design that reduces wake turbulence and allows turbines to be installed closer to each other, lowering costs by decreasing the amount of electrical lines and roads needed to connect them.

- The Dutch TIADE (Turbine Improvements for Additional Energy) project will develop and validate innovative wind turbine blade improvements (e.g. innovative tips) and blade add-ons (e.g. spoilers, vortex generators) to boost the performance of offshore wind turbines. The innovations developed in the project will be tested in the field on a dedicated, full-scale, state-of-the-art, R&D 3.8-MW wind turbine. The wind turbine has unique jointed blades that will enable cost effective quick swapping and testing of blade innovations. TNO, GE Power the Netherlands, and LM Wind Power are partners.

- The Chinese Aeromechanical Research and Development Center (CARDC), Goldwind, Hunan University, and Shantou University constructed the super-cooled large droplet testing system and finished relevant tests by a holographic technique in an icing wind tunnel of 0.3m*0.3m.

Advanced technology - Offshore wind

- In Europe, the COREWIND project aims to achieve cost reductions and increase the performance of floating wind technology through the research and optimisation of mooring and anchoring systems and dynamic cables. Simulations and experimental tests are performed (both in wave basin tanks and a wind tunnel) on two, concrete-based floater concepts

NREL RESEARCHERS ARE INVESTIGATING A NEW COMPOSITE OF REACTIVE THERMOPLASTICS THAT IS RECYCLABLE, LIGHTER, AND LESS EXPENSIVE TO MANUFACTURE (PHOTO: DENNIS SCHROEDER/NREL)

(semi-submersible and spar) supporting large, 15-MW wind turbines, at water depths greater than 40 m and 90 m for the semi-submersible and spar concepts, respectively.

- In Norway, the SINTEF WindMoor (Advanced Wave and Wind Load Models for Floating Wind Turbine Mooring System Design) project enables more efficient design of floating wind farms by improving load analysis methods. It challenges existing design practices for mooring systems with improved tools, additional high-quality experimental data, and new analysis approaches, including novel mooring systems for wind farms and better predictions of low-frequency responses.

- The Dutch TouchWind has developed a floating wind turbine concept which consists of a self-erecting mast acting as a passive pitch control. It can operate at very high wind speeds. The TouchWind turbine uses a one-piece, two-bladed rotor and has the potential to reduce costs by 29% and increase the number of turbines per km2.

- The Anemoi project is an Innovate United Kingdom funded project between ORE Catapult, Soil Machine Dynamics and Magnomatics. Anemoi provided new technologies for remotely operated vehicles (ROV) in extreme offshore environments, in addition to developing novel subsea cable-sensing technologies to accelerate deployment of offshore wind farm electrical infrastructure.

- In Italy, CNR, within the RdS project, is coordinating the construction of a laboratory at sea for the integration of different energy harvesting systems, including a floating wind turbine prototype (scale factor 1:5 with respect to a 2 MW machine).

Advanced technology – Life extension and decommissioning

- To tackle the challenge of end-of-life recycling of the existing thermoset materials commonly used in wind blades, U.S. researchers at NREL investigated a new composite of reactive thermoplastics that is recyclable, less expensive to manufacture, and enables a lighter and potentially more reliable manufacturing process.

- The Danish ReLife project is developing a new methodology for the assessment of the remaining useful life of wind turbine rotor blades, based on their individual damage states. This will enable most turbines to have their service life extended by 10-15 years, thereby lowering the LCOE.

- In Sweden, the project “Chemical recycling of glass fibre composite from wind turbine blades” is investigating the possibility of chemically recycling the composite in the wind turbine blades with solvolys/HTL. The thermoset is converted into chemical building blocks that can be used for plastics, chemicals, vehicle fuels, and the fiberglass fractions can be reused in new composites.

Energy systems with high amounts of wind

- In the United States, NREL collaborated with Argonne National Laboratory and the University of Texas-Dallas to create the WindView visualisation tool that extends the planning capabilities of power system operators to flex generation and meet load demands.

- 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 penetrations of renewables.

- In Portugal, the OptiGRID project demonstrates the Dynamic Line Rating approach to increase integration of renewables into the electric grid with particular focus on wind energy systems.

- In Denmark, the Low-Wind project will explore the potentials of a completely new wind turbine concept: the Low-Wind turbine, designed for optimal integration in a power system with a considerable amount of renewables. The Low-Wind turbine will produce more than double the amount of energy at low wind when the electricity prices typically are high, but the turbine will be shut down at wind speeds of 12-14 m/s.

Social, environmental and economic impact

- The BENSO project (Scour protection design for Biodiversity Enhancement in North Sea Offshore wind farms) contributes to the Dutch policy to use offshore wind farms to strengthen the North Sea ecosystem. The project will investigate the impact of scour protection around monopiles on species and the ecosystem and to develop a smart ecological design for scour protection. Bureau Waardenburg, Wageningen University Research, and Waterproof Marine Consultancy are partners.

- In Sweden, the project Eagle Watch uses intelligent technology to eliminate collisions between large birds and wind turbines. The IdentiFlight is a technology based on smart cameras that monitor the airspace within a wind farm, and if an eagle comes within a distance where the risk of collision is present, the turbine is shut down temporarily. This project is linked to the research project "Coexistence of wind power and eagles on Gotland" that Uppsala University currently is running.

- In Italy, RSE is developing a methodology to evaluate the actual production of offshore wind farms in the Italian marine areas, taking into account technical, economic, environmental and regulatory aspects. Moreover, ENEA and EcoAzioni are the Italian partners in the WinWind project aimed at increasing social acceptance and enhancing the development of land-based wind energy in "Wind Energy Scarce Regions" (WESRs).

Test facilities and demonstration projects

A major component of continued innovation in the wind industry is the ability to conduct demonstration projects and utilise test facilities, which are now located in countries around the world. The 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.

> The IEA Wind member countries support projects that test advanced design and construction methods as well as grid integration and components

Several new projects have commenced operations which reflect the sector's priority for offshore wind, particularly floating concepts and the novel installation and balance of plant solutions. Table 13 highlights several of the test and demonstration facilities in the IEA Wind TCP member countries.

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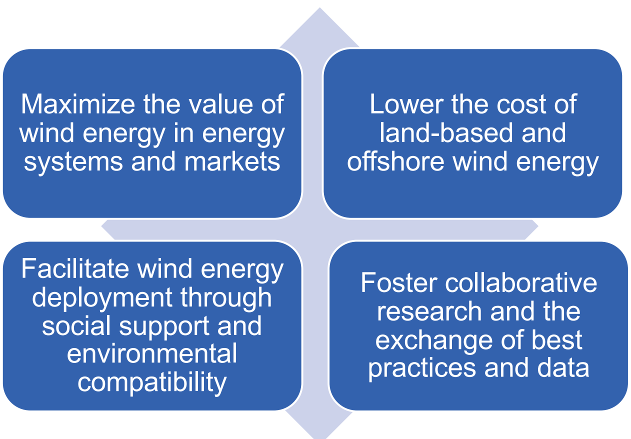
PARTICIPANTS AT IEA WIND EXCO 85, COPENHAGEN, SEPTEMBER 2019.

Activities of IEA Wind

RESEARCH TASKS & STRATEGIC PRIORITIES

The IEA Wind 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. IEA Wind 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 programmes and international efforts. Participants continue to exchange information on current and future activities at semi-annual meetings and participate in co-operative research tasks.

IEA Wind TCP Strategic Objectives 2019-2024



IEA Wind supported 17 Tasks working on wind energy research, development, and deployment (R,D&D) in 2019. These co-operative Tasks bring together hundreds of experts from industry, government, and research institutions around the world to exchange information and participate in research activities each year. Through these activities, the IEA Wind member countries leverage national efforts to complete larger and more complex projects than an individual organisation could complete.

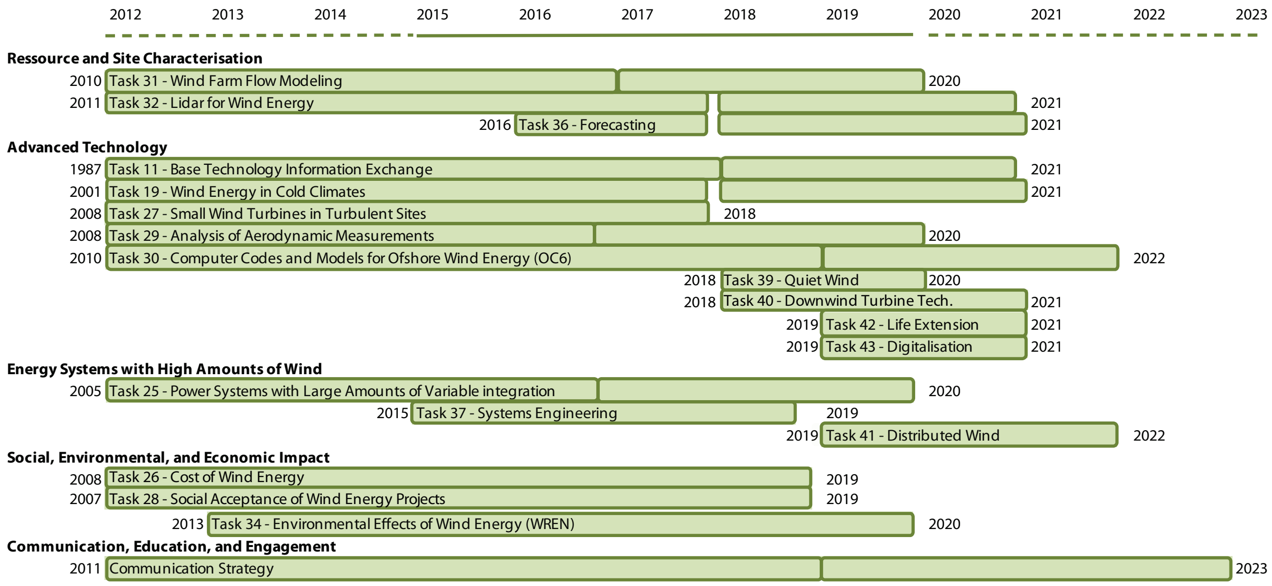
Task Participation

The IEA Wind Executive Committee (ExCo) approves and oversees each research Task. New Tasks are added to IEA Wind 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. Often, a participation fee from member countries supports the Operating Agents (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. Organisations 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 four to 18 participating countries working on issues related to wind energy technology and deployment in 2019 (Overview table on next page). The combined efforts devoted to a Task allow a country to leverage its research resources and collaboratively address complex wind research challenges.

2015-2020 STRATEGIC PRIORITY AREAS AND TASKS



In 2019, Task 41, a new task on distributed wind, began work. Task 42 Lifetime Extension Assessment and Task 43 Digitalization of Wind Energy were approved and began work in 2019.

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**. Task summaries for 2019 with links to Task Reports on page 30.

IEA Wind research tasks focus on sharing the latest technologies and best practices to advance wind power deployment and help meet renewable energy goals. In 2018, IEA Wind published the 2019–2024 Strategic Work Plan to help guide the IEA Wind activities for the next five-year term. In 2019, the IEA Wind activities aligned with revised Research Priorities 2019-2024, which aimed to reduce wind energy costs by conducting R&D in five strategic areas:

1. Resource and Site Characterization
2. Advanced Technology
3. Energy Systems with High Amounts of Wind Energy
4. Social, Environmental, and Economic Impacts
5. Communication, Education, and Engagement

The 2019–2024 Strategic Work Plan helps to guide the IEA Wind activities for the next five-year term. The plan is presented on the next pages.

Member Participation in Research Tasks During 2019

	2019-2020	2019-2021	2018-2020	2019-2021	2017-2019	2018-2020	2019-2022	2019-2021	2019-2021	2016-2020	2019-2021	2015-2019	2018-2020	2018-2021	2019-2022	2019-2021	2019-2021
Participant	**Research Task Number**																
	11	**19**	**25**	**26**	**28**	**29**	**30**	**31**	**32**	**34**	**36**	**37**	**39**	**40**	**41**	**42**	**43**
Austria		x							x		x				x		
Belgium		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	**OA**	X
European				x													
Finland	x	**OA**	**OA**		x						x						
France			x			x	x	x	x	x	x						
Germany	x	x	x	x	x	x	x	x	**OA**		x	x	x	x		X	Co-OA
Greece																	
Ireland	x		x	x	**OA**					x	x		**OA**		x		X
Italy	x		x			x	x			x					x		
Japan	x		x		x		x	x	x					**OA**	x		
Korea							x		x						x		
México	x		x														
Netherlands	x		x	x		**OA**	x	x	x	x		x					
Norway	x	x	x	x			x		x	x	x	x					
Portugal			x		x		x			x	x						
Spain	x		x				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					
United States	x		x	**OA**	x	x	**OA**	x	x	**OA**	x	**OA**		x	**OA**		**OA**
WindEurope			x														
Totals	**15**	**11**	**18**	**9**	**8**	**7**	**13**	**10**	**12**	**12**	**13**	**8**	**4**	**4**	**10**	**2**	**4**

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

IEA Wind 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 (IEA Wind). For 40 years, the IEA Wind has been multiplying national technology R,D&D efforts through information exchange and joint research projects. IEA Wind has 17 active tasks and 24 (...) member countries, including 3 sponsor organsations, with membership expanding.

Wind energy has achieved impressive milestones in the past few years, with auction prices dropping below 40 EUR/MWh for land-based projects and recent subsidy-free auctions for offshore wind projects. In 2019, over 60 GW of wind generation capacity was installed worldwide, bringing the global capacity to about 650 GW. Nearly 85% of this global capacity is deployed in IEA Wind member countries.

Still, there are significant opportunities for technological innovation and cost-competitiveness improvements in order to maximise 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 IEA Wind:

1. Maximise 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 maximise 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 standardisation and accelerate the pace of technology development and deployment. Engage with a global cohort of stakeholder groups and organisations to disseminate IEA Wind outputs.

IEA Wind Alignment with the IEA's Mission

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

Engagement Worldwide – The IEA Wind 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 TCP level (e.g., collaboration with IEA, IRENA, and others; efforts to expand membership in mature and emerging markets).

IEA IEA Wind 2019–2024 Research Priority Areas

Research Priority Areas	High-Level Actions	Current and Ongoing Activities
1. Resource and Site Characterisation		
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	• Characterise normal and extreme environmental conditions for both land-based and offshore wind plants • Improve design and analysis tools through formal verification, validation, and uncertainty quantification • Develop low-cost, high-resolution site assessment techniques to inform siting and plant design	• Topical Expert Meetings (TEMs) (Task 11) • Cold Climates (Task 19) • Aerodynamics (Task 29) • Offshore (Task 30) • Flow Modeling (Task 31) • Lidar (Task 32) • Forecasting (Task 36) • Quiet Wind (Task 39)
2. Advanced Technology		
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	• Advance and establish best practices for design, digitalisation and optimisation techniques for wind turbines and plants • Investigate advanced technologies to address specific site conditions (taller towers, logistics, offshore support structure design, advanced airfoils and strategies to increase flexibility, reliability, etc.) • Advance best practices and technologies for repowering and end-of-life processes	• TEMs (Task 11) • Cold Climates (Task 19) • Cost of Wind (Task 26) • Small Wind (Task 27) • Aerodynamics (Task 29) • Offshore (Task 30 • Life Extension (Task 42) • Digitalisation (Task 43)) • Lidar (Task 32) • Systems Engineering (Task 37) • Quiet Wind (Task 39) • Downwind (Task 40)
3. Energy Systems with High Amounts of Wind		
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 maximise the system value of wind energy in a broad range of applications	• Study flexibility in both production and demand to achieve 100% renewable energy systems in the future • 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 • Investigate improved wind power forecasts and increase the value of existing forecasts for users	• TEMs (Task11) • System Integration (Task 25) • Forecasting (Task 36) • Distributed Energy Future (Task 41)
4. Social, Environmental, and Economic Impacts		
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; maximise 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	• Document, develop, and advance best practices, planning approaches, and other tools to build social support for wind energy projects and mitigate social acceptance issues • Better understand and address wildlife conflicts and develop sensing, deterrent, mitigation, and minimisation technology • Expand technical knowledge and best practices for aeroacoustic design of wind turbine components	• TEMs (Task 11) • Cost of Wind (Task 26) • Social Acceptance (Task 28) • Aerodynamics (Task 29) • Environmental Assessment and Monitoring for Wind Energy Systems (Task 34) • Quiet Wind (Task 39)
5. Communication, Education, and Engagement		
Establish the IEA Wind 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	• 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 IEA Wind • Expand network of experts and researchers and communicate findings between IEA and TCPs to increase synergy • Promote a new integrated discipline of wind energy science and engineering to achieve the full potential of low cost/high value wind energy	• The IEA Wind Secretariat and all research Tasks support this priority area


MARTIGNY, SWITZERLAND, SUISSE EOLE PICTURE CONTEST (PHOTO CREDIT: CHARLY ARBELLAY)

TASK 11 REPORT 2019

Base Technology Exchange

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.

LLIONEL PERRET AND NICOLAS EL HAYEK, Planair SA, Switzerland

Task 11 also disseminates knowledge by developing IEA Wind Recommended Practices. Many IEA Wind Recommwended Practices have served as the basis for both national and international standards.

With three new members in 2019, 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

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READ TASK 11


WIND TURBINE AND A GROUND-BASED LIDAR IN ICING CONDITIONS IN FINNISH LAPLAND. COPYRIGHT VTT/TUOMAS JOKELA 2010

TASK 19 REPORT 2019

Wind Energy in Cold Climates

Cold climate wind is one of the largest special markets for onshore wind power. Many cold climate sites are attractive locations for wind power due to favourable wind conditions (increased air density due to colder air), low population density leading to fewer public questions and concerns, and increasing availability of technological solutions to cold and icing climate specific issues. Cold and icing climates result in unique issues for wind power projects deployed in these areas.

TIMO KARLSSON, VTT

The aim of Task 19 is to support widespread deployment of wind power in cold climates at a large scale in a safe and feasible way. The objective of the group is to collect and disseminate information about wind energy in cold climates, including project development, operation and maintenance (O&M), health, safety and environment (HSE) and recent research.

Technology Collaboration Programme by iea

READ TASK 19

TASK 11 SUMMARY

Nicolas El Hayek and Lionel Perret, Plainair SA

Base Technology Exchange

Task 11 of the IEA Wind Technology Collaboration Programme (TCP) promotes and disseminates knowledge on emerging wind energy topics by international co-operative activities. This is accomplished through Topical Expert Meetings (TEMs), in which active researchers, industry and government experts meet to exchange information on R&D topics of common interest to the IEA Wind TCP members. Four TEMs were organised in 2019: TEM#94 on Ultra-Long Component Testing in Boulder, CO, USA; TEM#95 on the Reliability/Availability of Electrical Infrastructure in Blyth, UK; TEM#96 on Wind Plant Decommissioning, Repowering and Recycling in Rome, IT; and TEM#97 on Wind Farm Control in Amsterdam, NL. As a result, two new Research Task proposals shall be submitted to the ExCo in 2020.

Task 11 also disseminates knowledge by developing IEA Wind TCP Recommended Practices in collaboration with other Tasks and the Secretary. Many IEA Wind Recommended Practices have served as basis for both national and international standards. The 20th Recommended Practice for Selecting Renewable Power Forecasting Solutions (Task 36) was published in 2019.

Task 11 reports and activities bring the latest knowledge to wind energy experts in the member countries, offer recommendations for the future work of the TCP and works as a catalyst for starting new IEA Wind TCP Research Tasks. With three new members in 2019, nearly every country in the consortium participates in this Task, which has been part of the IEA Wind TCP since 1978.

TASK 19 SUMMARY

Timo Karlsson, VTT

Wind Energy in Cold Climates

The objective of IEA Wind TCP Task 19 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. Task 19 aims to enable large-scale deployment of cold climate wind power in a safe and economically feasible manner. Currently, the Task is engaged with researchers, consultants, owners/operators, developers, turbine manufacturers and component manufacturers working in the wind energy sector.

2019 was the first year of a new term, and 2019 saw the completion of two of the deliverables planned for the term: the release of the new version of the Task 19 Ice Loss calculation software and a presentation summarising the publicly available studies on ice prevention system performance.

The ice loss analysis tool is free and open source and available for download through the Task 19 website. The result of the evaluation of the ice prevention system performance was presented at Winterwind in February 2020.

In addition to this, work has started on a report on evaluation and testing of ice detection systems and on performance warranty guidelines for wind turbines in icing climates. Task 19 also organised an industry workshop related to performance warranty guidelines work at the Winterwind conference in early 2020. The workshop participants represented all different sectors of the industry: research organisations, consultants, turbine owners and operators, and wind turbine and ice prevention system manufacturers.

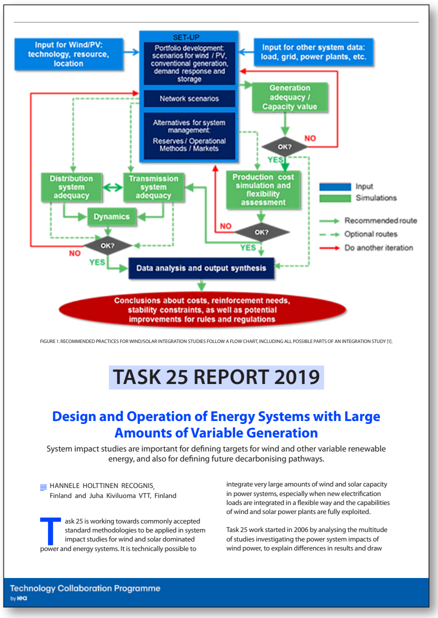

FIGURE 1. RECOMMENDED PRACTICES FOR WIND/SOLAR INTEGRATION STUDIES FOLLOW A FLOW CHART, INCLUDING ALL POSSIBLE PARTS OF AN INTEGRATION STUDY [1].

TASK 25 REPORT 2019

Design and Operation of Energy Systems with Large Amounts of Variable Generation

System impact studies are important for defining targets for wind and other variable renewable energy, and also for defining future decarbonising pathways.

HANNELE HOLTTINEN RECOGNIS, Finland and Juha Kiviluoma VTT, Finland

Task 25 is working towards commonly accepted standard methodologies to be applied in system impact studies for wind and solar dominated power and energy systems. It is technically possible to integrate very large amounts of wind and solar capacity in power systems, especially when new electrification loads are integrated in a flexible way and the capabilities of wind and solar power plants are fully exploited.

Task 25 work started in 2006 by analysing the multitude of studies investigating the power system impacts of wind power, to explain differences in results and draw

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READ TASK 25

TASK 25 SUMMARY

Hannele Holttinen, Recognis

Design and Operation of Energy Systems with Large Amounts of Variable Generation

System impact studies are important for defining targets for wind power and other variable renewable energies, and also for defining future decarbonising pathways. Task 25 is working toward commonly accepted standard methodologies to be applied in system impact studies for wind- and solar-dominated energy systems. International collaboration remains key to moving the industry and technology forward.

In 2019, the main focus was on system impact studies for 100% renewable power and energy systems. Task 25 participated in the ESIG workshop, wrote a report that is available at *www.esig.energy/esig-101/*, and wrote two collaborative journal articles entitled "Addressing Technical Challenges in 100% Variable Inverter-Based Renewable Energy Power Systems" and "System impact studies for near 100% renewable energy systems dominated by inverter based variable generation".

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 recommended practices report that included solar integration concepts.

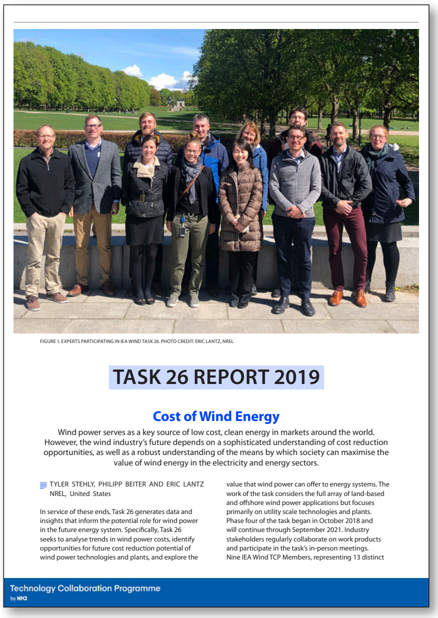

FIGURE 1. EXPERTS PARTICIPATING IN IEA WIND TASK 26. PHOTO CREDIT: ERIC LANTZ, NREL

TASK 26 REPORT 2019

Cost of Wind Energy

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 maximise the value of wind energy in the electricity and energy sectors.

TYLER STEHLY, PHILIPP BEITER AND ERIC LANTZ NREL, United States

In service of these ends, Task 26 generates data and insights that inform the potential role for wind power in the future energy system. Specifically, Task 26 seeks to analyse trends in wind power costs, identify opportunities for future cost reduction potential of wind power technologies and plants, and explore the value that wind power 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. Industry stakeholders regularly collaborate on work products and participate in the task's in-person meetings. Nine IEA Wind TCP Members, representing 13 distinct

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READ TASK 26

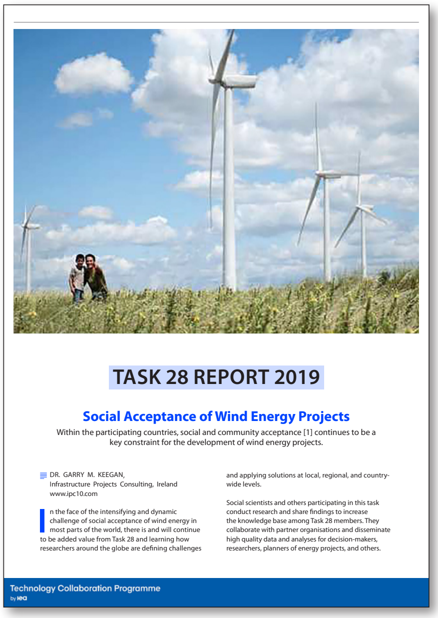
TASK 26 SUMMARY

Eric Lantz, NREL

Cost of Wind Energy

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 maximise the value of wind energy in the electricity and energy sectors.

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 and 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 the industry. Organisations such as IEA and the International Renewable Energy Agency have used Task 26 wind project cost and performance statistics and participants regularly use these data for internal and external purposes.



TASK 28 REPORT 2019

Social Acceptance of Wind Energy Projects

Within the participating countries, social and community acceptance [1] continues to be a key constraint for the development of wind energy projects.

DR. GARRY M. KEEGAN,
Infrastructure Projects Consulting, Ireland
www.ipc10.com

In the face of the intensifying and dynamic challenge of social acceptance of wind energy in most parts of the world, there is and will continue to be added value from Task 28 and learning how researchers around the globe are defining challenges and applying solutions at local, regional, and country-wide levels.

Social scientists and others participating in this task conduct research and share findings to increase the knowledge base among Task 28 members. They collaborate with partner organisations and disseminate high quality data and analyses for decision-makers, researchers, planners of energy projects, and others.

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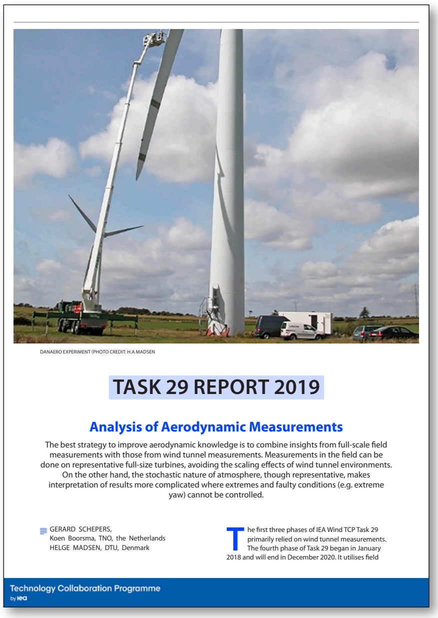
READ TASK 28



DANAERO EXPERIMENT (PHOTO CREDIT: H.A MADSEN

TASK 29 REPORT 2019

Analysis of Aerodynamic Measurements

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.

GERARD SCHEPERS,
Koen Boorsma, TNO, the Netherlands
HELGE MADSEN, DTU, Denmark

The first three phases of IEA Wind TCP Task 29 primarily relied on wind tunnel measurements. The fourth phase of Task 29 began in January 2018 and will end in December 2020. It utilises field

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READ TASK 29

TASK 28 SUMMARY

Garry M. Keegan, Infrastructure Projects Consulting

Social Acceptance of Wind Energy Projects

Social and community acceptance continues to be a key constraint for the development of wind energy projects. To achieve renewable energy policy objectives, social acceptance must focus on the needs of all stakeholders including policy makers, regulators, developers, local communities, and special interest groups.

Projects that encounter concerned host communities – and, in some cases, opposition – can have increased costs and timelines, which decrease the overall rate of wind energy deployment. Due to research among industry practitioners and academics undertaken by Task 28, social acceptance of off-shore projects is now a prominent research focus.

For the transition to a cleaner energy economy to be fully realised, wind power and other renewable energy sources must be responsibly developed, taking human and ecosystem impacts into consideration at early planning stages. The IEA Wind TCP recognises this need, and has included social impacts as a main priority and strategic objective for 2019-2024. Task 28 seeks to improve communication and information dissemination activities, and to enhance engagement and exchange, to ensure that social science becomes more thoroughly integrated across the traditionally disparate disciplines of wind energy science and engineering.

TASK 29 SUMMARY

Gerard Schepers, Koen Boorsma, TNO, and
Helge Madsen, DTU

Analysis of Aerodynamic Measurements

The main aim of IEA Task 29 is to validate, improve and develop aerodynamic models for wind turbine design codes. More specifically, the task focuses on validating and improving models for the following aspects: aerodynamic response to turbulent inflow; sheared inflow; 2D/3D aerodynamics; aeroelastic effects; and 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.

Until now, the main deliverable from Task 29 is the database of DanAero experimental data which has been made available to the aerodynamic research society. The DanAero experimental data meets a long-held demand for validation of aerodynamic design models.

Several analyses were carried out on these measurements which are reported during several dissemination activities. Also, a comparison takes places between results from various calculational codes and the detailed aerodynamic measurements.

Several industries participate in Task 29 and they use the insights obtained from Task 29 analyses in the assessment of their aerodynamic design calculations. In this respect, it is recalled that the DanAero experiment (i.e., the basis for Task 29) was carried out by an industrial consortium from LM Glasfiber, Siemens Wind Power, Vestas Wind Systems A/S and the utility company DONG Energy complemented with the Danish Technical University (DTU).

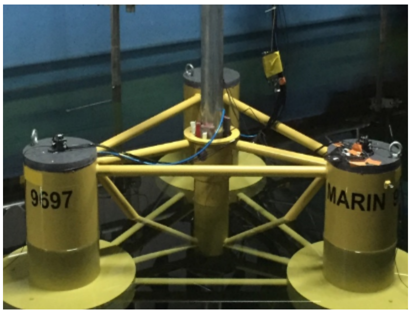
FIGURE 1: CONFIGURATION 1, OC6-DEEPCWIND FLOATING SEMI-SUBMERSIBLE WITH RIGID TOWER (PHOTO BY AMY ROBERTSON, NREL)

TASK 30 REPORT 2019

Offshore Code Comparison Collaboration

The OC3 (Offshore Code Comparison Collaboration) – OC6 projects (Offshore Code Comparison Collaboration, Continued with Correlation and unCertainty) were created under the framework of the International Energy Agency (IEA) Wind to address the need to verify and validate the load predictions of coupled modelling tools for offshore wind design.

AMY ROBERTSON,
National Renewable Energy Laboratory

These projects have proven to be vital to the companies developing and improving the numerical modelling tools used to design offshore wind systems, as well as designers, certifiers, and research institutes who apply these tools for design, research, and instruction (see Table 1 for current OC6 members).

Within the previous OC3-OC5 projects, differences were observed between the modelling approaches and the measured data, and often times the reason for the differences were not well understood. The focus of the new OC6 project is to develop more focused

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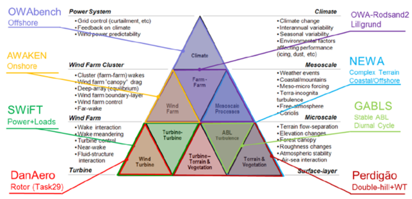
READ TASK 30


EXAMPLE OF LIDAR MEASUREMENTS FROM THE SWIFT STEERINGWAKES EXPERIMENT (SOURCE: SANDIA NATIONAL LABORATORIES)

TASK 31 REPORT 2019

International Wind Farm Flow Modelling and Evaluation Framework (Wakebench)

WAKEBENCH: Benchmarking Wind Farm Flow Models

JAVIER SANZ RODRIGO,
CENER, Spain

Introduction

Current wind energy models often lead to overprediction of wind plant performance, leading to high uncertainties and significant financial losses in the wind industry. State of-the-art wind resource assessment and wind farm design techniques employ four main topics: characterization of large-scale climatology; mesoscale meteorological processes; microscale, terrain, and wind farm array effects; and wind turbine aerodynamics.

Traditionally, these topics were analyzed separately, giving rise to different independent research communities (meteorologists, wind engineers, aerodynamicists). As a result, a wide variety of models have been developed by each specialized group with little interaction between them [1]. The next generation of wind-energy models need 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 that will 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 with the objective of implementing the international V&V framework through exploitation of data from recent field experiments carried out in the New European Wind Atlas (NEWA) project and the U.S. Department

Technology Collaboration Programme by iea

READ TASK 31

TASK 30 SUMMARY

Amy Robertson, NREL

Offshore Code Comparison Collaboration

A new extension of IEA Wind Task 30 named the Offshore Code Comparison Collaboration, Continued, with Correlation and unCertainty (OC6) was initiated in 2019. The goal of OC6 is to validate engineering-level offshore wind modelling tools that consider the simultaneous loading from wind and waves, as well as the interaction with the structural dynamics of the system and its control algorithms (aero-hydro-servo-elastic tools).

In addition, the OC6 project includes higher-fidelity models (such as computational fluid dynamics models [CFD]) to better understand the underlying physics. A three-way validation is performed where both the engineering-level modelling tools and higher-fidelity tools are compared to measurement data. The results will be used to help inform the improvement of engineering-level models, and/or guide the development of future test campaigns.

In 2019, Phase I of the project was initiated. This phase is focused on validating the ability of modelling tools to accurately predict the nonlinear hydrodynamic loading and response of floating wind systems at their surge and pitch natural frequencies. Participants built models representing two experimental campaigns performed at the MARIN wave basin to assess the hydrodynamic loading on a floating semisubmersible design studied in the previous OC5 project. Participants included research institutions, testing facility owners, certification agencies, technology developers (turbine and support structure), and software tools developers.

TASK 31 SUMMARY

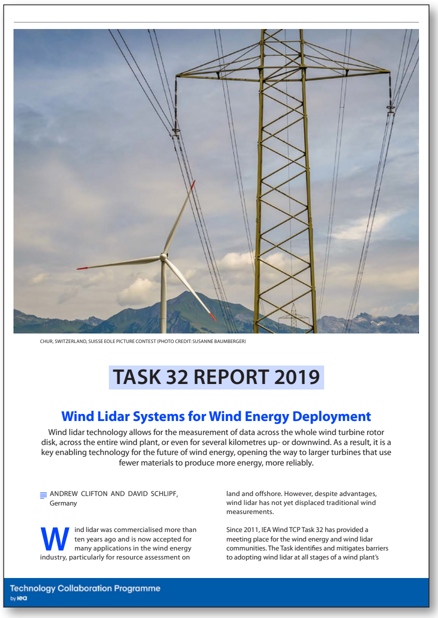
Javier Sanz Rodrigo, CENER

International Wind Farm Flow Modelling and Evaluation Framework (Wakebench)

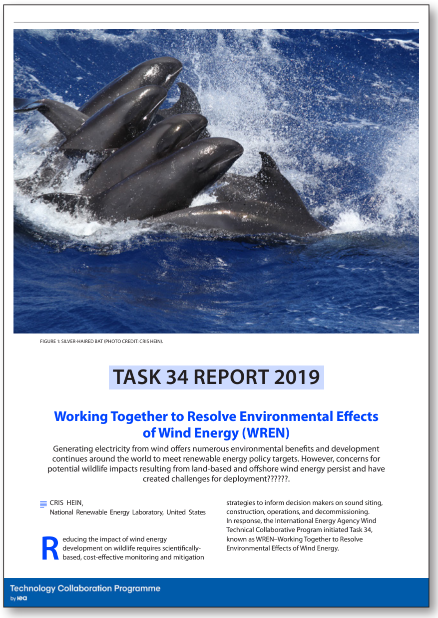
Task 31 "Wakebench" is a community of wind farm flow model developers and end-users from industry that works toward establishing an international framework for verification, validation, and uncertainty quantification.

Participants collaboratively work with model intercomparison benchmarks addressing high-impact phenomena for wind energy applications. Validation data is generated from high-fidelity experiments leveraged from national and European research initiatives, such as A2e in the United States and the New European Wind Atlas (NEWA) in Europe, as well as from industry-led initiatives such as the Offshore Wind Accelerator in the United Kingdom.

A recently completed single-wake benchmark included 13 simulations to compare inflow, turbine (power and loads), and wake measurements for near-neutral atmospheric conditions. Recent benchmarks focus on meso-wake methodology for offshore wind farms, and multi-scale and steady-state atmospheric models for wind resource assessment and siting conditions in complex terrain. Benchmarks are published open-source as part of the Wind Energy Model Evaluation Protocol (WEMEP) to provide guidance to flow modellers and set priorities for new experiments and validation activities.



READ TASK 32



READ TASK 34

TASK 32 SUMMARY

Andrew Clifton, Stuttgart Wind Energy, and David Schlipf, Flensburg U. Applied Science

Wind Lidar Systems for Wind Energy Deployment

Task 32 Wind Lidar is an international community to identify and mitigate barriers to the adoption of wind lidar for wind energy applications. Wind lidar technology allows winds to be measured across the wind turbine rotor disk, across the entire wind plant, or even for several kilometres up- or downwind of wind energy installations. It is a key enabler for larger and lighter wind turbines in actively-managed wind energy facilities.

More than 300 experts from 12 member countries work together to transfer technologies from the R&D community into everyday use. In 2019, we continued to prime the technology transfer pipeline with a workshop on lidar for wind turbine controls; brought together experts in working groups on wind lidar in cold climates and in complex terrain to identify opportunities to better leverage wind lidar; and supported the development of international standards for floating lidar. Our successful year was capped with a General Meeting at the Danish Technical University. In 2020 we plan a series of regular topical webinars and will be collaborating with other wind-energy groups to support workforce development and the deployment of wind lidar.

TASK 34 SUMMARY

Cris Hein, NREL

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

Wind energy continues to be developed, yet barriers persist relative to environmental effects of wind turbines which can prevent or delay deployment. There continues to be a strong need to share research, including recommended practices for monitoring and mitigation. The global nature of the wind energy industry, combined with the understanding that many affected species cross jurisdictional boundaries, highlight the need to collaborate at an international level. In response to global concerns for wildlife impacts at land-based and offshore wind energy development, the IEA Wind TCP initiated Task 34, known as WREN—Working Together to Resolve Environmental Effects of Wind Energy.

Since its inception in 2013, WREN has served as a leading international forum providing relevant, scientifically credible data for policymakers, natural resource managers, and wind energy developers/operators to facilitate informed decisions that meet both conservation and energy production objectives.

In 2019, WREN continued managing the Tethys knowledge base (tethys.pnnl.gov) and began implementing a new outreach plan. Task 34 also completed a short science summary entitled "Bat Interactions with Land-based Wind Energy: A European and North American Perspective", hosted a webinar entitled "Multiple Uses for Offshore Space: Incorporating Wind Energy Development"", and submitted a white paper on Risk-based Management. In addition, WREN developed a proposal to extend Task 34 through 30 September 2024. During two in-person Task 34 meetings in 2019, stakeholders from the wind energy, regulatory, and conservation communities were invited to present their perspectives and relevant research.

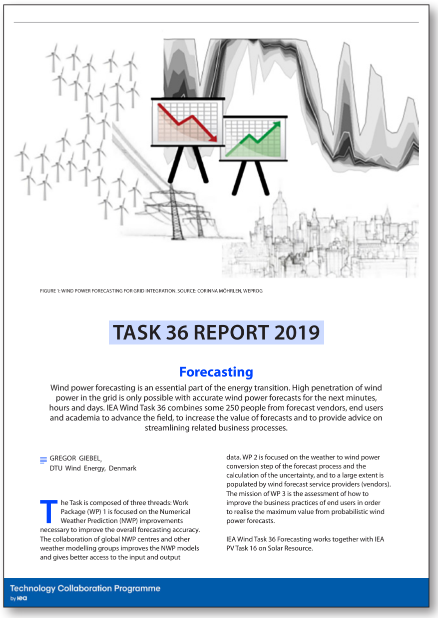


FIGURE 1: WIND POWER FORECASTING FOR GRID INTEGRATION. SOURCE: CORINNA MÖHRLEN, WEPROG

TASK 36 REPORT 2019

Forecasting

Wind power forecasting is an essential part of the energy transition. High penetration of wind power in the grid is only possible with accurate wind power forecasts for the next minutes, hours and days. IEA Wind Task 36 combines some 250 people from forecast vendors, end users and academia to advance the field, to increase the value of forecasts and to provide advice on streamlining related business processes.

GREGOR GIEBEL,
DTU Wind Energy, Denmark

The Task is composed of three threads: Work Package (WP) 1 is focused on the Numerical Weather Prediction (NWP) improvements necessary to improve the overall forecasting accuracy. The collaboration of global NWP centres and other weather modelling groups improves the NWP models and gives better access to the input and output data. WP 2 is focused on the weather to wind power conversion step of the forecast process and the calculation of the uncertainty, and to a large extent is populated by wind forecast service providers (vendors). The mission of WP 3 is the assessment of how to improve the business practices of end users in order to realise the maximum value from probabilistic wind power forecasts.

IEA Wind Task 36 Forecasting works together with IEA PV Task 16 on Solar Resource.

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READ TASK 36

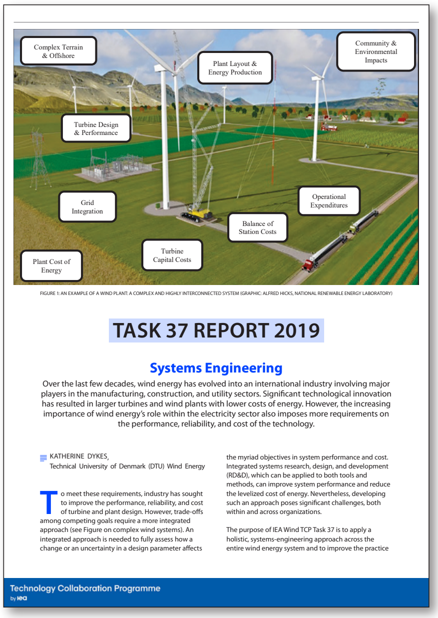

FIGURE 1: AN EXAMPLE OF A WIND PLANT: A COMPLEX AND HIGHLY INTERCONNECTED SYSTEM (GRAPHIC: ALFRED HICKS, NATIONAL RENEWABLE ENERGY LABORATORY)

TASK 37 REPORT 2019

Systems Engineering

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.

KATHERINE DYKES,
Technical University of Denmark (DTU) Wind Energy

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 Figure on complex 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

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TASK 36 SUMMARY

Gregor Giebel, DTU

Forecasting

Task 36 is the collaborative work of meteorologists, forecast vendors, academia, and end users to investigate and identify significant advances in wind power forecasting and make them more visible to the user community. This includes demonstrating the value of forecasts, especially of probabilistic forecasts.

The main result in 2019 was the release of the Recommended Practice on Forecast Solution Selection, discussing how to select an optimal forecast solution for a user's application, how to avoid the pitfalls often seen in the process of trials and benchmarks and how to best evaluate forecasts. In our meetings, special sessions, and open-space workshops, we also collected further feedback from industry and academic users. Additionally, the task worked on use cases and games for probabilistic forecasts, standardisation of the data transfer and of meteorological instruments for forecast use, an information portal for weather data relevant for wind power forecasts, and the value of improved forecasts in different markets.

TASK 37 SUMMARY

Katherine Dykes, DTU, and Garrett Barter, NREL

Systems Engineering

Phase II for IEA Wind Task 37 began in 2019 and involved extension of activities from phase I around ontologies and data format standards for wind energy applications, reference systems and design case studies, as well as new activities on expert workshops on specialised wind energy systems engineering workshops. A key deliverable in 2019 for Task 37 included the release of three new reference turbines: the IEA Wind 3.4-MW, IEA Wind 10-MW, and the IEA Wind 15-MW wind turbines. Along with full technical reports, the detailed design specifications for all turbines can be found at *github.com/ieawindtask37*. This work includes aeroelastic models for FAST, HAWC2, and Cp-Lamda.

The 15-MW turbine in particular is aimed at floating wind energy applications and design of the support structures for the turbine which will be developed in 2020. In addition, the first expert workshop for the task was held in the fall of 2019 in collaboration with Task 32 on the potential for lidar-assisted control (LAC) to influence wind turbine design. The proceedings of the workshop were developed into a conference paper that will be presented at Torque 2020: *www.torque2020.org/*. Work continued on the ontology development and optimisation case studies with publications expected in 2020 on both efforts.

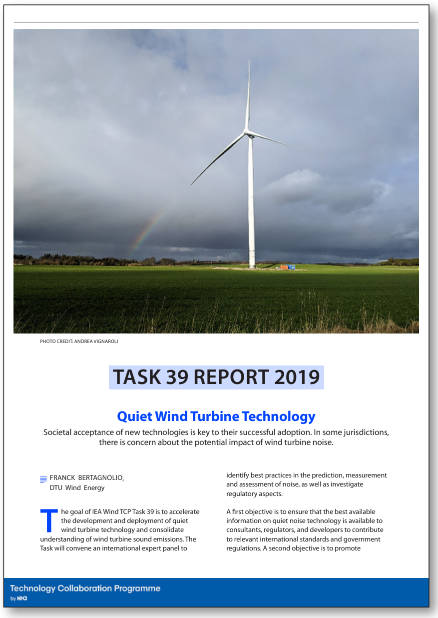
PHOTO CREDIT: ANDREA VIGNAROLI

TASK 39 REPORT 2019

Quiet Wind Turbine Technology

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.

FRANCK BERTAGNOLIO, DTU Wind Energy

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.

A first 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. A second objective is to promote

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[READ TASK 39]

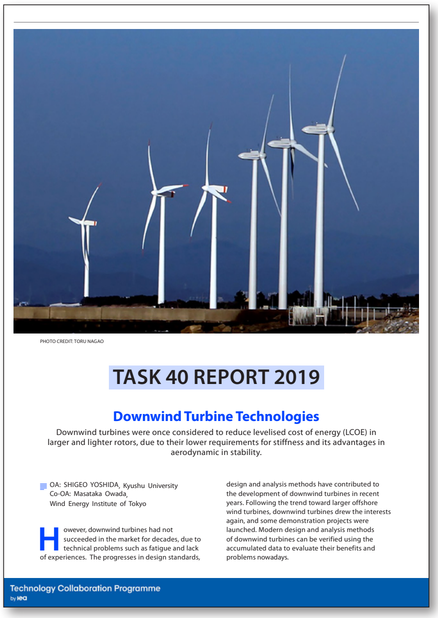
PHOTO CREDIT: TORU NAGAO

TASK 40 REPORT 2019

Downwind Turbine Technologies

Downwind turbines were once considered to reduce levelised cost of energy (LCOE) in larger and lighter rotors, due to their lower requirements for stiffness and its advantages in aerodynamic in stability.

OA: SHIGEO YOSHIDA, Kyushu University
Co-OA: Masataka Owada, Wind Energy Institute of Tokyo

However, downwind turbines had not succeeded in the market for decades, due to technical problems such as fatigue and lack of experiences. The progresses 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 the interests again, and some demonstration projects were launched. Modern design and analysis methods of downwind turbines can be verified using the accumulated data to evaluate their benefits and problems nowadays.

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[READ TASK 40]

TASK 39 SUMMARY

Franck Bertagnolio, DTU

Quiet Wind Turbine Technology

Wind turbine noise is recognised as a key factor for social acceptance of wind energy. 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 approach is two-fold. On one hand, technical experts are convened to investigate various aspects of modelling, measurement, assessment techniques, as well as regulatory aspects, in the field of wind turbine noise to improve our general understanding of these various interacting factors. On the other hand, the best available information on quiet wind turbine technologies should be made available to all stakeholders, from decision makers and regulators to developers.

Wind turbine noise experts from the largest wind turbine manufacturing and consultancy companies and from the academic world, originating from a large variety of countries, have been active in the Task endeavour to reach these goals. The main activities have been concentrated on two benchmark exercises: one concerning wind turbine noise simulation codes, the second concerning measurement of airfoil serration noise with subsequent benchmarking of corresponding noise models. Furthermore, a series of documents, including fact sheets on specific topics, are being drafted and should provide valuable and up-to-date technical information in an easily accessible format to a larger audience.

TASK 40 SUMMARY

Shigeo Yoshida, Kyushu University, and
Masataka Owada, Wind Energy Institute of Tokyo

Downwind Turbine Technologies

Following the trend toward larger offshore wind turbines, downwind turbines began to draw more interest. At this point, modern design and analysis methods of downwind turbines can be verified using accumulated data to evaluate their benefits and challenges. Task 40 was launched in March 2018. Its objective is to coordinate international research and investigate the benefits of downwind turbine technologies, and it is expected to publish IEA Wind TCP Recommended Practices on relevant technologies as well as journal and conference papers. Task 40 consists of the following Work Packages regarding downwind turbine technologies:

- *Model Development and Verification*: conduct model development and verification. A 2-MW baseline turbine aeroelastic model was developed to evaluate the models and analyses in other sub-WPs. Fundamental research revealed the rotor-tower aerodynamic interaction phenomena (i.e., tower shadow effects) which is one of the technical problems of downwind turbines, and three tower shadow models in blade-element and momentum method were reported. CFD was conducted to verify the nacelle/spinner-blade interaction model. Environmental conditions for passive yaw idling in a storm, which is a promising advantage of downwind turbines, were proposed based on analysis and field measurement.
- *Design and LCOE Assessment*: conduct design and LCOE assessment, especially for extremely large-scale downwind turbines. Aeroelastic and optimisation models were developed for a 10-MW turbine. The optimisation of the downwind rotor shows promising results in reduced blade mass from the baseline design and LCOE reduction.
- *Recommended Practices*: participants integrate and summarise the achievements of the first two work packages in a series of Recommended Practices. The main technical topics were chosen in 2019.


TASK 41 PARTICIPANTS WITH ATTENDEES FROM THE NORTH AMERICAN WIND ENERGY ACADEMY/ WINDTECH SYMPOSIUM IN FRONT OF THE 90-METRE WIND TURBINE BLADE TEST FRAME AT THE MASSACHUSETTS CLEAN ENERGY CENTER'S WIND TECHNOLOGY TESTING CENTER IN BOSTON, MASSACHUSETTS. PHOTO CREDIT: GEORGE BLAGDON / WIND TECHNOLOGY TESTING CENTER

TASK 41 REPORT 2019

Enabling Wind Power to Contribute to a Distributed Energy Future

Task 41 was initiated in January 2019 to advance wind technology as a cost-effective and reliable distributed energy resource. While large-scale wind project costs have decreased over time, distributed wind system costs have not decreased.

ALICE ORRELL, Pacific Northwest National Laboratory

Furthermore, great potential exists, worldwide, for expanded distributed energy resource markets, particularly as grids evolve and the need for clean, low-cost energy increases.

To address these issues, the objectives of Task 41 are to expand international collaboration and promote engagement in the wider distributed energy research fields and deployment markets to lower the costs and deployment barriers for wind as a distributed energy resource.

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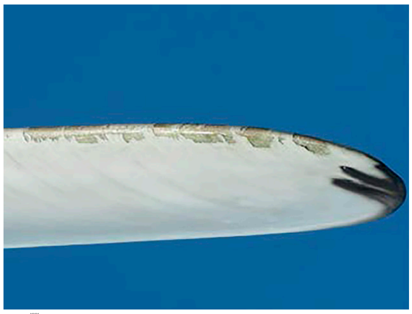
[READ TASK 41]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TASK 42 REPORT 2019

Lifetime Extension Assessment

With a significant number of wind turbines reaching their planned design life (usually 20 years), it is essential that wind-farm owners take decisions regarding their viable options: life extension, repowering or decommissioning.

XXXXXXXXX, xxxxxxxxx

The objectives of this task are to coordinate international research activities towards the assessment of the remaining operational life of wind turbines nearing the end of their certified design life and identification of strategies for extending the end of useful life. This will be done through research activities for determining the probability of failure of different wind turbine components upon continued operation, examination of procedures that demonstrate the feasibility for life extension, the requirements for maintenance and to recommend findings to international standards and regulatory bodies. The decision on lifetime extension is to be taken based on technical, legal and economic aspects.

Technology Collaboration Programme by iea

[READ TASK 42]

TASK 41 SUMMARY

Alice Orrell, PNNL, and Ian Baring-Gould, NREL

Enabling Wind Power to Contribute to a Distributed Energy Future

Task 41 was initiated in January 2019 to advance wind power technology as a cost-effective and reliable distributed energy resource. The objectives of Task 41 are to expand international collaboration and promote engagement in the wider distributed energy research fields and deployment markets to lower the costs and barriers for wind power as a distributed energy resource.

In 2019, Task 41 participants made progress on identifying research opportunities to support updates to design and testing guidelines for small and mid-sized wind turbines and created an information-sharing platform for distributed wind research and data. Task 41 participants also explored ways to enable efficient and reliable integration of wind technology into evolving electricity systems, facilitated and coordinated distributed wind research with other International Energy Agency (IEA) tasks and international organisations, and applied innovations in large-scale wind technology to smaller-scale wind technology.

TASK 42 SUMMARY

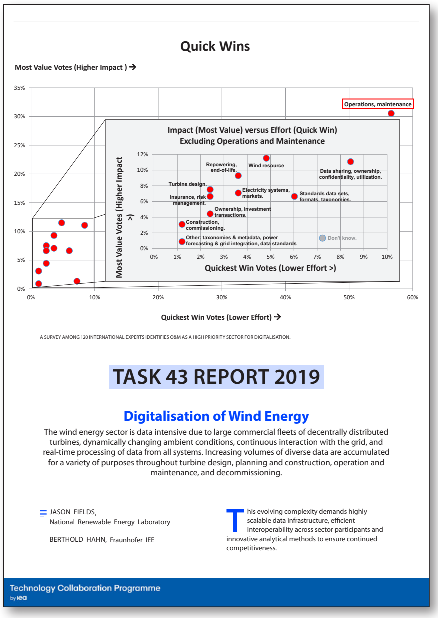
Anand Natarajan, DTU

Lifetime Extension Assessment

Task 42 was initiated in September 2019. The objectives of the task include the development of benchmark methods for assessment of the reliability level of primary structures under relevant limit states; the development of methods to detect damage and discuss how to categorise damages based on established knowledge; reporting on the management of data and its usefulness for life extension and application to predictive maintenance and repairs; and policy and state-of-the art reports on regulatory approaches and public perception.

The results of the task should be utilisable in the development of standards for lifetime extension and by national bodies putting in place regulations on lifetime extension; Industry participation includes wind turbine manufacturers Enercon Gmbh and Goldwind, along with service companies Woelfel and EMD A/S.

In 2019, all partners participated in a brainstorming session to determine gaps in the process for life extension today and key priorities for the task. The resulting key priorities focused on necessary actions in methods for life extension and inspection methods, including: differentiation between asset monitoring and asset inspection, and quantification of variations in predicted lifetime for various methods of lifetime extension. This benchmarking exercise is being planned with available wind farm data and the work will be initiated mid-2020.


Quick Wins

Most Value Votes (Higher Impact) →

Operations, maintenance

Impact (Most Value) versus Effort (Quick Win)
Excluding Operations and Maintenance

Repowering, end-of-life.
Wind resource
Data sharing, ownership, confidentiality, utilization.
Turbine design.
Electricity systems, markets.
Standards data sets, formats, taxonomies.
Insurance, risk management.
Ownership, investment transactions.
Construction, commissioning.
Other: taxonomies & metadata, power forecasting & grid integration, data standards
Don't know.

Most Value Votes (Higher Impact >)

Quickest Win Votes (Lower Effort >)

Quickest Win Votes (Lower Effort) →

A SURVEY AMONG 120 INTERNATIONAL EXPERTS IDENTIFIES O&M AS A HIGH PRIORITY SECTOR FOR DIGITALISATION.

TASK 43 REPORT 2019

Digitalisation of Wind Energy

The wind energy sector is data intensive due to large commercial fleets of decentrally distributed turbines, dynamically changing ambient conditions, continuous interaction with the grid, and real-time processing of data from all systems. Increasing volumes of diverse data are accumulated for a variety of purposes throughout turbine design, planning and construction, operation and maintenance, and decommissioning.

JASON FIELDS, National Renewable Energy Laboratory

BERTHOLD HAHN, Fraunhofer IEE

This evolving complexity demands highly scalable data infrastructure, efficient interoperability across sector participants and innovative analytical methods to ensure continued competitiveness.

Technology Collaboration Programme by iea

READ TASK 43

TASK 43 SUMMARY

Jason Fields, NREL, and Berthold Hahn, Fraunhofer IEE

Digitalisation of Wind Energy

While the wind industry has already made progress digitising specific segments of the wind energy life cycle, much remains to be done to increase digitalisation momentum. This includes developing a holistic view and identifying wider opportunities to reduce lifecycle costs, to enhance performance of assets and to integrate wind energy effectively into evolving energy grids and markets. The topic aligns well with the aims and strategy of the IEA and is ideal to address under the IEA Wind TCP task framework, enabling broad collaboration within the global wind community.

The scope of the Task includes digitisation topics across the dimensions of lifecycle stages, value-chain components, and interaction between and across lifecycle and value-chain players. The Task intends to address the recurring themes identified at the Topical Expert Meeting (TEM) 92 meeting in October 2018 and further explored through 2019. The purpose is to coordinate research and development activities from data and analytics to connectivity across the global wind industry, and to recommend best practices that maximise realisation of benefits from digitalisation while minimising duplicate effort. This will be achieved by convening an international expert body that will define what is meant by wind energy digitalisation; describe the current state of digitalisation capability and practice within the wind energy sector; identify and prioritise value-added opportunities enabled by further digitalisation; and to develop recommended digitalisation practices for the wind energy sector.

With the kick-off meeting in Boulder, CO, in November 2019, the task confirmed the proposed aims, formed working groups, and started active work.

Appendices

(Available from September 2020)

Task Reports 2019
Country Reports 2019
Statistics

Country Reports - Overview

IEA Wind Member countries and EU and WindEurope have a 2019 report report (available in September 2020) with progress & achievements, outcomes & significance and next steps.

AUSTRIA

READ COUNTRY REPORT - AUSTRIA

BELGIUM

READ COUNTRY REPORT - BELGIUM

CANADA

READ COUNTRY REPORT - CANADA

CHINA

READ COUNTRY REPORT - CHINA

DENMARK

READ COUNTRY REPORT - DENMARK

EU

READ COUNTRY REPORT - EU

FINLAND

READ COUNTRY REPORT - FINLAND

FRANCE

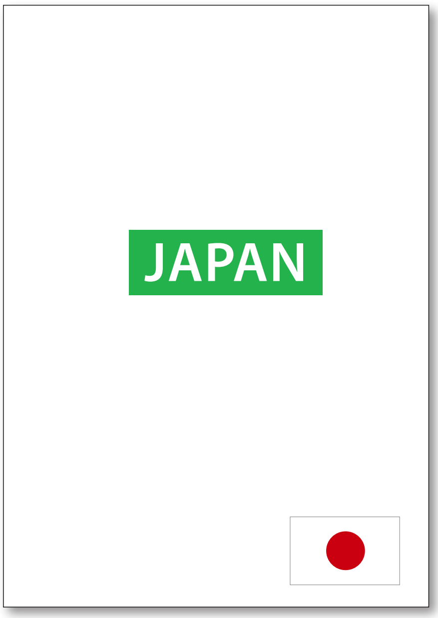
READ COUNTRY REPORT - FRANCE

READ COUNTRY REPORT - GERMANY

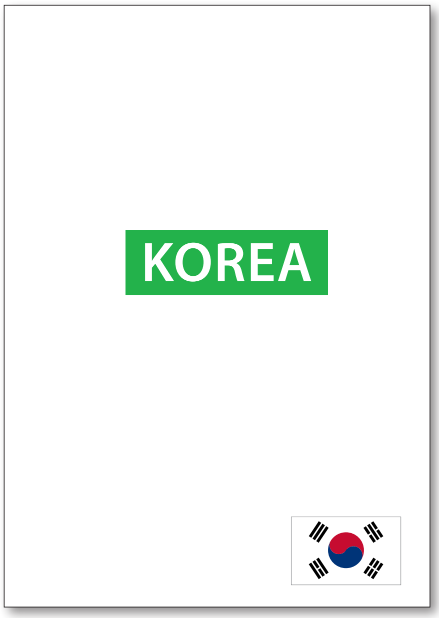
READ COUNTRY REPORT - GREECE

READ COUNTRY REPORT - IRELAND

READ COUNTRY REPORT - ITALY



READ COUNTRY REPORT - JAPAN



READ COUNTRY REPORT - KOREA

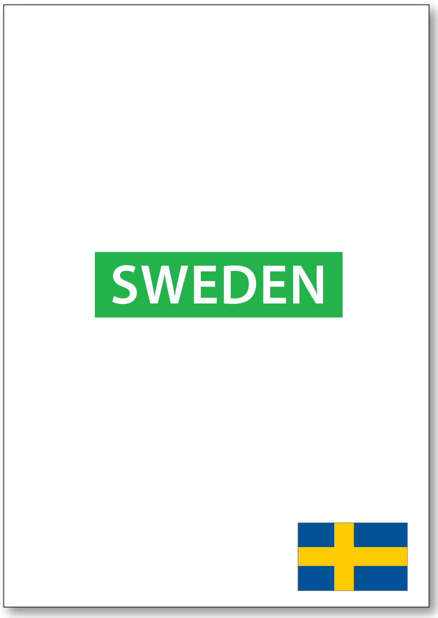
READ COUNTRY REPORT - MEXICO

READ COUNTRY REPORT - NETHERLANDS

READ COUNTRY REPORT - NORWAY

READ COUNTRY REPORT - PORTUGAL

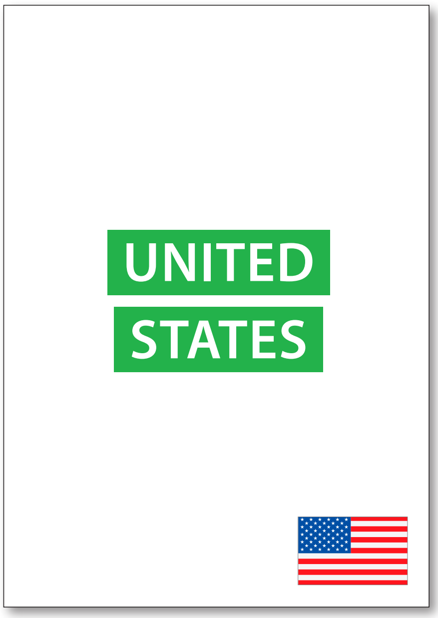
READ COUNTRY REPORT - SPAIN



READ COUNTRY REPORT - SWEDEN

READ COUNTRY REPORT - SWITZERLAND

READ COUNTRY REPORT - UNITED KINGDOM



READ COUNTRY REPORT - UNITED STATES


PHOTO: COLOURBOX

Table 4, National Statistics of the IEA Wind Member Countries 2019

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	3,2	120	7,0	63	11,1 %
Belgium	3,8	519	9,5	84	11,4 %
Canada	13,4	597	32,8	593	5,5 %
China	236,3	26,785	405,7	7,226	5,6 %
Denmark	6,1	-12	16,2	34	47,2 %
Finland	2,3	243	6,0	86	7,0 %
France	16,7	1,419	34,1	489	7,0 %
Germany	60,8	2,092	126,0	595	21,2 %
Greece	3,6	710	7,2	58	12,5 %
Ireland	4,1	497	9,4	31	30,7 %
Italy	10,5	457	20,1	319	6,3 %
Japan	3,9	270	6,7	883	0,8 %
Korea	1,5	191	2,7	524	0,5 %
México	6,1	1,281	16,7	318	5,3 %
Netherlands	4,5	228	10,7	122	8,8 %
Norway	2,4	754	5,5	135	4,1 %
Portugal	5,4	69	13,7	52	26,3 %
Spain	25,7	2,219	54,2	249	20,8 %
Sweden	9,0	1,588	19,9	138	14,4 %
Switzerland	0,1	0	0,1	57	0,3 %
United Kingdom	24,0	2,195	64,1	324	19,8 %
United States	105,6	8,916	300,0	4118	7,3 %
Totals	**549,0**	**51,138**	**1,168,0**	**16,496**	**7,1 %**
Non-IEA Wind TCP countries	*101,1*	*9,212*	*427,9*	*10,578*	*4,1 %*
World total	**650,1**	**60,350**	**1,597,4**	**27,074**	**5,9 %**

Table 5. Potential Capacity Increases Beyond 2019 in Reporting Member Countries

Country	Planning Approval [a] (MW)		Under Construction [b] (MW)		Total (MW)
	Land-based	Offshore	Land-based	Offshore	
Austria	1,185	---	25	---	1,210
Belgium	776	1,586	---	706	3,068
Canada	1,176	---	---	---	1,176
Denmark	---	600	---	---	600
Finland	3,839	---	1,347	---	5,186
France	---	480	---	480	960
Germany	---	3,200	---	100	3,300
Ireland	---	---	---	---	---
Italy	---	30	---	---	30
Korea	---	---	---	---	---
México	---	---	1,070	---	1,070
Norway	4,270	---	2,487	---	6,757
Netherlands	66	700	3,092	2,800	6,658
Spain	13,138	---	9,984	---	23,122
Sweden	6,257	1,925	4,271	---	12,453
Switzerland	---	---	12	---	12
United Kingdom	---	850	---	1,810	2,660
United States	35,032	9,121	22,115	---	66,268

--- = no data available. a Projects have been approved by all planning bodies but work at site not yet started. b Physical work has begun on the projects

Table 6. Wind Power Capacity Rankings: Capacity, Percent Increase, Relative to Country Size and Average size of turbines

	Cumulative Capacity (end of 2019)		New Capacity (2019)		Increase in Cumulative Capacity (2019)		Capacity Relative to Country Size		Average Capacity New Land-based Turbines		Average Capacity All Turbines	
	Country	MW	Country	MW	Country	%	Country	kW/km²	Country	MW	Country	MW
1	China	236,320	China	26,785	Norway	45%	Germany	170	Finland	4.34	Norway	3.06
2	US	105,591	US	9,137	México	26%	Denmark	140	Norway	4.13	Finland	3.03
3	Germany	60,840	Spain	2,243	Greece	25%	Belgium	125	Sweden	3.55	Austria	2.36
4	Spain	25,704	UK	2,205	Sweden	21%	Netherlands	109	Spain	3.54	Sweden	2.19
5	UK	23,975	Germany	2,189	Belgium	16%	UK	99	Korea	3.47	Korea	2.16
6	France	16,654	Sweden	1,588	Korea	15%	Portugal	59	Canada	3.41	México	2.14
7	Canada	13,413	France	1,419	Ireland	14%	Ireland	59	Germany	3.32	France	2.09
8	Italy	10,513	México	1,281	China	13%	Spain	51	Austria	3.10	Switzerland	2.03
9	Sweden	8,984	Norway	785	Finland	12%	Austria	38	México	3.06	Canada	1.98
10	México	6,125	Greece	725	UK	10%	Italy	35	Ireland	3.05	Germany	1.97
11	Denmark	6,104	Canada	597	Spain	9%	France	30	Italy	2.96	Netherlands	1.96
12	Portugal	5,437	Belgium	519	France	9%	Greece	27	Netherlands	2.87	Ireland	1.96
13	Netherlands	4,520	Ireland	497	US	9%	China	25	France	2.78	Portugal	1.94
14	Ireland	4,137	Italy	457	Japan	7%	Sweden	20	Japan	2.60	US	1.76
15	Japan	3,923	Netherlands	278	Netherlands	5%	US	19	US	2.55	China	1.75
16	Belgium	3,779	Japan	270	Canada	5%	Korea	15	Portugal	2.46	Japan	1.63
17	Greece	3,589	Finland	243	Italy	5%	Japan	11	China	2.35	Italy	1.49
18	Austria	3,159	Korea	191	Austria	4%	Finland	7	Greece	2.31	Greece	1.47
19	Norway	2,444	Austria	152	Germany	4%	Norway	6	Denmark	1.32	Spain	1.23
20	Finland	2,284	Portugal	69	Portugal	1%	México	3			Denmark	0.98
21	Korea	1,490	Denmark	28	Switzerland	0%	Switzerland	2				
22	Switzerland	75	Switzerland	0	Denmark	0%	Canada	1				

Table 7. Targets Reported for IEA Wind TCP Member Countries

Country	Official Target Renewable Energy Sources (RES)	Official Target Wind Energy	2019 Total Wind Power Capacity (MW), Annual Contribution to Demand (%), or Annual Production (TWh)
Austria	34% RES share in final gross energy demand by 2020; 100% of electricity by 2030; climate neutral by 2040	3,800 MW by 2020 (from year 2019) 10 TWh more by 2030	3,159 MW 7 TWh
Belgium	13% RES share in final gross energy demand by 2020	2,741 MW offshore and 3,000 MW land-based by 2020	3,779 MW (1,555 MW offshore and 2,224 MW land-based)
Canada	No federal targets, several provinces have renewable targets	---	
China	680 GW by 2020	210 GW by 2020	236 GW (210 GW grid-connected)
Denmark	30% of final gross energy demand by 2020; 55% by 2030; climate neutral by 2050	50% by 2020; doubling land-based to 20 TWh and 5-fold offshore to 33 TWh by 2030	47%
European Union	20% of final gross energy demand by 2020; 32% by 2030; climate neutral by 2050	486 TWh by 2020	417 TWh
Finland	39% of final gross energy demand by 2020;climate neutral by 2035	6 to 6.5 TWh/yr by 2020; 9 TWh/yr by 2025	6 TWh
France	33% of final gross energy demand by 2030 (40% of electricity); 74 GW by 2023	24.1 GW land-based and 2.4 GW offshore by 2023; 33.2-34.7 GW land-based and 5.2-6.2 GW offshore by 2028	16.65 GW land-based;0.002 GW offshore
Germany	Gross energy demand: 30% by 2030, 45% by 2040, 60% by 2050; gross electricity demand: 40-45% by 2025, 55-60% by 2035, >80% by 2050. An amendment to the current targets will follow in 2020, introducing the ambitious target of 65% RES by 2030.	Regular auctions for land-based wind will tender around 2.7 GW/yr from 2019-2021 and from 2022 on 2.9 G/yr. Furthermore, extra onshore auctions will tender 4 GW from 2019-2021. Offshore: 20 GW by 2030	61 GW (7.5 GW offshore; 53.3 GW land-based)
Greece		7 GW by 2030	3.6 GW
Ireland	16% RES share in final gross energy demand by 2020;projected 40% of electricity demand; 70 % by 2030	4.2 GW by 2020 (3900 – 4400MW Eirgrid All-island Generation Capacity Statement 2019 *http://www.eirgridgroup.com/site-files/library/EirGrid/EirGrid-Group-All-Island-Generation-Capacity-Statement-2019-2028.pdf*	4.1 GW 31%
Italy	17% RES share in final gross energy demand by 2020	12 GW land-based and 0.68 GW offshore by 2020; 19 GW (41.5 TWh) by 2030	10.5 GW land-based
Japan	21-23% by 2030	10 GW by 2030	3.7 GW
Korea	20% renewable energy penetration of the electricity demand by 2030	17.7 GW by 2030 (12 GW offshore)	0.5% (provisional), 1490MW, 2.7TWh (Provisional)
México	30% of electricity by 2021 and 35% by 2024	5.5 GW by 2031; industry target 8 GW by 2020	6.1 GW
Netherlands	14% RES share in final gross energy demand by 2020	Offshore 11 GW by 2030 (old onshore target 6 GW by 2020, estimated to be reached by 2023)	4.5 GW
Norway	New renewables 28 TWh/yr by 2020. The target is shared with Sweden	---	
Portugal	31% of final gross energy demand by 2020; 47% by 2030	5.3 GW land-based and 0.027 GW offshore by 2020; 9.3 GW by 2030	5.4 GW
Spain	20% of final gross energy demand by 2020	35 GW by 2020; 50 GW by 2030	25.7 GW
Sweden	50% of final gross energy demand by 2020; 100% renewable electricity in 2040; climate neutral by 2045	30 TWh by 2020 (20 TWh land-based; 10 TWh offshore)	20 TWh
Switzerland	Increase generation by 24.2 TWh by 2050	0.4 TWh by 2020; 4.3 GW by 2050	0.15 TWh
United Kingdom	30% of electricity from renewable sources by 2020	40 GW by 2030	21.7 GW
United States	Increase the generation of electric power from renewables through cost reductions.	By 2030, reduce the cost of land-based wind power to $0.023/kWh (0.020 EUR/kWh) without incentives, and reduce the modeled cost of offshore wind power to $0.051/kWh (0.045 EUR/kWh).	105,591 MW 7.3%

--- = No official target available

Table 8. Turbine Details 2019

Country	Total Number of Turbines Operating	Average Capacity of All Turbines	Average Capacity of Land-based Turbines	Average Capacity of New Offshore Turbines	Average Capacity of New Land-based Turbines	Average Capacity of All New Turbines
		MW	MW	MW	MW	MW
Austria	1,340	2.4	2.4	---	3.1	3.1
Belgium	---	---	---	8.4	---	---
Canada	6,771	2.0	2.0	---	3.4	3.4
China	134,854	1.8	1.7	4.2	2.4	2.5
Denmark	6,236	1.0	0.8	---	1.3	1.3
Finland	754	3.0	3.0	---	4.3	4.3
France	7,951	2.1	2.1	---	2.8	2.8
Germany	30,941	2.0	1.8	6.9	3.3	5.2
Greece	2,435	1.5	1.5	---	2.3	2.3
Ireland	2,149	1.9	1.9	---	2.8	2.8
Italy	7,042	1.5	1.5	---	3.0	3.0
Japan	2,414	1.6	1.6	---	2.6	2.6
Korea	690	2.2	2.1	---	3.5	3.5
México	2,857	2.1	2.1	---	3.1	3.1
Netherlands	2,304	2.0	1.8	---	2.9	2.9
Norway	800	3.1	3.1	---	4.1	4.1
Portugal	2,801	1.9	1.9	---	2.5	2.5
Spain	20,939	1.2	1.2	---	3.5	3.5
Sweden	4,099	2.2	2.2	---	3.6	3.6
Switzerland	37	2.0	2.0	---	---	---
United Kingdom	---	---	---	6.1	---	---
United States	60,000	1.8	1.8	---	2.6	2.6
Average		2.0	1.9	6.4	3.0	3.1
Maximum		3.1	3.1	8.4	4.3	5.2
Minimum		1.0	0.8	4.2	1.3	1.3

--- = no data available

Table 9. Estimated Average Turbine Cost and Total Project Cost for 2019 in Reporting IEA Wind Countries

Country	Land-based Turbine Cost	Offshore Turbine Cost	Total Installed Land-based Project Cost	Total Installed Offshore Project Cost
	(USD/kW)	(USD/kW)	(USD/kW)	(USD/kW)
Austria	---	---	---	---
Canada	---	---	1,769	---
China	518	953	1,008	2,160
France	---	---	1,685	---
Germany	---	---	1,542	1,910
Ireland	---	---	---	---
Italy	---	---	1,348	---
Korea	---	---	---	---
México	1,215	---	1,687	---
Norway	891	---	1,174	---
Portugal	1,308	---	1,635	---
Spain	880	---	1,050	---
United States	800	---	---	---

--- = No data available

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

Table 10. Overview of Subsidy Systems and Other Tools Employed by IEA Wind Countries to Increase Wind Power Deployment

	Incentive Programs	Description	Countries Implementing
Financial incentives	**Auctions for guaranteed price**	Competitive bidding procurement processes for electricity from wind energy or where wind energy technologies are eligible	Canada, China, Denmark, Germany, Greece, Italy, México, Spain, United Kingdom
	Auctions for premium	Competitive bidding procurement processes for electricity from wind energy or where wind energy technologies are eligible.	Finland, France
	Feed-in tariff (FIT)	An explicit monetary reward for wind-generated electricity that is paid (usually by the electricity utility) at a guaranteed rate per kilowatt-hour that may be higher than the wholesale electricity rates paid by the utility	Austria, China, Germany, Greece, Ireland, Italy, Japan, Korea, Portugal, Switzerland, United Kingdom, United States
	Variable premium over market price	A variable premium paid is the difference between a guaranteed price and the electricity market price—producers are in the electricity markets	Finland, France, Germany, Netherlands, Switzerland, United Kingdom
	Fixed premium over the market price	A fixed premium is paid over the electricity market price—producers are in the electricity markets	United States
	Tax relief from import tax or other taxes	Some or all expenses associated with wind power installation may be deducted from taxable income streams; large wind turbine technologies have imports exempt from customs and import VAT charges	China, Netherlands, United States
Market-oriented regulatory incentives	**Renewable portfolio standards (RPS), renewables production obligation (RPO), or renewables obligation (RO)**	Mandate that the electricity utility (often the electricity retailer) source a portion of its electricity supplies from renewable energies.	Canada (BC, SK, NB, NS), Italy, Korea, México, Norway, United Kingdom, United States
	Green certificates	Approved power plants receive certificates for the amount (MWh) of electricity they generate from renewable sources. They sell electricity and certificates; the price of the certificates is determined in a separate market where demand is set by the obligation of consumers to buy a minimum percentage of their electricity from renewable sources	China, Italy, México, Netherlands, Norway, Sweden, United States
	Electric utility activities like green electricity schemes	Activities include green power schemes, allowing customers to purchase green electricity, wind farms, various wind generation ownership and financing options with select customers, and wind electricity power purchase models	Austria, Finland, Ireland, Netherlands, Norway, Sweden, United States
	Carbon tax	A tax on carbon that encourages a move to renewables and provides investment dollars for renewable projects	Canada (BC, AB, QC, ON), Europe
Planning and policy	**Investment funds for wind energy**	Share offerings in private wind investment funds are provided, plus other schemes that focus on wealth creation and business success using wind energy as a vehicle to achieve these ends	Italy, Netherlands, United Kingdom
	Spatial planning activities	Areas of national interest that are officially considered for wind energy development	Austria, China, Denmark, Finland, France, Greece, Ireland, Korea, Netherlands, Portugal, Switzerland, United Kingdom, United States (offshore)
	Special incentives for small wind	Reduced connection costs, conditional planning consent exemptions; value-added tax (VAT) rebate for small farmers; accelerated capital allowances for corporations; can include microFIT	Canada (ON, SK), Greece, Ireland, Italy, Netherlands, Portugal, United Kingdom, United States

Table 11. Capacity in Relation to Estimated Jobs and Economic Impact 2019

Country	Capacity	Estimated Number of Jobs	Economic Impact
	MW		million USD[a]
China	236,320	510,000	---
United States	105,591	114,800	14,000
Germany	60,840	---	7,220
Spain	25,704	24,000	4,526
United Kingdom	23,975	12,700	10
France	16,654	18,200	---
Canada*	13,413	2,716	1,056
Italy	10,513	16,000	4.2
Sweden	8,984	---	---
México	6,125	7,250	---
Denmark	6,104	85,000	---
Portugal	5,437	3,250	---
Netherlands	4,520	---	---
Ireland	4,137	---	---
Japan	3,923	---	---
Belgium	3,779	---	---
Greece	3,589	4,500	---
Austria	3,159	3,555	5
Norway	2,444	---	---
Finland	2,284	4,600	---
Korea**	1,490	1,500	700
Switzerland	75	---	---
Total	**549,060**	**808,071**	**27,517**

*Canada annual wind power investment. ** Korea domestic manufacturing sector / direct jobs only (Estimated)

Table 12. National R,D&D Budgets for Reporting Countries, 2010–2019

Country	2010 Budget	2011 Budget	2012 Budget	2013 Budget	2014 Budget	2015 Budget	2016 Budget	2017 Budget	2018 Budget	2019 Budget
	million USD	million USD	million USD	million USD	million USD	million USD	million USD	million USD	million USD	million USD
Austria	---	---	---	---	---	---	---	---	---	---
Belgium	---	---	---	---	---	4.7	---	---	---	---
Canada		7.8	5.8	5.0	4.7	2.3	3.4	3.3	2.9	3.1
China	---	---	---	---	---	11.7	1.4	---	8.8	9.4
Denmark [a)]	24.2	1.0	11.5	24.2	---	---	15.4	---	26.8	22.2
European Commission	47.0	36.7	80.9	90.5	29.9	315.0	68.5	32.7	81.1	62.1
Finland	5.2	12.9	2.8	4.3	1.2	1.9	1.9	0	1.7	0.4
France	---	---	---	---	---	---	---	---	---	---
Germany	71.2	105.1	103.2	50.6	46.6	99.1	93.4	108.2	103.8	90.7
Greece	---	---	---	---	---	---	---	---	---	2.1
Ireland	0.4	0.4	1.1	---	---	---	---	---	---	---
Italy	4.0	4.0	3.9	4.1	3.6	2.7		---	---	---
Japan	24.6	42.9	55.3	47.5	63.8	127.9	72.2	62.3	69.6	66
Korea	38.1	37.7	44.7	49.1	---	---	30.0	---	40.0	36
México	---	---	---	---	2.1	---	---	2	---	0.3
Netherlands	51.1	9.2	11.6	7.0	4.5			14.7	33.8	40.4
Norway	16.7	19.7	22.7	18.2	15.0	10.2	10.8	7.3	6.4	5.1
Portugal	---	---	---	---	---	---	---	---	---	---
Spain	115.9	115.9	158.2	117.8		94.0	85.5	11	17.2	26.3
Sweden	14.5	14.5	14.2	14.9	7.8	7.7	7.7	7.3	6.6	6.4
Switzerland	0.5	0.5	0.5	0.5	0.5	0.6	0.7	0.8	0.8	5.4
United Kingdom	---	---	---	---	---	---	---	---	---	---
United States	80.0	80.0	93.5	68.2	52.2	107.0		---	92	92

---- indicates no data available. Currency is expressed in year of budget. It is not adjusted to present value. a) Projects supported by public funds.

Table 11. Capacity in Relation to Estimated Jobs and Economic Impact 2019

Area	Country	Facility Description
Wind tunnels / Wave tanks	Denmark	The Poul La Cour Wind Tunnel inaugurated in August 2018 offers tests combining Reynolds Number and acoustic properties. Innovative aerodynamic blades profiles are also tested.
	Italy	CNR-INM hosts a wave tank and circulating water channel, which allows testing of model-scale offshore wind turbines installed on a floating platform in a controlled environment. POLI-Wind wind tunnel includes actively controlled and aero-elastically scaled wind turbine models for the simulation of wind farms and the study of wake interactions.
	Greece	FloatMAst Blue floating Tension Leg Platform (TLP) features a Lidar system and a 40-m mast and provides high accuracy wind speed and regime measurements. The prototype platform is currently deployed in the Aegean Sea.
Climatic testing facilities	Belgium	Climatic test chamber (OWI-lab) and cold climate wind tunnel (VKI)
	Finland	An Icing Wind Tunnel for testing of instruments and materials in representative icing conditions
Resource assessment	Belgium	A new floating lidar (FLiDAR) system available at OWI-lab
	Canada	Nergica owns and operates a research site that includes three met-masts, a WindCube 200s scanning lidar (and a hybrid microgrid comprising wind, solar PV, storage and diesel)
	Ireland	Two new meteorological Lidars were installed in 2017. UCC/HMRC Wave test tank.
	Norway	A floating Lidar buoy was developed by NOWITECH and Fugro
Offshore wind test and demon-strations sites	Belgium	OCAS fatigue testing facility for weld seams in offshore substructures
	Denmark	Four new test sites added at Høvsøre and Østerild. Turbines as tall as 330 m may be tested in Østerild.
	Finland	A demonstration offshore wind farm (42 MW) in a Baltic Sea site with winter ice started operation in 2017.
	France	Four floating wind demonstration projects awarded in 2016 continue progressing
		Floatgen was inaugurated and tested along the quay of Saint-Nazaire: a floating offshore demonstrator featuring an innovative "damping pool" concrete floating substructure and a 2-MW Vestas turbine
		Faraman: three Siemens 8-MW 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 engage in marine energy research include floating offshore wind. It will test BluWind, a Floating Wind 1:6 Scale Prototype Demonstrator. SEAI AMETS full scale floating test site in consenting with planned test of SAIPEM Hexafloat in EU AFLOWT project.
	Japan	A new floating offshore demonstrator commenced operations in the Fukushima FORWARD offshore wind farm, namely a Hitachi 5-MW downwind turbine with an advanced spar-type floater.
	Portugal	ReaLCoE is a H2020 demonstration project of offshore wind energy converters with a high-performance 12+MW demonstration wind turbine.
	Spain	PLOCAN (Canary Islands) and BiMEP (Biscay) are research facilities for testing marine energies.
	United Kingdom	A demonstration wind farm was commissioned by EDF, featuring five MHI Vestas V164 8.3-MW turbines mounted on float-and-sink gravity-based foundations at the Blyth Offshore Demonstration site.
	United States	Maine Aqua Ventus I and Central Maine Power Company signed a 20-year power purchase agreement for a DOE-funded offshore wind demonstration project, allowing the project to sell its electricity to the utility. NREL and Avangrid demonstrated wind energy's ability to maintain grid reliability and frequency regulation services at a California commercial wind plant.

CONTINUES NEXT PAGE

Table 11. Capacity in Relation to Estimated Jobs and Economic Impact 2019 - continue		
Area	**Country**	**Facility Description**
Land-based test and demonstration sites	Canada	WEICan 10-MW test site includes energy storage that demonstrates secondary frequency regulation
	China	China General Certification Center successfully tested a 83.6-m blade (natural frequencies and static testing)
	Denmark	The new Large-Scale Facility at DTU is in operation (part of Villum Center for Advanced Structural and Material Testing)
	Germany	The Center for Solar Energy and Hydrogen Research (ZSW) is constructing and operating the WindForS test site WINSENT in the Swabian Alps for wind energy research. The test site's purpose is to enable researchers, manufacturers and suppliers of wind turbines to test and validate new technologies in complex mountainous terrain by the use of two open-accessible turbines and four met masts. The HAPT project aims at increasing the reliability of rotor blade bearings and facilitating the application of new bearing-related technologies for wind turbines of up to 10 MW rated power. For the application of the test strategies, a full scale test rig is designed and manufactured.
	Greece	The GREEN ISLAND demonstration project, Agios Efstratios, aims at transforming a small isolated island grid into a RES powered system The system will include800-900kW wind turbine and 100-200 kW PV array supported by a 2.5 MWh Li-Ion battery and thermal storage for load balancing and medium term storage.
	Ireland	Eirgrid, the Irish TSO, completed trials in 2017 to verify the capabilities of power-generation and other technologies to provide newly defined system services. The wind power plant qualified to provide: 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).
	Korea	A blade test laboratory, Korea Institute of Materials Science (KIMS-WTRC), was recognised as RE Testing Laboratories of IECRE in 2019. It can accommodate and test 7-MW blade; the facility is 203 m long and 26 m tall, and is equipped with static and fatigue test equipment for blades.
	México	A blade manufacturing laboratory and a test facility for small blades are available atCEMIE-Eólico.
	Sweden	Rise Research Institutes of Sweden and Skellefteå Kraft are about to establish a test centre aimed at testing wind turbines and other equipment in cold and icy conditions.
	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
	Switzerland	Airborne wind energy is prioritized in Switzerland with a successful test flight of a TwingTec prototype T28 in Chasseral in 2018. The T29, with a rated power of 10 kW, was continuously tested in 2019. A demonstration project is being prepared by TwingTec and Skypull as a follow-up.
	United Kingdom	The Blade Erosion Test Rig (BETR) facility was commissioned by ORE Catapult
	United States	Massachusetts Clean Energy Center received Department of Energy funding to upgrade its Wind Technology Testing Center to enable structural testing of 85- to 120-meter-long blades.

More comprehensive data on test facilities can be found in the US DOE's Wind Energy Facilities Book 2017 and at Catalogue of Facilities Available, published by EU FP7-project IRPWIND (www.irpwind.eu/publications/deliverable)

IEA Wind TCP Annual Report 2019

The IEA Wind Technology Collaboration Programme (IEA Wind) is the leading international organisation for wind energy research cooperation. For more than 40 years, IEA Wind has been multiplying national technology research, development and deployment (R,D&D) efforts through information exchange and joint research projects.

Researchers from 22 member countries and 2 international organisations, representing over 85% 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.

IEA Wind fosters collaborative research and the exchange of best practices and data by supporting international expert collaboration and promoting standardisation to accelerate the pace of technology development and deployment.

This IEA Wind 2019 Annual Report highlights the work of the 17 active research tasks and provides an extensive summary of how member countries benefit from wind energy, how much wind power generation each country has deployed, and how policies and research programs will increase wind power's contribution to the world energy supply. The full report with separate country and task chapters and datasheet appendix is available at
community.ieawind.org

Authors:
Birte Holst Jorgensen, DTU, Denmark
Hannele Holttinen, Recognis, Finland
IEA Wind Operating Agents
IEA Wind Secretariat (Kirstine Dahlgaard, Klaus Rosenfeldt Jakobsen, Ignacio Martí, DTU)

Cover photo: Block Island Schroeder. The United States' first offshore wind farm near Block Island off the coast of Rhode Island (Photo: Dennis Schroeder/NREL)

Layout: www.STEPPRINTPOWER.dk

ISBN: 978-87-93549-78-4

AUGUST 2020

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