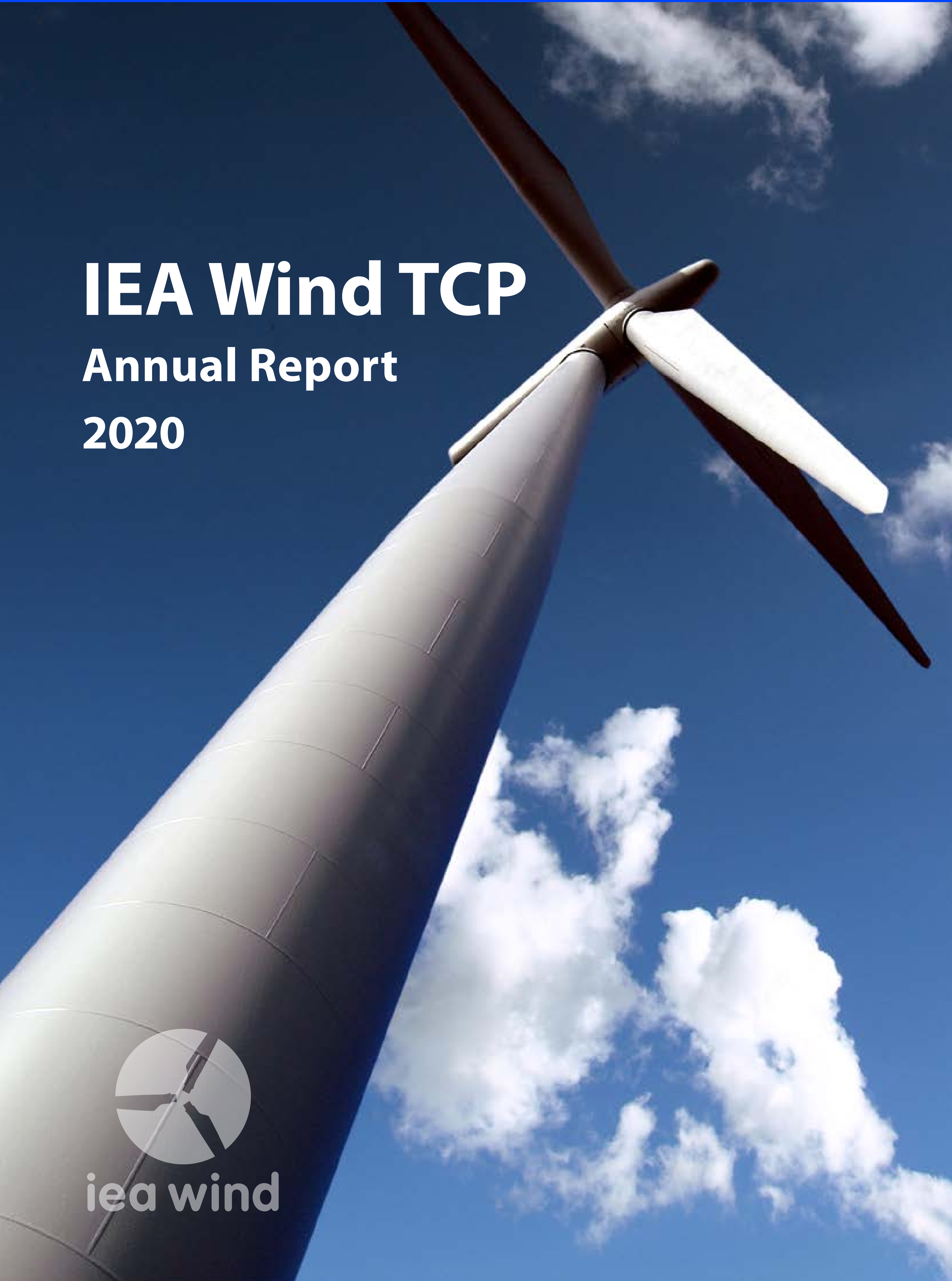
Technology Collaboration Programme
by iea



IEA Wind TCP
Annual Report
2020

iea wind

Message from the Chair


JOHN MC CANN

2020 was a year that challenged society's concepts of normality, citizens globally voluntarily engaged with restrictions on their liberties to protect the lives of those most vulnerable to COVID 19. The dramatic effects upon lives and livelihoods/economies and energy consumption/human activity was unprecedented in modern times. The response to the pandemic did, however, demonstrate that, where there is sufficient will, leadership and cooperation, humanity can respond rapidly to a global crisis to avert its worst effects.

The COVID 19 travel restrictions also required IEA Wind to quickly change the manner in which its activities are executed. We had to rapidly move to online meetings for all our core activities including Task meetings, Topical Expert Meetings and Executive Committee meetings.

As a distributed organisation, IEA Wind already uses online meetings for its day-to-day business meetings. Moving to online platforms for core activities is not without its challenges. Informal exchanges at the fringes of in-person meetings bring an additional richness to encounters that can be difficult to replicate online. Online meetings, webinars and conferences also have upsides. More delegates and observers can participate and they do not have to incur the time, cost and emissions impact of international travel. Presentation recordings may also be used for research dissemination. In the future, once restrictions relax, IEA Wind will use a mix of online and in-person meetings for its core activities.

Our Task Operating Agents strove to minimise the disruption from COVID 19 to IEA Wind research collaborations. Only one Task suffered a delay, to a single workpackage, because of closure of a research facility. We also continued to develop the IEA Wind work programme to deliver upon our strategy. Four Topical Expert Meetings were hosted online by the Task 11 Operating Agent. Two new Tasks, on Wind Turbine Blade Recycling and Wind Farm Flow Control were initiated in 2020 and proposals were developed for three further new Tasks on Floating Offshore Wind Arrays, Hybrid Power Plants and Airborne Wind Energy. These new Tasks will project our research activities into important new areas.

I would commend the IEA Wind Annual Report to you as a source of information about both existing and new IEA Wind research collaborations and wind energy deployment and research in member countries. I hope that it inspires you to become involved with our collaborations in some manner.

Yours Sincerely

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2020 IEA Wind overview

2020 was a record-breaking year for wind power. Global wind power installed capacity increased by 93 GW to 770 GW: onshore wind power surpassed 700 GW, and offshore wind surpassed 35 GW. The exceptional year showed the resilience of renewables—wind power additions were only slightly affected by the global pandemic, and the demand for renewables including wind surged. Policy momentum to reach new targets set for 2030 and beyond are ensuring continued market growth in years to come.

Globally, the new record of 93 GW newly added wind power in 2020 was a staggering 70% increase from 2019, (Table 1) [1], mainly boosted by the huge increase in China (54,4 GW).

Within the IEA Wind TCP member countries, 670 GW of operational wind power capacity generated 1,375 TWh in 2020, meeting close to 8% of the electricity demand. 85% of the world's wind generating capacity—and all offshore capacity—resides in countries participating in the IEA Wind TCP. These countries added almost 80 GW of capacity in 2020, accounting for more than 87% of worldwide market growth (year 2020 includes India as the new member of IEA Wind TCP).

Governments launched ambitious targets for a low- and zero-carbon future, supported by policies and research efforts. Year 2020 continued to see net zero targets announced for 2050 and 2060. These translated to doubling the wind power capacity from current numbers by 2030, even tenfold for offshore. To achieve the new wind energy targets, a simplification of the authorization procedures is expected in several countries in order to reduce the time it takes to obtain permits for new sites.

Auctions for both land-based and offshore capacity secured the wind deployment for the next years. These government efforts were complemented by the private sector announcing investment decisions for new subsidy-free wind power plants through PPAs (Power Purchase Agreements).

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 for green recovery programmes, boosting the economies after the coronavirus pandemic.

Within the total public energy RD&D funding of 22.5 billion USD, renewable energy RD&D public funding constituted only 15% of total public energy RD&D. This 15% includes wind energy RD&D funding, which experienced a smaller increase compared to the year before.

This summary of the Annual Report 2020 presents highlights and trends from 22 countries as well as the European Union and WindEurope—for both deployment and R&D activities. Data reported in previous IEA Wind TCP documents (1995-2019) are included as background for the evolution of trends. The annual report is freely downloadable at https://iea-wind.org/

Table 1. Key Statistics of Wind Energy 2020

	IEA Wind Member Countries	Global Statistics
Total installed capacity (land-based and offshore)	631.1 GW	778 GW
Total offshore wind capacity	36.2 GW	35 GW
Total new wind capacity installed	79.8 GW	93 GW
Total annual output from wind	1,312.7 TWh	1,590 TWh
Wind generated electricity as a% of electric demand	8,1%	6,2%

Progress toward Policy Targets

2020 was a mark-up year for wind deployment targets—close to fulfilled in most countries. New targets for renewable energy—including wind power—are set, reflecting the energy and climate targets for 2030 and beyond.

Record year in wind energy for many countries

The biggest star of 2020 was China with a remarkable 54,4 GW new built capacity—and 72 GW grid connected capacity. The global leader now has 290,7 GW installed capacity and 281 GW grid connected wind power, of which 11 GW offshore (9 GW grid connected at the end of 2020). The US, the NL, Norway, Sweden, Belgium, and Japan achieved all-time records in annual installed capacity. Spain, Greece, and Finland saw a second year in a row with high additions.

Wind power capacity increased by 14% in 2020. The annual installations increased by 54% compared to deployment numbers in 2019 (60 GW) (Figure 1).

Year 2020 also saw record generation figures from most countries—with the share of wind achieving even higher numbers due to suppressed demand due to pandemic.

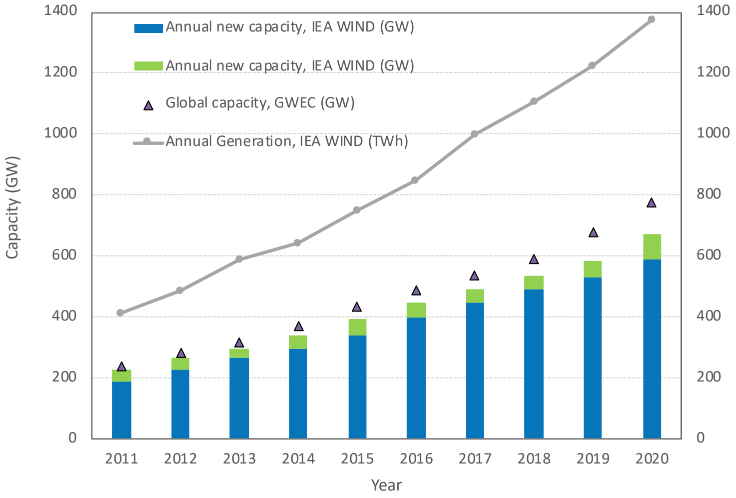


FIGURE 1. ANNUAL NET, NEW, AND CUMULATIVE WIND POWER CAPACITY AND ELECTRICITY PRODUCTION FOR MEMBER COUNTRIES. THE CUMULATIVE GLOBAL CAPACITY IS SHOWN WITH MARKERS (INDIA GENERATION DATA BEFORE 2020 IS ESTIMATED).

Some delays due to pandemic were reported from EU (Italy, Sweden, and UK). Even the countries that reported slow growth show anticipation of more deployment after 2020. See Appendix Table 4 for additions in 2020 and Table 5 for anticipated build-out.

Key deployment milestones in 2020:

- New records in annual installations were made in China (54,5 GW), the US (16,8 GW), the Netherlands (2.2 GW), Norway (1.5 GW), Sweden (1.4 GW), Belgium (0.8 GW), and Japan (0.5 GW). Spain, Germany, India, and France installed more than 1 GW each. China installed 56% of the global wind energy market (more than 40% in 2019), followed by the United States (18%), and the NL (2%).
- China, the United States, and Germany continue to lead in cumulative wind capacity. China is at 290,7 GW (of which 281 GW is grid connected), Europe at 220 GW (EU-27 180 GW) and the US at 122 GW. As Sweden passed the 10 GW landmark in 2020, now eleven countries have 10 GW or more of installed wind power capacity (ten IEA Wind TCP members plus Brazil).
- Norway increased the cumulative capacity with more than 60%, the Netherlands more than 40% and China and Belgium more than 20% (Table 2, the full ranking in appendix Table 6).
- Landmarks in wind-generated electricity were surpassed in China (>450 TWh), the US (>330TWh), Germany (>130 TWh), UK (>75 TWh), France (almost 40 TWh), Sweden (>25 TWh), Belgium, and Ireland (>10 TWh).

Offshore wind with increasing momentum

Offshore wind power installations made a new record of 7 GW in 2020, adding 17% more than in 2019, representing 9% of the annual global market (more than 20% of the European market). The cumulative capacity totalled 36 GW (Figure 2).

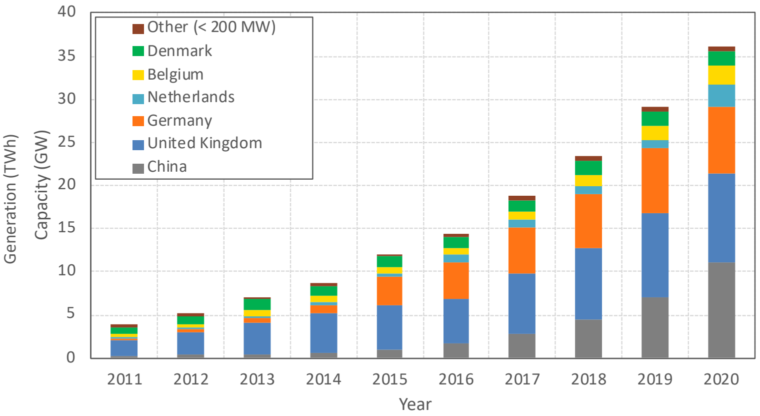


FIGURE 2. THE EVOLUTION OF OFFSHORE WIND POWER INSTALLED CAPACITY.

China, the Netherlands, and Belgium led new offshore installations with new records achieved in 2020: 3,85 GW, 1.5 GW, and 0.7 GW, respectively. UK, the Netherlands, and Belgium installed more offshore than onshore capacity in 2019.

China overtook UK as the leader in cumulative offshore capacity in 2020, with approximately 11 GW installed. Six countries have more than 1 GW of offshore wind.

The first three-turbine floating wind farm was commissioned at the Windfloat Atlantic offshore floating wind farm in Portugal, using V164-8.4 MW turbines. The UK has a 10 GW floating wind power target in addition to the 30 GW offshore wind in 2030, with separate auctions planned.

China will see a huge increase of offshore capacity this year, to benefit the last year of its subsidy scheme. Offshore projects under construction are reported from the UK, the NL, Denmark, and finally also France, where the start-up of construction of 3 of the 6 awarded offshore wind farms from Round 1 and 2 tenders. In Italy, the first offshore wind power plant is being built (10x3 MW).

More countries were in process of planning for offshore installations:

- In the US, there were 15 active leases and 25.5 GW offshore wind in various stages of development off the East Coast and in the Great Lakes regions.
- In Norway, two offshore areas opened for applications.
- In Finland, the first offshore projects are in Environmental Impact phase.

- In Sweden offshore potential areas and a study for grid connection to help deployment are in process.

- In Japan, 4 offshore promotion areas were announced in 2020, where the next step is a call for tenders.

- In Korea, licenses for electricity business offshore totalled 4.7 GW wind projects at 33 locations end of 2020.

- In Ireland, 2020 saw the increase of the offshore pipeline to 23 projects, and work proceeded within the government on the key-enabling legislation for a new offshore wind-consenting regime, including the National Marine Planning Framework and the Marine Area Planning Bill.

- In India, stakeholder processes for Offshore Wind Energy Lease Rules were completed in 2020.

Offshore grids advanced in 2020 with the inauguration of world's first hybrid offshore interconnector, integrating the Danish Krieger's Flak and the German Baltic 1 and 2 offshore wind power plants.

Plans for energy islands were advancing in 2020 as Denmark reserved areas for one energy island in the North Sea and one in the Baltic Sea. The energy islands will be hubs that can improve the connection between energy from offshore wind and the energy systems in the region. Cooperation on energy islands with Denmark, Germany, and the Netherlands has been declared, fulfilling the political wish of the energy islands being connected to several countries.

Wind power continues to grow in the electricity mix

Wind power continues to steadily increase its share of the electricity mix. In 2020, wind produced an average of 8% of the electricity demand in member countries—up from 7% in 2019 (Figure 3). Wind-generated electricity met more than 6% of the world's demand in 2020 [2].

In Finland, renewables generated more electricity than other generators. In Spain, wind generation was second largest source of energy, and in UK renewable energy outpaced fossil fuel generation for the first time.

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

- Seven countries now meet more than 20% of their electricity demand with wind power, and eleven countries meet more than 10%. The EU is at 15% share of its electricity demand with 14 of the 27 Member States having wind shares above 10%.

- The highest share was in Denmark where 47% of the electricity demand in 2020 was met by wind energy, followed by Ireland at 36%, Portugal at 25% and Germany at 24%. Denmark and Portugal report instant shares of more than 100% of wind during one hour.

- In 2020, UK and Sweden passed the 20% landmark while the Netherlands made a leap from less than 9% share in 2019 to almost 14% share in 2020. Finland and the US were close to the 10% landmark.

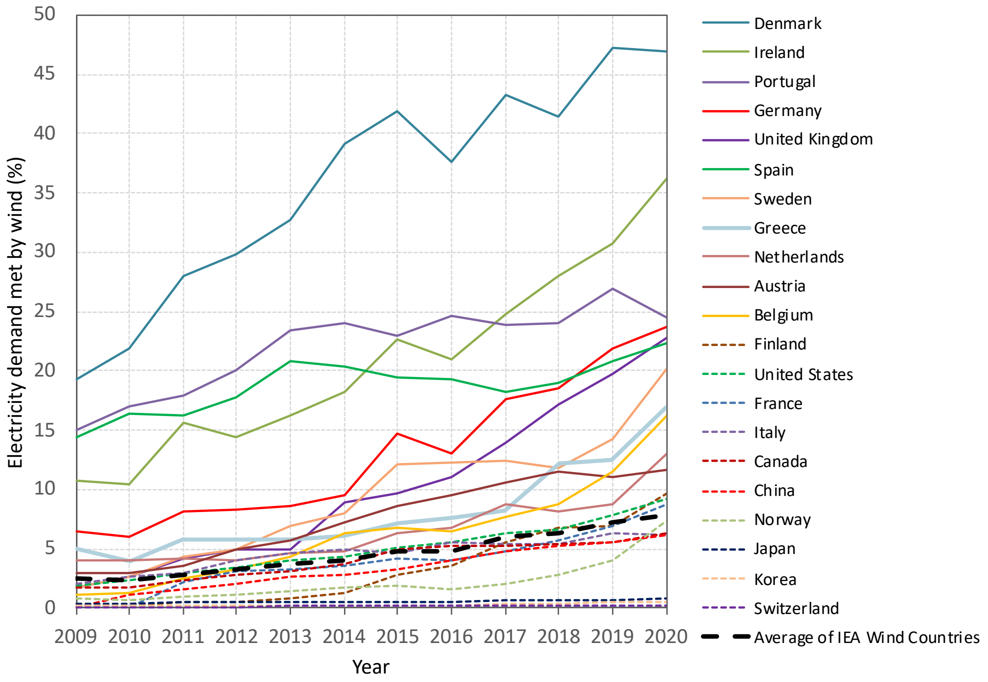
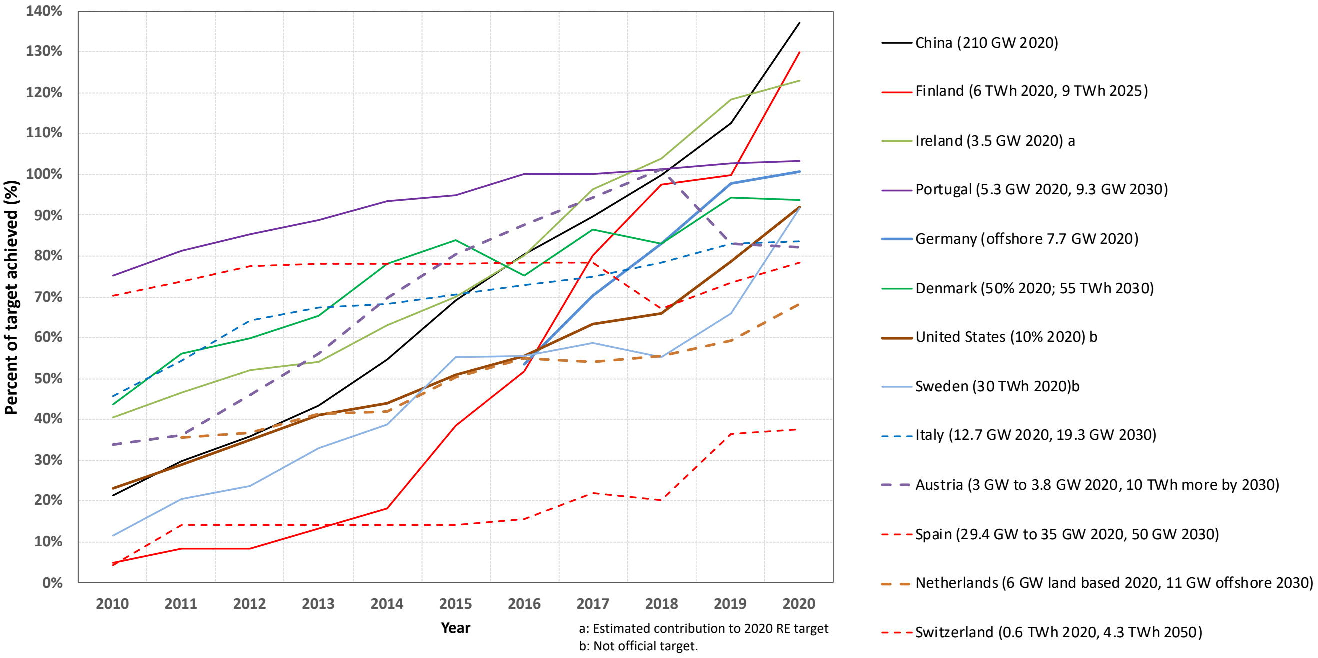


FIGURE 3. NATIONAL ELECTRICITY DEMAND MET BY WIND-GENERATED ELECTRICITY (2020 FIGURES IN APPENDIX TABLE 4).



a: Estimated contribution to 2020 RE target
b: Not official target.

FIGURE 4. PROGRESS IN REACHING 2020 WIND ENERGY TARGETS AND PERCENTAGE OF TARGET REACHED (EXPRESSED IN GW, TWH OR SHARE OF ELECTRICITY). SEE TABLE 6 FOR TARGETS ALSO BEYOND 2020.

Policy targets will double the wind capacity by 2030

Most policy targets are set for renewables and not for wind specifically. However, 13 of the member countries had set wind-specific targets for year 2020—often not as official targets, but as an estimate of how much wind would contribute to the renewable targets. On average, a 95% fulfilment of targets is seen (Figure 4). Austria and Spain would have reached the original target, but the Figure shows a drop of achievement due to increased targets in recent years. Italy fell 1 GW short of the capacity targets but achieved the renewables target as share of electricity. The Netherlands estimates the 6 GW land base wind target to be fulfilled in 2023.

Year 2020 continued to see important carbon neutrality targets announced globally: the US, Canada, Japan and Korea joined Europe in targeting net zero in 2050. In Europe, Germany announced striving for greenhouse gas neutrality already in 2045—complementing previous announcements from Austria (by 2040), Finland (by 2035), and Sweden (by 2045). In China, the net zero target for 2060 was announced together with a target to turn coal generation to downward trend by 2030.

In Europe, the 2030 targets (32% RES share of final energy consumption, 50% of electricity demand) are currently reviewed, aiming at a 55% GHG reduction target by 2030—fit for 55. The European Offshore Renewable Energy Strategy published in 2020 aims at increasing offshore wind capacity, including floating wind, from its current level of 12 GW to at least 60 GW by 2030 and to 300 GW by 2050. Several member countries include wind specific targets in their National Energy and Climate Plans (NECP) for 2030. The targets will double the current land-based wind capacity in 2030 for Austria, Greece, Italy, Spain, and Portugal. For Denmark, France and Ireland, doubling the land-based wind power is matched with an even higher target for offshore. The offshore wind targets in the United Kingdom and the Netherlands equal a fourfold increase. In Germany, the new target 20 GW is more than double the current offshore capacity, with target for 2040 (40 GW) again doubling the offshore wind capacity.

Korea target for 20% renewable electricity in 2030 means 17.7 GW wind capacity, including 12 GW offshore—ambitious increase from the current 1.5 GW land-based and 0.1 GW offshore installed.

The current national targets established by IEA Wind TCP member governments for renewable energy and wind energy are listed at the end of this chapter in Table 7. The goals represent a powerful driving force for renewables, particularly wind energy.

Performance Gains from Wind Technology Improvements

The trend towards larger turbines, increased capacity factors, and cost reductions continued in 2020. The average installed capacity of new turbines surpassed 3 MW in member countries reporting. For offshore, 7 to 8 MW turbines are increasingly used.

Turbines continue to increase in size

Table 2 shows wind power capacity rankings for size of new and total capacity for reporting countries. The rated capacity of new turbines in member countries reporting shows an increasing trend (Figure 6, see also Sweden chapter for rotor diameter and rated capacity trends).

In Finland, the average size of new land-based turbines in 2020 surpassed 4.5 MW, with Norway, Denmark and Sweden also holding an average size of close to 4 MW or more. In Europe, the average size was 3.3 MW.

Offshore turbine sizes are increasing even more: the Netherlands reported more than 9 MW average size in 2020, Belgium 8.7 MW, Portugal 8.4 MW, and UK 7 MW. (Appendix Table 8). According to country reports, the average size for newly installed offshore turbines was 7 MW, up from 6.6 MW in 2019 (in Europe 8.2 MW, up from 7.2 MW in 2019).

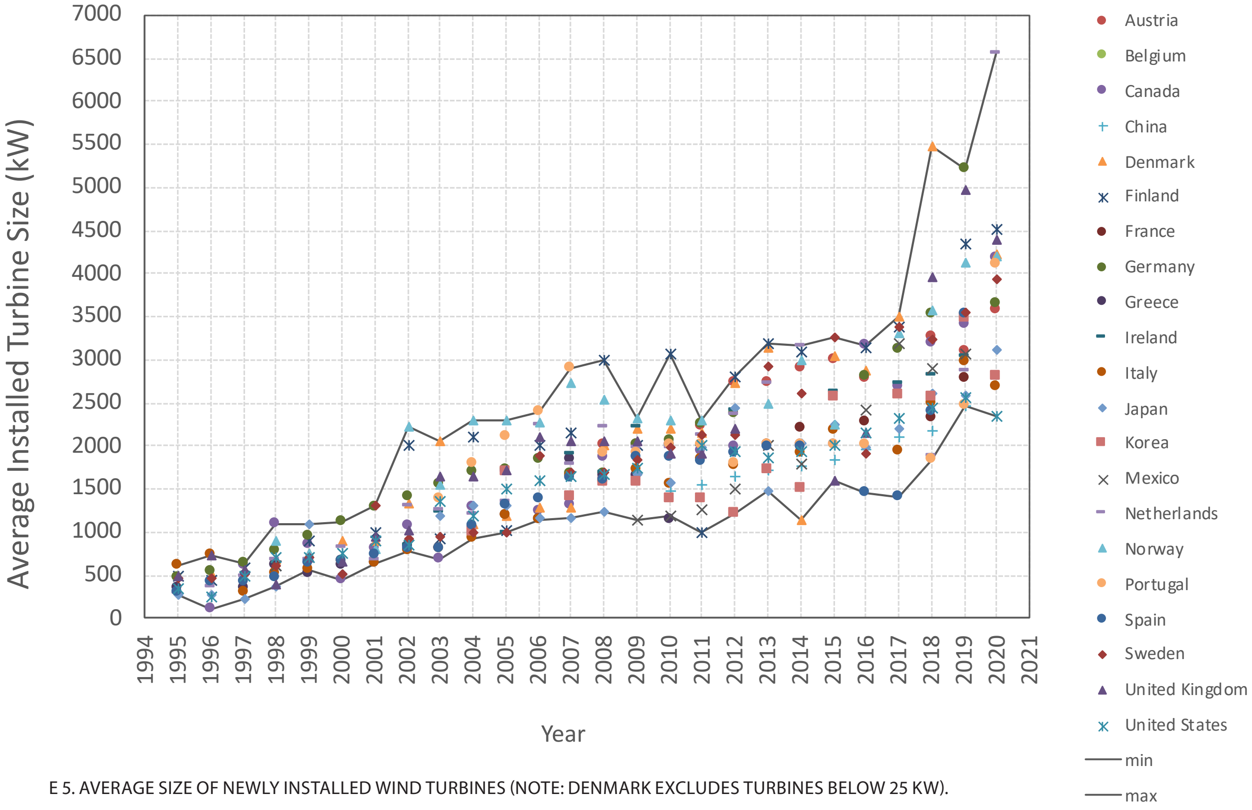
Improved technical performance leads to higher capacity factors

Technology advancement with higher turbines and longer blades drives the long-term trend of improved performance (see also Task chapters 29 on aerodynamics, as well as chapters 30, 32, 37 on model tool development, and chapter 43 on digitalization).

On average, both land-based and offshore wind power capacity factors show a slightly increasing trend (Figure 8). The highest capacity factors in 2020 for land-based wind turbines were reached in Norway (37%), and UK, and Finland (35%), with Belgium, the US, Sweden, Canada, Denmark, and Ireland at more than 30% average capacity factor for their wind power fleet generation. For most countries this was the new record. UK hit a new record of more than 45% capacity factor for the offshore wind power plants. Most countries reported more than 40% capacity factor for their offshore fleet.

Table 2. Top Ten Wind Power Capacity Rankings: Capacity, % Increase, Relative to Country Size, Average size of turbines and Average capacity factor

	Cumulative Capacity (end of 2020)		New Capacity 2020		Increase in Cumulative Capacity		Capacity Relative to Country Size		Average capacity new land based turbines		Average capacity all turbines		Average capacity factor		Capacity per capita	
	Country	**MW**	**Country**	**MW**	**Country**	**%**	**Country**	**kW/km²**	**Country**	**MW**	**Country**	**MW**	**Country**	**%**	**Country**	**kW**
1	China	290.747	China	54.427	Norway	63	Germany	174	Finland	4,51	Norway	3,42	Norway	37	Denmark	1,06
2	USA	121.985	USA	16.800	Netherlands	43	Netherlands	159	Denmark	4,23	Finland	3,15	UK	35	Sweden	0,97
3	Germany	62.167	Netherlands	2.060	China	23	Belgium	155	Norway	4,21	Netherlands	2,52	Finland	35	Ireland	0,90
4	India	39.248	Spain	1.720	Belgium	22	Denmark	143	Canada	4,17	Austria	2,39	Belgium	34	Germany	0,75
5	Spain	27.445	Germany	1.650	Sweden	16	UK	102	Sweden	3,93	Sweden	2,33	USA	34	Norway	0,74
6	UK	24.665	Norway	1.532	Switzerland	16	Ireland	61	Netherlands	3,62	UK	2,26	Sweden	31	Spain	0,58
7	France	17.610	India	1.504	Greece	15	Portugal	59	Austria	3,57	Korea	2,23	Ireland	31	Portugal	0,53
8	Canada	13.588	Sweden	1.403	Finland	13	Spain	54	Spain	3,46	Switzerland	2,07	Canada	31	Finland	0,47
9	Italy	10.619	France	1.105	USA	14	Austria	37	Germany	3,41	Germany	2,00	Denmark	30	Belgium	0,41
10	Sweden	10.084	Belgium	836	Japan	13	Italy	35	Japan	3,11	Canada	1,99	Netherlands	28	Austria	0,39
11	Mexico	6.789	Mexico	664	Mexico	11	France	32	Korea	2,70	Portugal	1,97	Greece	28	Netherlands	0,38
12	Netherlands	6.600	UK	570	Korea	10	Greece	31	Italy	2,67	USA	1,81	France	27	Greece	0,37
13	Denmark	6.218	Greece	525	France	7	China	30	Greece	2,63	Japan	1,74	Portugal	26	USA	0,37
14	Portugal	5.478	Japan	516	Spain	7	Sweden	23	Switzerland	2,35	Greece	1,56	Austria	26	UK	0,37
15	Belgium	4.700	Finland	302	India	4	Korea	16	USA	2.75	Italy	1,49	Germany	24	Canada	0,36
16	Japan	4.439	Denmark	220	Ireland	3	USA	12	Portugal	2,26	Spain	1,28	China	24	France	0,26
17	Ireland	4.300	Canada	175	Denmark	3	Japan	12	UK	2,23	Denmark	1,10	Spain	23	China	0,21
18	Greece	4.114	Korea	160	Germany	2	India	12			India	1,02	Korea	23	Italy	0,18
19	Norway	3.977	Ireland	125	UK	2	Norway	10					Switzerland	21	Mexico	0,05
20	Austria	3.120	Italy	102	Canada	1	Finland	8					Japan	21	Japan	0,03
21	Finland	2.586	Portugal	41	Italy	1	Mexico	3					Italy	20	Korea	0,03
22	Korea	1.650	Austria	25	Portugal	1	Switzerland	2					India	18	India	0,03
23	Switzerland	87	Switzerland	12	Austria	-1	Canada	1							Switzerland	0,01



E 5. AVERAGE SIZE OF NEWLY INSTALLED WIND TURBINES (NOTE: DENMARK EXCLUDES TURBINES BELOW 25 KW).

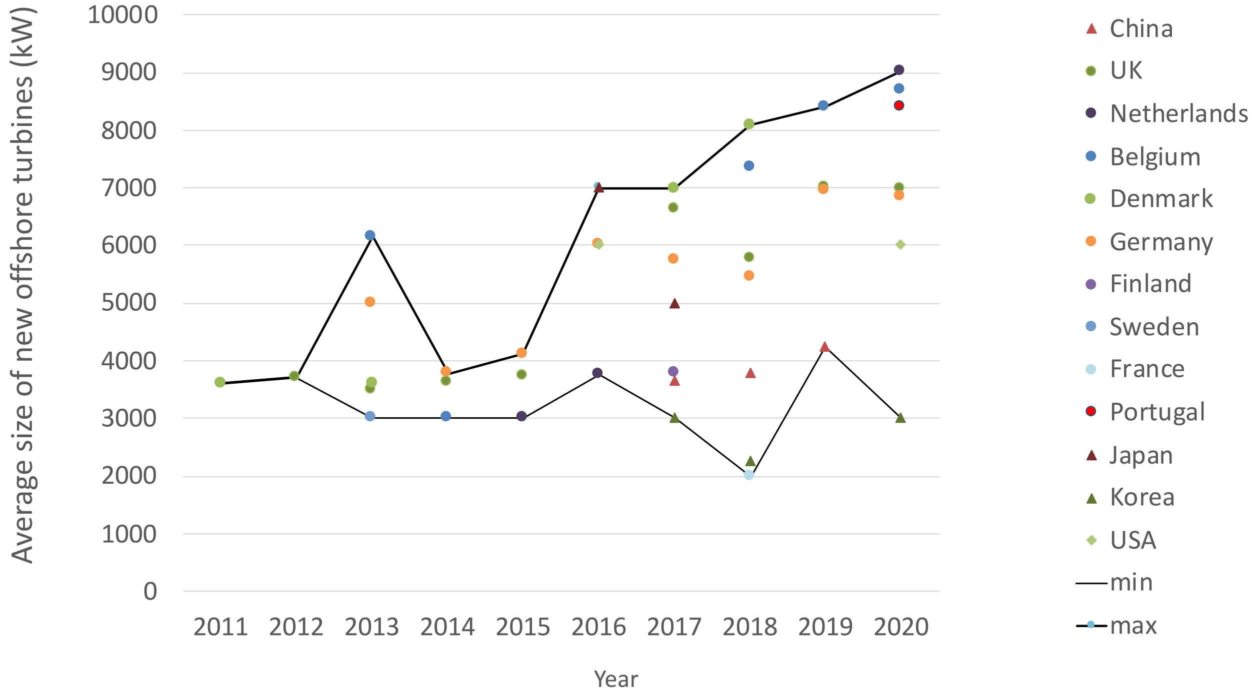


FIGURE 6. AVERAGE SIZE OF NEWLY INSTALLED OFFSHORE WIND TURBINES.

Cost reductions from auctions leading to increasing subsidy free projects

The wind power industry continues to improve its competitiveness. In Norway, the LCOE of wind energy in 2019 was on average record low at 28 EUR/MWh. The average costs of land-based projects reported from seven member countries were 1,097 EUR/kW (1,342 USD/kW) in 2020 (Figure 9 and Appendix Table 9). Project costs have decreased by 41% since their peak in 2011 (inflation-corrected). See also Task 26 Cost of Wind Energy.

The shift to tendering from fixed guaranteed price support has prompted increasingly competitive prices for wind energy. Decreasing auction prices have been reported across IEA Wind TCP member countries since

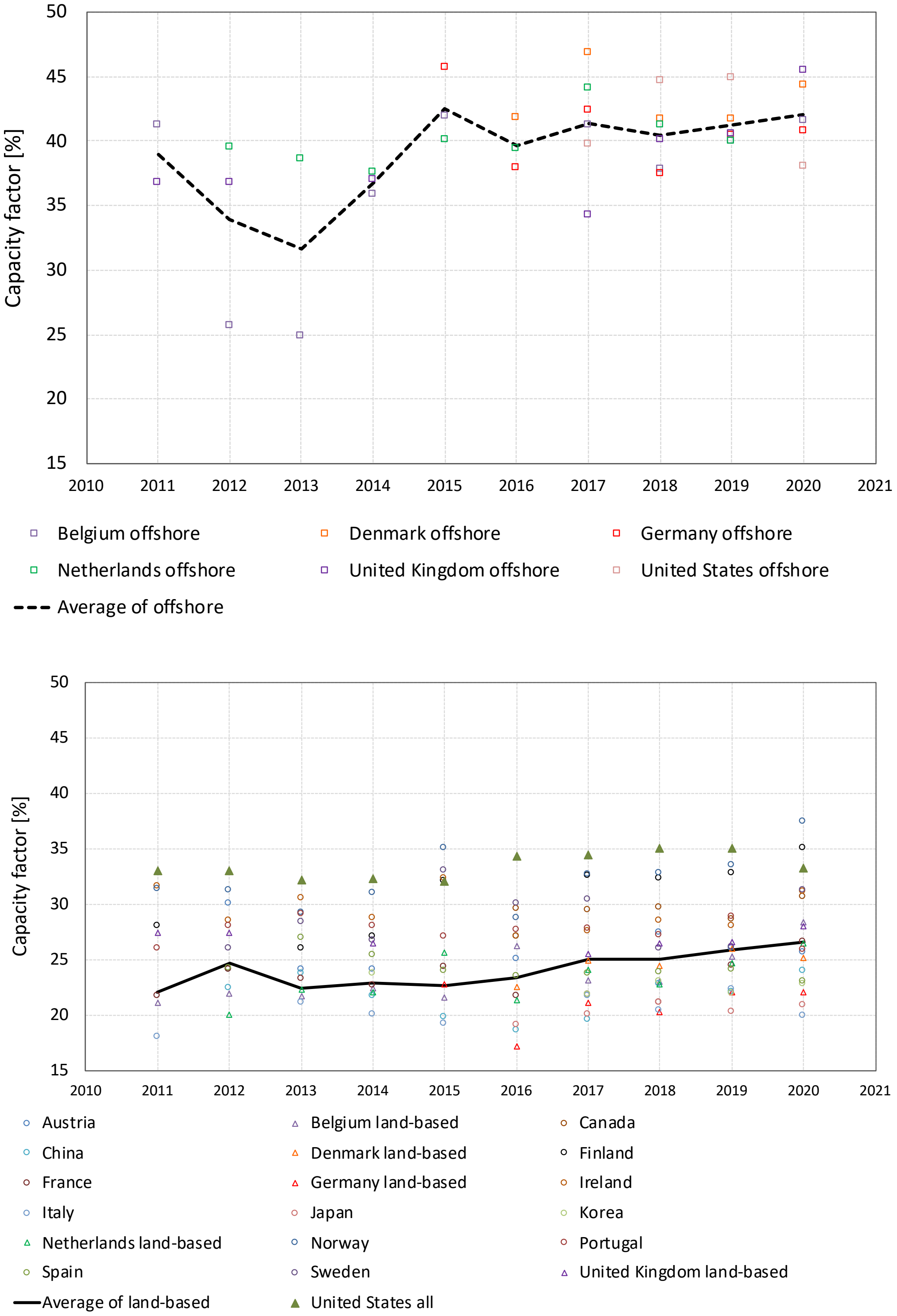
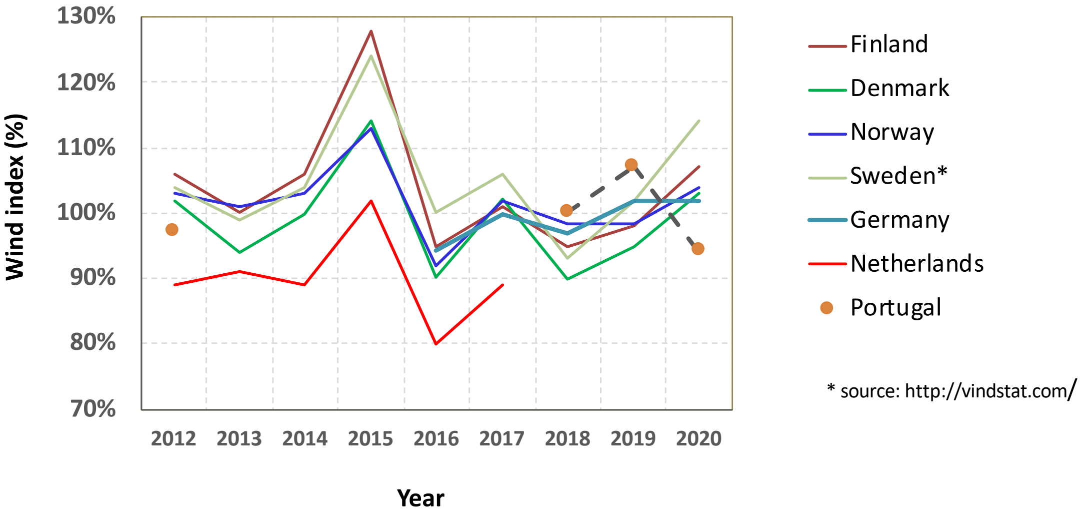


FIGURE 7. AVERAGE WIND POWER OUTPUT (CAPACITY FACTOR) BY COUNTRY FOR OFFSHORE AND LAND-BASED WIND POWER GENERATION. THESE FIGURES HAVE ESTIMATED DATA FOR 2017-20 FOR THE COUNTRIES THAT DO NOT REPORT THE CAPACITY FACTORS: TOTAL WIND GENERATION IN 2020 DIVIDED BY THE AVERAGE INSTALLED CAPACITY BEGINNING OF YEAR AND END OF YEAR.

2017, when Mexico and Canada reached record low prices of 14.2 EUR/MWh (16.3 USD/MWh) and 23 EUR/MWh (26 USD/MWh) respectively. In Germany the record low bid of 2017 has been 22 EUR/MWh (25 USD/MWh). In 2019, Finnish technology neutral tender (1.4 TWh/a) winners were all 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 2020, 8 GW of wind power capacity was secured in auctions in EU, mainly for land-based wind energy. The Spanish auction saw wind farms secure 1 GW with bids being record low, below 30 EUR/MWh (36.7 USD/MWh). In France, three onshore wind tenders were made in 2020 for a total of 1.38 GW. The average prices have decreased from 65.4 EUR/MWh (2017) to 59.7 EUR/MWh (July 2020). In Greece, the auction prices



* source: http://vindstat.com/

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. ITALY AND SPAIN REPORTED LOWER-THAN-AVERAGE WIND RESOURCE IN 2020.

decreased from close to 70 EUR/MWh (July 2018) to 56 EUR/MWh—this is lower than the wholesale price of electricity in Greece. In the technology neutral auctions in Italy in 2020, wind was winning 87% of 1 GW. In Ireland, the first auction of the new Renewable Electricity Support Scheme was held in 2020 with wind energy projects totalling 479 MW (1.5 TWh/a) awarded contracts.

The success of cost reductions has also brought about corporate Power Purchase Agreements (PPAs) building wind power outside the subsidy schemes. This has been used in the US already for years, and in Europe, growing steadily since 2015. 2020 was a record year for corporate renewable PPAs as 3.7 GW were contracted in the EU: 22 new PPAs signed in 9 countries with wind farms for a total of 1.9 GW. In Finland, all 300 MW of new capacity was without subsidy, second year in a row.

Offshore wind power has also seen a dramatic price reduction in the tendering process. In the United Kingdom, the average price of bids in Contract of Difference auctions has reached a tipping point where projects are starting even if left out of the auction

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

(no-subsidy merchant projects). The average bids accepted were 39 GBP/MWh (in 2019 40.63 GBP/MWh, 46.16 EUR/MWh) including 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).

Opportunities for repowering

An increasing proportion of installed capacity will reach its end of life between 2020 and 2030. To address this challenge, the IEA Wind TCP started a new 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.

Out of the 14.7 GW of onshore wind installed in 2020 in Europe, only 345 MW were through repowering projects. The majority came from Germany, but there was also repowering activity in Greece, Luxembourg, and the UK. Complex permitting rules have been the main reason for the slow uptake of repowering projects in Europe.

Overcoming Policy and Development Barriers

Member countries work together in the context of the IEA 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 2020 include long permitting procedures and increasing number of legal disputes and citizens 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.

Wind energy generally has a high public acceptance in the surveys conducted. For example, in 2020, over 80% of the Austrian population supported a further wind power expansion—a continuing trend since 2011. In Finland, 80% of respondents chose "increase" for wind energy in Finnish electricity production. However, in many countries opposition still exists locally for any new wind power plant proposed, even if the general public is supporting wind energy. In Korea, there is low acceptance both for land-based and fixed bottom offshore wind power. The local opposition from many ongoing projects around the country turned the general public acceptance to low level in Norway in 2019. This was also seen in Finland in previous years, but after research on noise concerns did not find any health impacts on people living nearby, the public acceptance figures have improved again.

Belgium and Canada report lengthy legal procedures affecting the deployment, as cases where local communities appealed against the construction of wind energy facilities may take years to resolve. Such legal cases could potentially be avoided by involving the local communities more closely at the project planning stage and by offering them the opportunity to take part in investments through cooperatives.

In Norway, a new white paper on permitting, including compensation to local municipalities, was published in 2020. In Finland, the property tax from wind power plants for small municipalities has received positive publicity. In France, measures improving the consenting process include favouring the implication of local communities and citizen in wind related projects. In Ireland, the new auction mechanism includes measures supporting community acceptance of renewable energy projects, including a mandatory 2EUR/MWh community benefit payment and a reserved auction category for community owned projects. In Korea, the Plan for Offshore Wind Power Generation in Collaboration with Local Residents and the Fishing Industry sets out specific measures to trickle-down benefits to local stakeholders.

Some governments have been working to support public acceptance of wind power by funding research on wind power and ornithology, bats, and noise (Finland, Switzerland, the US). In 2020, Canada published a study on bat concerns and measures to minimize, and the US supported the development of several mitigation measures for bat and bird impacts.

See also IEA Wind TCP Task 28 that focuses on social acceptance of wind energy and Task 34 on studies conducted on environmental impacts in several countries.

Mitigating administrative barriers

Wind energy deployment can be hindered by lengthy permitting procedures and appeal processes. EU (and Belgium, Germany, Greece, and Italy) report that to achieve the new challenging wind energy targets for 2030, a simplification of the authorization procedures is expected. A 'one-stop shop' simplifying and speeding up licensing procedures has mitigated the complexity of permitting procedures in Sweden and France, and adopted in Belgium. In the Netherlands, collaboration between authorities overseeing the permitting is required, however, it is still very long process and fitting more than 6 GW onshore wind in the NL seems unfeasible. In Sweden, a roadmap for wind power expansion was published in January 2021, facilitating planning and permit processes with tools and proposals for legal and regulatory measures, as well as setting regional targets and an implementation strategy. In Italy, associations, operators, and policymakers are working together to improve permitting process.

Spatial planning limitations and lack of sufficient eligible wind zones are reported from Austria, Belgium, Germany, Italy, and the Netherlands. In Finland, more state lands are being offered for wind power plants. Distance regulations, height limits near airports, and turbine lighting have been reported as barriers, and updates to regulations are seen in many countries to mitigate these and allow for larger turbine sizes. In France, propositions for reducing lighting and signalling of wind turbines were announced in 2020. Restrictions related to the defence sector may conflict with wind deployment, mainly due to interference with communications, navigation, and surveillance (CNS) systems. Mitigation solutions are being developed from radar interference research in Switzerland and Germany and the US.

In Germany, the decreasing deployment trend has been attributed to a gap in subsidy schemes for offshore wind as well as a massive curtailment in availability of space in individual onshore regions due to regulations by the federal state administrations. Protection of species, air traffic control, weather radar or military issues also impact availability of sites. To counteract these inhibiting issues, shortened permission procedures and support of repowering projects have been set up. To achieve future targets, higher tender volumes including financial participation of communities, system and market integration as well as measures for social acceptance are important elements of the new law EEG 2021.

In Switzerland, the renewable targets were adapted to a more local level by declaring that interests of the state should be taken into consideration in the wind project planning process locally. Combined procedure for land use planning and build permitting has been opened in some Cantons (provinces), with first wind farm projects following the new simplified process in 2021.

In France, improving the recycling of wind turbines (with targets for 2022 and 2024) and generalizing the removal of concrete foundations during dismantling were proposed in 2020.

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

In Europe, implementation of the Offshore Strategy to meet the 25-fold increase of capacity expected by 2050 means improving permitting, including the coordination of maritime spatial plans, and the grid build-out between member countries.

Supporting further cost reductions and competitiveness in electricity markets

Incentivising wind power investment has been a major tool used to improve deployment. Table 10 provides an overview of the subsidy systems and other tools employed by member countries to increase wind power deployment. In 2020, the US PTC was extended at 14.7 EUR/MWh until the end of 2021, and investment credits are applied to offshore and distributed wind. In Norway and Sweden, green certificates have been extended until end of 2021, and in China, land-based wind power subsidies ended in 2020, but offshore is still subsidized until the end of 2021. Austria, Italy, and Japan have been lowering their subsidy levels of feed-in-tariffs (FITs). Korea has a technology-neutral and market-based RPS system.

Stimulating industrial consumers to procure their energy needs directly from wind energy through power purchase agreements (PPAs) is one way of securing long-term income for wind power producers—this is also important for lowering the cost-of-debt financing. US and Europe have seen a steady growth of PPAs. In Korea, PPAs were allowed in 2020 for renewable energy directly with loads, however, there are still practical issues to be solved as need large stable loads to be able to make a PPA contract.

In 2020, low market prices were seen and also negative prices for the first time in Finland and Sweden. Building energy markets that support the long-term sustainability of wind deployment will be important. Electrification and energy system coupling with

electricity, gas, transport, industry as well as heating and cooling provide options for managing future energy systems, as seen in EU Strategy for smart sector integration within the new European Green Deal.

Allowing wind power plants to access markets for grid support will provide revenue for wind power plants and help the balancing task of system operators. This is increasingly happening in Europe and the US. For example, in Spain, 16.7 GW of the total of 27.4 GW wind power capacity installed had successfully passed the Operational Capability Tests at the end of 2020.

In the US, battery storage additions to wind power plants is a trend. There is increasing interest in hybrid solutions combining wind and solar with storage, also in other countries. In India, 2,550 MW capacity of transmission-connected wind-solar hybrid projects have been awarded in three auctions since the system was launched in 2018. In Greece, legislative framework for hybrids is gradually taking shape, with expected activity in near future.

See also Task 36 on the development of short-term forecasting for electricity markets.

Reducing wind power curtailment

Research from the IEA Wind TCP Task 25 on grid integration shows that high rates of curtailments is a signal of insufficient flexibility and an integration challenge.

In China, a series of policies and regulations to reduce wind curtailment, in addition to large transmission upgrades, have been successful in reducing the curtailed energy to less than 17 TWh (less than 4%) in 2020, compared to 41.9 TWh (more than 10%) in 2018.

In Europe, the curtailments in several countries have an increasing trend, as the shares of wind increase. Denmark, Germany, Ireland, Italy, and UK report curtailments in the range of 2.5% to 11% .

At the same time, system operators in several countries have been achieving high instantaneous shares of wind without technical problems, and introducing new measures to reduce curtailments. In Ireland, Denmark, and Spain, the wind power plants are providing balancing energy by controlled curtailing which is a market-based use of flexibility of wind power.

Grid access and adequacy of transmission infrastructure

Grid connection opportunities are crucial to enable development of both land-based and offshore wind sectors to meet 2030 targets. Sweden and the US report concerns of inadequate transmission becoming a limit in the future if no reinforcements made. In Greece, the grid is being strengthened, also for islands like Crete to connect to main grid. The Green Island Agios Efstratios project is used to demonstrate how power systems will be operated in future with wind, solar PV, and batteries.

Permits for grid access may need to be revised, to make sure that permit holders actually build the project. In the beginning of 2020, Spain had a backlog of more than 430 GW worth of requests for grid access, but at the same time, around 60% of grid access holders have not applied for a corresponding connection permit. In 2020, a new law sets deadlines for each milestone in the permitting chain that project developers have to meet to get the next permit. Failing that, any granted permits will expire automatically and deposited financial guarantees will be lost. Developers have five years to complete the whole process. Another law adapting the grid connection with EU requirements adds to the pressure for obtaining permits in the different Autonomous Communities, where there has been a lack of administration to manage a large number of requests and claims over time.

The EU offshore strategy targets mean grid upgrades, both onshore and offshore. Also, developments such as offshore hybrids, energy islands, offshore renewable hydrogen production, and multi-terminal HVDC systems are seen, which will require adjustments to EU legislation, notably on market design. In the UK, grid integration for the targeted 40 GW offshore wind is critical and there are also plans for green hydrogen. In Germany published a national hydrogen strategy in 2020, noting that green hydrogen will play a key role in enhancing and completing the energy transition by being an energy storage medium or enabling sector coupling.

Transition towards new regulatory frameworks

Despite cost reduction achievements, future market uncertainty in terms of demand and availability of financing may impact the deployment 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. Gaps in regulatory programmes and regulatory changes have been mentioned as reasons for growth rates lower than expected in some countries, like Germany and Ireland. In the UK pandemic and Brexit have created an uncertain investment environment.

In Norway, the excellent deployment rates are already foreseen to stop after 2022 as no new licenses have been issued—this will impact deployment to 2027. In Sweden, a decision to remove grid connection cost from projects to compensate for offshore costs being higher than onshore is still under discussion.

In 2020, some positive developments took place. In UK, land-based wind was added back to auctions and in Greece, the ban on offshore was lifted. Austria had a gap year of installations while waiting for new legislation; in 2021 this is expected to get the project queue funded.

In Sweden, government action to regulate the green certificate allocations took place to tackle price erosion of green certificates. In Norway, the low green certificate income has resulted in the transition towards subsidy free wind energy, acting in electricity markets when current subsidy scheme will end in 2021.

In China, the tariffs for wind will be aligned with coal tariffs after 2020 for land-based wind energy and 2021 for offshore wind.

The Netherlands future energy generation will be subsidised based on their CO_2 reductions. This is a major shift in the subsidy framework.

Permitting hurdles can affect the design of tendering processes. With a lower number of permitted projects and an increased uncertainty due to court appeals, the number of projects that are able to compete in an auction can be significantly reduced, leading to undersubscribed auctions, and ceiling values because of the lack of competition. In Germany, the first six out of the seven onshore wind auctions held in 2020 were undersubscribed. Only 2.7 GW out of the 3.9 GW on offer were awarded because there were not enough projects permitted.

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.

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 the middle of a pandemic with huge impact on the economy. Wind energy is an abundant resource around the world and contributes to reducing 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

The record year of 2020 with more than ~90 GW new installations, bringing the total capacity to 743 GW, was in particular led by large growth in China. The US also increased new installations 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, maintenance, and decommissioning. During the 2009-19 period, the number of jobs in the global wind energy industry more than tripled with 1.17 million jobs in the sector in 2019 (IRENA, 2020). A recent forecast states that large-scale onshore and offshore

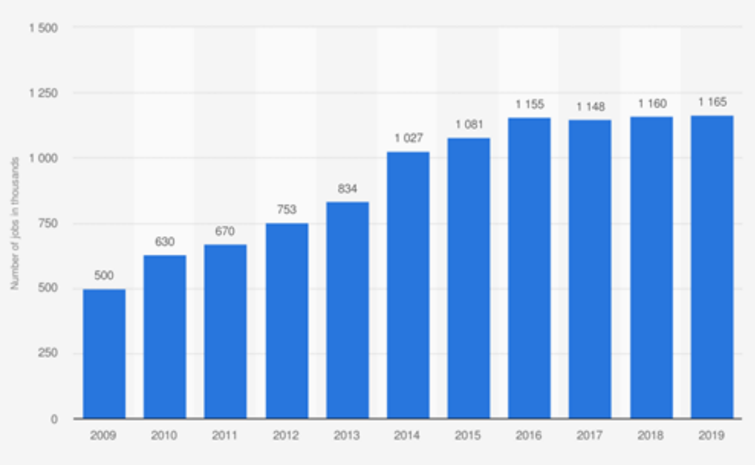


FIGURE 10. NUMBER OF JOBS IN THE GLOBAL WIND ENERGY INDUSTRY 2009-19. SOURCE: IRENA (2020) AND STATISTA (2021).

wind projects will generate 3.3 million jobs across the full value chain over the coming five years when global annual wind power installations are expected to exceed 110 GW (GWEC, 2021).

Wind energy is energy is an important sector in the European economy. In the EU, it generated 37 billion EUR (45.2 billion USD) to the GDP and employs 300,000 people (75% of these onshore and 25% offshore). In Denmark, the wind energy industry employed 32,744 people in 2019. Spain and France employed 30,000 and 18,200, respectively (Appendix Table 11). The UK reported that turnover in the UK low-carbon and renewable energy economy was estimated to be 54.2 billion GBP (53.5 billion EUR/64.3 billion USD) in 2019, of which 6.0 billion GBP was generated by the wind energy sector. In terms of employment, the total number of employees remained stable around 12,700. In the US nearly 117,000 Americans were directly employed by the wind industry.

Emission reduction and other environmental impacts

Several member countries calculated the CO_2 emissions (million tons/year) avoided 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 UK). The special circumstances of 2020 led the electricity demand to drop in several countries. In the UK, the pandemic has a major impact on the GHG emissions being 48.8% lower than in 1990 and the average carbon intensity fell to 181 g CO_2/kWh, a reduction of 66% over the last seven years due to higher shares of renewable in the system, more than half coming from wind energy.

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. More information is available in Task 34 on environmental impacts of wind energy.

Value of Research, Development, and Innovation

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

National RD&D funding and priorities

Wind energy RD&D funding increased slightly in 2020 at both the country level and globally. Of the 15 countries reporting RD&D budgets in 2020, five reported an increase from 2019 (US, Japan, Korea, Canada, and Switzerland). The US is by far the largest investor in wind energy RD&D with 104 million USD followed by Germany with 76.9 million USD and Japan with 76.5 million USD. Horizon 2020—the EU Research and Innovation Programme 2014 to 2020—is coming to an end with 69.7 million USD allocated in 2020 to wind energy-related research. Public RD&D funding varies from year to year for 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 RD&D constitutes only 15%, or 3.4 billion USD (3.8 billion EUR), of the global public energy RD&D expenditures of 22.5 billion USD (25.2 billion EUR). In comparison, nuclear energy constitutes 21% and fossil fuels 7% of total expenditures. National budgets for wind RD&D from 2010–2020 are shown in Appendix Table 11.

In 2020, the U.S. Department of Energy's Wind Energy Technologies Office (WETO) prioritized its 104 million USD (85.07 million EUR) within four categories: Offshore wind technology demonstration and resource characterization; next generation land-based wind; distributed wind energy resource design and planning tools, components, and hybrid systems; and systems integration including cybersecurity, resilience, and advanced control.

In Europe, the majority of RD&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 RD&D priorities and funding. Some countries like for example Portugal relies exclusively on EU funding for wind energy RD&D.

Horizon 2020—the EU Research and Innovation Programme 2014 to 2020—continued to fund a substantial number of wind energy projects (13) with a cumulative investment of 57 million EUR (69.7 million USD). Half of this EU funding was granted to floating offshore technologies, followed by new materials & components /24%) and offshore wind technology (14%).

Japan has prioritised seven larger projects within three categories: Research for Demonstration focuses on next generation floaters and low-cost construction, Development and Deployment focuses on fixed bottom offshore wind and Efficient Practical Use on advanced operation, O&M and components.

Research Initiatives and Results

Member countries highlighted key topics driving ongoing and future RD&D activities, many of which identified as national priorities. The highlights of national and cooperative projects below show the variety in RD&D priorities. The priorities are grouped 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

Wind resource and site characteristics

- The German X-Wakes project focuses on the assessment of the change of wind conditions for the operation of offshore wind farm clusters under large-scale offshore wind farm installation. Extensive measurements with airborne vehicles, satellites and LiDAR at various offshore locations within the German Bight. The findings on interactions of wind farm clusters, which will be investigated with large eddy simulations (LES) in addition to the measurements, will be implemented in industry as well as a in a mesoscale weather prediction model.

This will allow the definition of a more realistic energy yield for future wind farm installation scenarios.

- Winds of the North Sea in 2050 is a Dutch project analysing the interactions between a large-scale roll-out of wind energy and the atmosphere. Global blockage, farm-to-farm interactions, deep array effects, and limits to yields can no longer compensate for wake effects. This project therefore uses various models to develop a wind atlas which incorporates existing and future wind farms.

- Finland conducted two studies on forecasting. One study focused on better probabilistic forecasts for weak and moderate winds by utilizing statistical methods and new types of wind observations in the development of weather models. The other study evaluated atmospheric icing forecasts, relevant for wind power, with ground-based ceilometer-measurements.

- Geological Survey of Canada (GSC) has been characterizing Canadian Atlantic subsea geology, including considerations for implications for offshore wind.

Advanced technology—Components

- In the British Joule Challenge Phase 1, ORE Catapult and the National Composites Centre reviewed key opportunities for producing wind turbine components using next generation advanced composites technologies. These could facilitate a step change in device capabilities, enabling 20MW generation capacity for fixed foundation/ floating wind requirements.

- As part of the US DOE's efforts to develop advanced materials and processes for wind energy technologies, Oak Ridge National Laboratory and the National Renewable Energy Laboratory (NREL) researched how additive manufacturing and advanced materials could benefit wind turbines as they increase in size and efficiency. Researchers at NREL also demonstrated that using thermoplastic resin to manufacture wind turbine blades could make them more recyclable, lighter, and less expensive.

- The Dutch WindSense project aims at developing more slender blades from the root on by integrating optical sensory fibres running from the blade root to the point with the widest chord. These fibres provide insight in the actual loads whereby the minimal required dimensions of the blade can be determined more accurately.

- The French ePARDISE (Evaluation des Perturbations AéRodynamiques sur les pales pour l'Amélioration de la Durabilité et de l'Impact Sonore des Eoliennes) aims at developing a sensor to measure the air flow near wind turbine blades, to optimize their operations and minimize acoustic emission.

- The Austrian N.Ice project uses an ultra-short pulse laser to generate nanostructures in the sub-µm range on technical surfaces (like rotor blades) in order to avoid or prevent the adhesion of ice. Individual samples will be used in field tests on a small wind turbine and will be exposed together with reference samples to monitor the degree of ice formation and the duration of icing.

- Sweden reported that Modvion has developed a modular turbine tower in laminated wood which lowers the cost and simplifies transportation of tall turbine towers (https://www.modvion.com/).

Advanced technology—Offshore wind

- The EU Commission reported that the LEADFLOAT project developed BW Ideol's floating offshore concept (floating barge) for new offshore wind markets allowing developing projects farther away from shore and with no restriction on the water depth or on the seabed soil conditions. Since 2018, two demonstrators are operating in France (2 MW Floatgen demonstrator) and Japan (3 MW Hibiki project) (https://www.bw-ideol.com/en). Further, a pre-commercial plant is expected to be operational by 2023, following the French government selection of the Eolmed consortium for the development of a 30 MW Mediterranean offshore wind farm (3 wind turbines) 15 km off the coastal town of Gruissan.

- The Norwegian Upscale project builds knowledge about the next generation 25MW floating wind turbines and technologies needed to enable them. This includes a realistic 25MW reference semi-submersible floating wind turbine, new advanced rotor aerodynamics models and improved load reducing control systems.

- The British HOME Offshore is a collaboration between the universities of Manchester, Durham, Warwick, Strathclyde and Heriot-Watt, as well as 16 partner companies and research organizations. It explores new modelling, data science, A.I., robotic technologies which de-risk offshore wind operations, reduce costs and make better use of existing assets.

- The Danish project Offshore Wind Suction Bucket on an Industrial Scale—Part 2 Trial Installation prepared the suction bucket for test installation

and to demonstrate installation in different types of seabeds. The project showed that the modular suction bucket could contribute to a cheaper production of foundations, cheaper transport, and a more efficient and simplified logistics around assembling the bucket structure on the quay.

- The Dutch Tetrahedron crane can lift an extra 50 metres over the classical cranes on the same vessel while lifting performance is preserved. Existing crane vessels can be upgraded with the Tetrahedron crane.

Advanced technology—Life extension, recycling and decommissioning

- The EU NEOHIRE project demonstrated how to reduce the use of rare earth elements, and Co and Ga, in the permanent magnets used in wind turbine generators through a new concept of bonded NdFeB magnets and the usage of new recycling techniques from future and current permanent magnets (PM) wastes.

- The British Leading Edge for Turbines (LEFT) transferred rotor blade leading edge protection technology from the helicopter to the wind industry. The technology demonstrated extremely high erosion resistance and potential to unlock far higher blade tip speeds, whilst providing lifetime leading edge protection. Demonstration and modelling showed the shields could survive extreme design load cases.

- 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.

- The German project SeeOff focuses on cost efficient and environmentally friendly decommissioning of offshore wind farms. The project facilitates how stakeholders develop and assess efficient, project specific decommissioning strategies which are cost-minimizing, comply with legal requirements, ensure safety at work and environmental protection, and are publicly accepted.

Energy systems with high amounts of wind

- In the US, the ExaWind is a suite of high-performance-computing codes developed by

NREL. It provides simulations of wind turbines and power plants to enable engineers to test designs in real time, minimizing industry risk and ensuring optimized performance. DOE's Lawrence Livermore National Laboratory developed a wind power plant modelling framework that is the first to simulate plant performance under complex atmospheric conditions.

- The Danish Power Pack Wind—Hybrid installation generator for offshore wind turbines demonstrated a hybrid generator unit that can supply offshore wind turbines with energy during periods when they are off grid. In collaboration with Ørsted A/S, the project developed a wind turbine integrated supply unit and backup unit for the entire life of the turbine.

Social, environmental and economic impact

- In the US, several projects focus on approaches to protecting wildlife at wind plants: a) a bat deterrent system that uses nacelle-mounted ultrasound-generating devices; b) a 3D-thermal tracking system of birds and bats developed by DOE's Pacific Northwest National Laboratory and c) research by Purdue University and the University of Minnesota exploring eagle physiology to improve the effectiveness of deterrents used around wind energy facilities.

- In the German VISSKA project, the innovative installation method 'vibratory pile driving' is assessed and verified as a potential low-noise and sustainable alternative to impact hammering with respect to duration and underwater noise emission. Measurements are conducted during the installation of the offshore wind farm 'KASKASI II' in the German North Sea. The development and validation of prediction models for installation and noise emission as well as the investigation of the reaction of harbour porpoises to continuous noise shall promote the transfer of the innovative installation method to a state-of-the-art installation method.

- The research programme Vindval finances four projects on regional and national planning of wind power in Sweden and management of conflict of interests. These projects develop methods for finding good locations for wind power both onshore and offshore that minimize negative impacts on humans, animals, and nature. They address the challenge of the planning stage for a large deployment of sustainable wind power in Sweden.

- The Italian WinWind aimed at enhancing social acceptance fostering a continued dialogue via regional thematic workshops, and policy roundtables. Multiple stakeholders were engaged and provided

insight into social acceptance and knowledge on wind energy. The open access tool PocketWinWind (https://www.pocketwinwind.eu/) was designed to facilitate socially inclusive wind energy development and provided useful information to citizens, public administrators, and market actors.

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.

In Yangjiang City, Guangdong Province, China General Certification Center was inaugurated in 2020 and now operates the world's largest full-scale testing platform, capable of testing 150-metre long wind turbine blades.

Some projects are not wind energy specific, but indirectly support the wind industry by seeking to further integrate renewable energy sources into the energy system. This includes the ARIES energy research platform that allows NREL researchers and the scientific community to address the fundamental challenges of integrated energy systems at the 20 MW scale.

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. For example, the AFLOWT (Accelerating market uptake of Floating Offshore Wind Technology) aims to demonstrate the survivability and cost-competitiveness of a floating offshore wind technology. Along with the SEMREV test site on the Atlantic Coast, the HexaFloat demonstrator deployment will take place on at the MISTRAL test site on the Mediterranean Coast.

Table 13 highlights several of the test and demonstration facilities in the IEA Wind TCP member countries.

NEXT TERM

The near future for wind energy is bright and yet challenging. On one hand, it is expected to see a huge growth both in deployment rate and in technological advances; and on the other hand, this growth must be done sustainably, with circularity and societal support at its heart. 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.

PHOTO: COLOURBOX

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

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 supported 17 Tasks working on wind energy research, development, and deployment (R,D&D) in 2020. 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 I EA Wind. Often, a participation fee from member countries supports the Operating Agents (OA's) efforts to coordinate the research and report to the ExCo.

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.

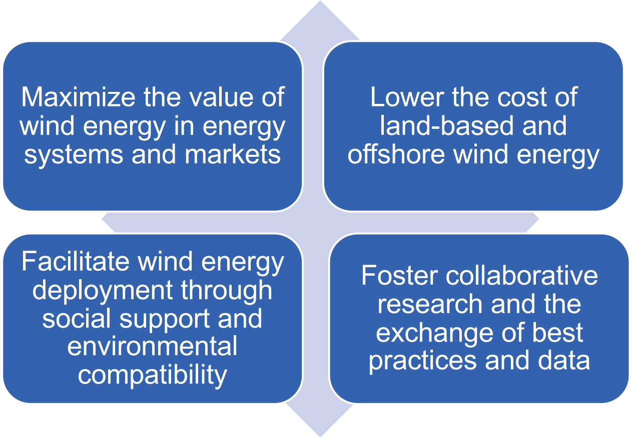
Obituary: Patricia Weis-Taylor

On October 29 2020, former Secretary of the IEA Wind TCP Patricia Weis-Taylor peacefully passed away at the age of 70 years old.

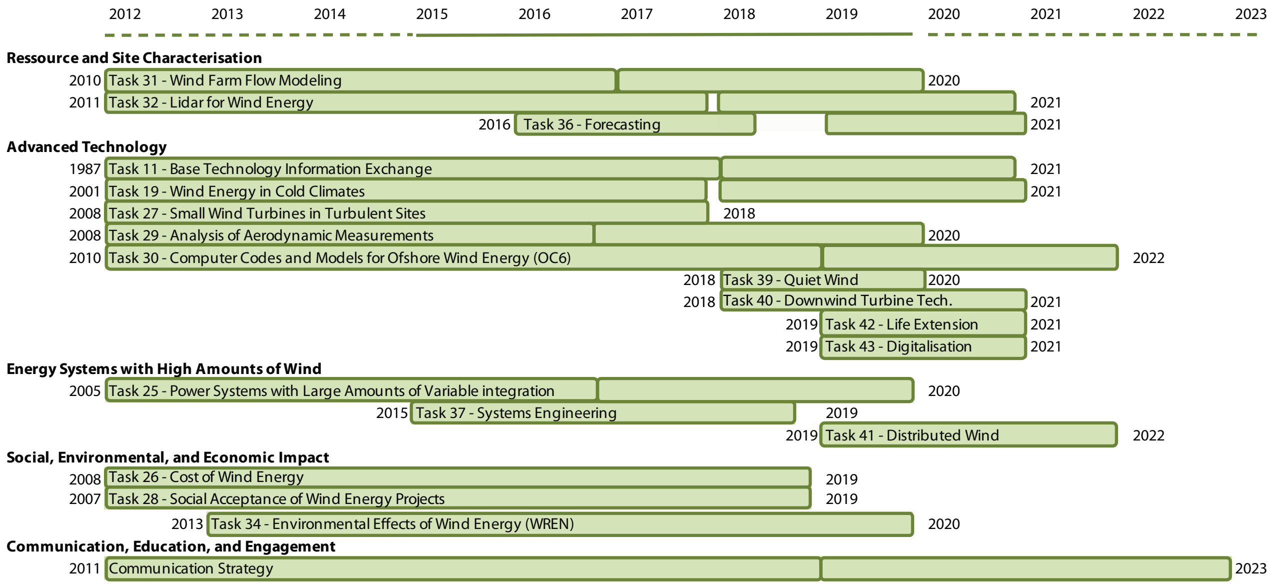
Patricia Weis-Taylor was Secretary of IEA Wind from 1998 and until 2015. In addition to her many contributions, Patricia published the IEA Wind Annual Reports through her company PWT Communications LLC.

She is survived by her husband Rick Hinrichs, mother Patricia Weis, brother Paul Weis, children Alex Taylor and Amber Taylor and grandchildren Oscar and Toby Levesque-Taylor.

IEA Wind TCP Strategic Objectives 2019-2024



2015-2020 STRATEGIC PRIORITY AREAS AND TASKS



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 2020, 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					
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.

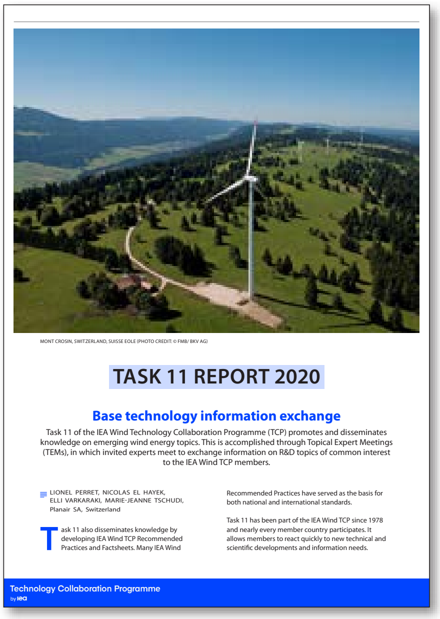
Appendices

Task Reports 2020

Country Reports 2020

Statistics

PHOTOS: COLOURBOX



MONT CROSIN, SWITZERLAND, SUISSE EOLE (PHOTO CREDIT: © FMB/ BKV AG)

TASK 11 REPORT 2020

Base technology information 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.

LIONEL PERRET, NICOLAS EL HAYEK,
ELLI VARKARAKI, MARIE-JEANNE TSCHUDI,
Planair SA, Switzerland

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

Task 11 has been part of the IEA Wind TCP since 1978 and nearly every member country participates. It allows members to react quickly to new technical and scientific developments and information needs.

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READ TASK 11

TASK 11 SUMMARY

Elli Varkaraki, and Lionel Perret, Planair SA

Base technology information 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. Five TEMs were organised in 2020, with the last four taking place online: TEM#98 on Erosion of Wind Turbine Blades in Roskilde, Denmark; TEM#99 on Floating Offshore Wind Arrays; TEM#100 on Aviation System Cohabitation, TEM#101 on Hybrid Power Plants; and TEM#102 on Airborne Wind Energy. Following the success of the TEMs, two new Research Task proposals have been submitted to the ExCo in 2020. When considered useful, a factsheet is prepared with the main results of a TEM. 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. A Leadership Team Summit was organized in 2020 for the first time, to increase the dynamics of the TCP Wind, to accelerate the procedures for task approval, and discuss the interaction with other IEA TCPs. 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 work as a catalyst for starting new IEA Wind TCP Research Tasks. Nearly all IEA Wind TCP countries participate in this Task, which has been active since 1978.

RIME ICE ON A WIND TURBINE BLADE. PICTURE COURTESY OF METEOTEST

TASK 19 REPORT 2020

Wind energy in cold climates

Roughly 20% of onshore wind has been installed in areas where atmospheric icing conditions or low operating temperatures affect the operation of the wind turbines. IEA wind TCP Task 19 was created to address the issues that arise from operating wind farms in cold climate and icing conditions.

TIMO KARLSSON,
VTT, FI

The mission of Task 19 is to *"enable large-scale deployment of cold climate wind power in a safe and economically feasible manner".* The plan for the current term can be divided into three categories: Deployment of wind energy in cold climates, safety, and acceptance, and moving towards certification practices for cold climate solutions.

The goals of the term are represented by a diverse set of deliverables planned for the term. Focus of the work within the Task is developing guidelines and recommendations for the industry, with the long-term goal of pushing for further standardization of cold climate related technologies.

As a highlight of the year, Task 19 completed a new recommendation for *Performance warranty guidelines for wind turbines in cold climates.* The warranty

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READ TASK 19

TASK 19 SUMMARY

Timo Karlsson, VTT, FI

Wind energy in cold climates

Roughly 20% of onshore wind has been installed in areas where atmospheric icing conditions or low operating temperatures affect the operation of the wind turbines. IEA wind TCP Task 19: Wind Energy in Cold Climates was created to address the issues that arise from operating wind farms in cold climate and icing conditions. The mission of Task 19 is to "enable large-scale deployment of cold climate wind power in a safe and economically feasible manner". The plan for the current term can be divided into three categories: Deployment of wind energy in cold climates, safety, and acceptance, and moving towards certification practices for cold climate solutions.

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As a highlight of the year, Task 19 completed a new recommendation for Performance warranty guidelines for wind turbines in cold climates. The warranty guidelines document was developed in collaboration with a group of industry partners from all different sectors of the wind power industry: academic research organizations, consultants, turbine owners, and operators and wind turbine and ice prevention system manufacturers. This group of outside industry participants provided valuable feedback to the work developing these guidelines during the development process.

TASK 25 WIND INTEGRATION FACT SHEETS UPDATED IN 2020, ALSO IN JAPANESE

TASK 25 REPORT 2020

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 decarbonizing pathways. 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. International collaboration remains key to learn from both experience and studies in different countries, in the evolving power and energy systems of the future.

HANNELE HOLTTINEN,
Recognis, Finland

In 2020, Task 25 published updated fact sheets for integration issues—also in Japanese. Hourly timeseries of measured data was gathered from the participating countries, to publish as profiles of large-scale wind power production—correcting for curtailments, if necessary. A summary report for all results in national case studies was compiled, to be published in 2021. Two collaborative journal articles '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' were published in Wiley's WIREs and IEEE TPWRS (open access).

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 main industry stakeholders are the system operators, that also follow Task 25 work directly (from Denmark, France,

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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 and other variable renewable energy, and also for defining future decarbonizing pathways. 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. International collaboration remains key to learn from both experience and studies in different countries, in the evolving power and energy systems of the future.

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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 main industry stakeholders are the system operators, that also follow Task 25 work directly (from Denmark, France, and Italy). The collaboration with IEA PVPS Task 14 in 2018 resulted in a Recommended Practices report including solar integration issues, and is planned to continue in the update process starting in 2021.

PHOTO CREDIT: COLOURBOX

TASK 26 REPORT 2020

Wind power

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

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

Task 26 generates data and insights that inform the potential role for wind power in the future energy system. Specifically, Task 26 seeks to analyze 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

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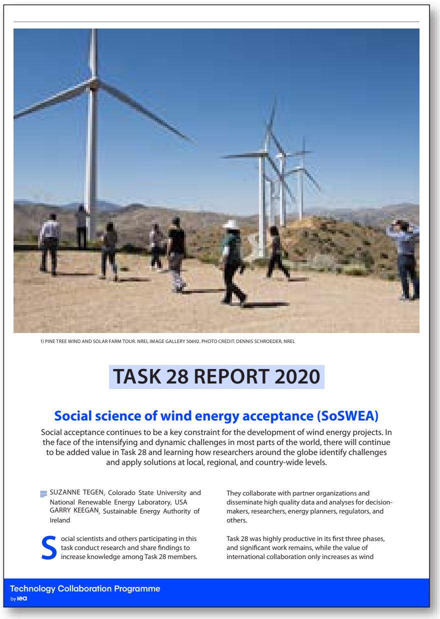
READ TASK 26

TASK 26 SUMMARY

Tyler Stehly, Philipp Beiter, and Eric Lantz,
NREL, United States

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



1) PINE TREE WIND AND SOLAR FARM TOUR. NREL IMAGE GALLERY 50692. PHOTO CREDIT: DENNIS SCHROEDER, NREL

TASK 28 REPORT 2020

Social science of wind energy acceptance (SoSWEA)

Social acceptance continues to be a key constraint for the development of wind energy projects. In the face of the intensifying and dynamic challenges in most parts of the world, there will continue to be added value in Task 28 and learning how researchers around the globe identify challenges and apply solutions at local, regional, and country-wide levels.

SUZANNE TEGEN, Colorado State University and National Renewable Energy Laboratory, USA
GARRY KEEGAN, Sustainable Energy Authority of Ireland

Social scientists and others participating in this task conduct research and share findings to increase knowledge among Task 28 members.

They collaborate with partner organizations and disseminate high quality data and analyses for decision-makers, researchers, energy planners, regulators, and others.

Task 28 was highly productive in its first three phases, and significant work remains, while the value of international collaboration only increases as wind

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READ TASK 28

TASK 28 SUMMARY

Suzanne Tegen, and Garry Keegan

Social science of wind energy acceptance (SoSWEA)

Social and community acceptance continues to be a key constraint for the development of wind energy projects around the world. In the face of the intensifying and dynamic challenge of the acceptance of wind energy, there is and will continue to be added value in Task 28 and learning how researchers define challenges and apply solutions at local, regional, and country-wide levels. Task 28 facilitates international cooperation that advances global understanding of the social science and community-level effects of land-based and offshore wind energy development. The international collaboration creates shared knowledge of ongoing research, lessons, and best practices to assist host communities, governments, industry, and other stakeholders with the deployment processes for wind-generated electricity projects.

In 2020, Task 28 published several fact sheets on common social acceptance issues such as annoyance from noise. These can be used by communities, developers, and local government planners to gain quick information about topics with examples from around the world. Members also published in academic journals on topics popular this year, such as community ownership and energy justice [5].

Task 28 held two virtual meetings and initiated a 4-year extension to operate through May 2024. The wind industry is part of Task 28 in every member country. For example, developers in Denmark worked with Task 28 members to present Wind Farm Developers: a Typology of Acceptability at the 11th International Sustainability Transitions conference [6].

TASK 29 REPORT 2020

Analysis of aerodynamic measurements

DANAERO EXPERIMENT (PHOTO CREDIT: H.A MADSEN)

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READ TASK 29

TASK 29 SUMMARY

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

Analysis of aerodynamic measurements

The main aim of IEA Task 29 was to validate, improve, and develop aerodynamic models for wind turbine design codes. More specifically, the task focused 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. The model assessment was largely, but not exclusively, based on the detailed aerodynamic measurements taken on an NM80 2-MW turbine from the Danish DanAero field experiment. This DanAero experiment was carried out by Danish consortium from Technical University of Denmark (DTU) with LM Glasfiber, Siemens Wind Power Vestas Wind Systems A/S, and the utility company DONG Energy.

Task 29 was finished in December 2020, and the results are described in a final report. The main deliverable is a 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, and a comparison is made between the detailed aerodynamic measurements and results from various calculational codes of different degrees of confidentiality, varying from industrial efficient BEM model to high fidelity CFD codes with intermediate models in between.

Several industries participate in Task 29, and they use the insights obtained from Task 29 analyses in the assessment of their aerodynamic design calculations.

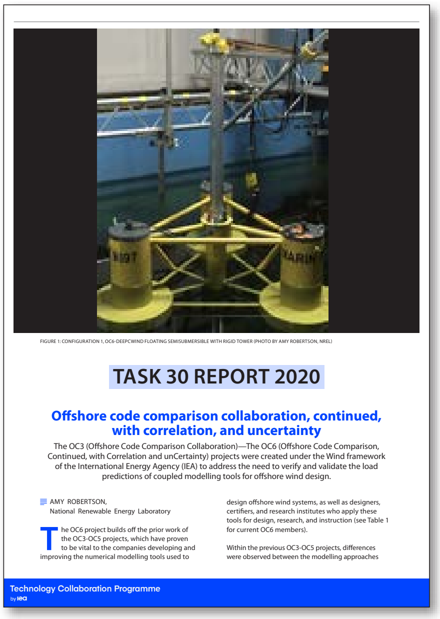

FIGURE 1: CONFIGURATION 1, OC6-DEEPCWIND FLOATING SEMISUBMERSIBLE WITH RIGID TOWER (PHOTO BY AMY ROBERTSON, NREL)

TASK 30 REPORT 2020

Offshore code comparison collaboration, continued, with correlation, and uncertainty

The OC3 (Offshore Code Comparison Collaboration)—The OC6 (Offshore Code Comparison, Continued, with Correlation and unCertainty) projects were created under the Wind framework of the International Energy Agency (IEA) 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

The OC6 project builds off the prior work of the OC3-OC5 projects, which 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

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READ TASK 30

TASK 30 SUMMARY

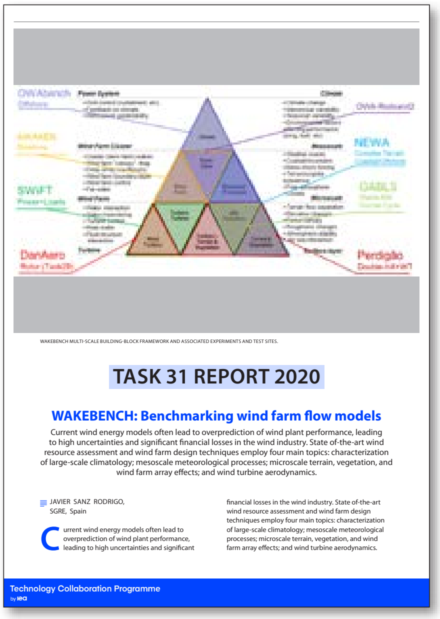
Amy Robertson, NREL

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 2020, Phase I of the project was completed, which 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.

Also in 2020, Phase II of the project was initiated. Phase II focuses on integrating in a new, higher-fidelity modelling capability for representing the interaction between the soil and the piles for fixed-bottom offshore wind systems.



WAKEBENCH MULTI-SCALE BUILDING-BLOCK FRAMEWORK AND ASSOCIATED EXPERIMENTS AND TEST SITES.

TASK 31 REPORT 2020

WAKEBENCH: Benchmarking wind farm flow models

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, vegetation, and wind farm array effects; and wind turbine aerodynamics.

JAVIER SANZ RODRIGO,
SGRE, Spain

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READ TASK 31

TASK 31 SUMMARY

Javier Sanz Rodrigo, CENER

WAKEBENCH: Benchmarking wind farm flow models

The third phase of Task 31 has gathered more than 80 organizations from ten IEA-Wind countries in a mission to establish an international model evaluation framework for wind farm flow models. This phase has launched seven benchmarks addressing wind conditions in offshore, forested, and complex terrain using data from the New European Wind Atlas (NEWA) project; and two benchmarks addressing wake effects from the A2e-SWiFT single-wake experiment and array efficiency from five offshore wind farms from the Offshore Wind Accelerator (OWA) Wake Modeling Challenge. These benchmarks are progressively incorporated to the Wind Energy Model Evaluation Protocol (WEMEP), an open-source documentation project for the Wakebench model evaluation framework. With respect to previous phases (e.g. SWiFT vs Sexbierum single-wake case), we are noticing more consistent results and lower spread due to higher quality experimental data and more robust evaluation methods. Industry involvement has also improved with two industry-led benchmarks: the OWA challenge on array efficiency prediction for 5 offshore wind farms and the Alaiz numerical site calibration case in complex terrain in support to the IEC 61400-12-4 working group. The Wakebench framework is now following the AWAKEN experiment, a large campaign led by NREL and open for international collaboration which will run until 2024. This experiment is discussed within a follow-up new IEA Task that will focus on wide-industry adoption of the framework.

TASK 32 REPORT 2020

Wind lidar for wind energy applications

As wind turbines get larger, go offshore, and contribute ever more to our electricity supply, we need more information about the wind. Conventional anemometry—cup anemometres mounted on masts or turbines—simply cannot provide the level of detail that is needed to measure wind resources at 200 m or higher, monitor wakes, or make control decisions.

ANDREW CLIFTON, University of Stuttgart, Germany
DAVID SCHLIPF, Flensburg University of Applied Sciences, Germany

That's where remote sensing of the wind using lasers—wind lidar—comes in. With wind lidar, we can measure wind conditions several kilometres away, allowing us to replace cup anemometres in existing applications, but also enabling new approaches to operating wind turbines.

IEA Wind Task 32 is focused on identifying and mitigating the barriers to the adoption of wind lidar for wind energy applications. We do this by bringing stakeholders together and identifying what needs to be

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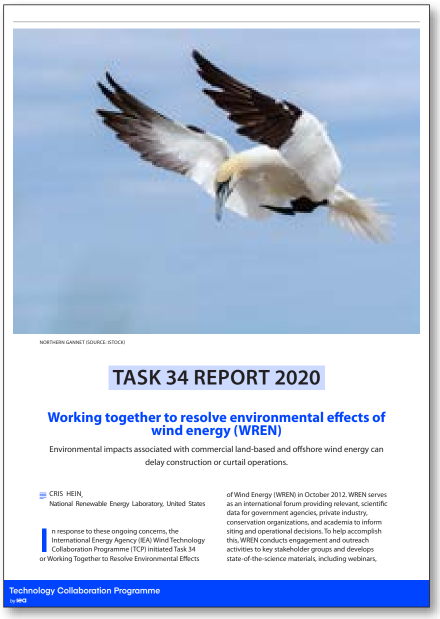
READ TASK 32

TASK 32 SUMMARY

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

Wind lidar for wind energy applications

Wind lidar helps the wind energy industry get crucial information about wind resources on land and offshore, and helps in the efficient and reliable operation of wind plants. IEA Wind Task 32 works to identify and mitigate the barriers to the adoption of wind lidar for wind energy applications by bringing together the community of wind lidar vendors, researchers, and end-users. During 2020 we continued to support the introduction of wind lidar into new areas, including in complex terrain and in cold climates, and by publishing the results of a 2019 workshop on optimizing wind turbines to take advantage of wind lidar. We also explored the implications of digitalisation on wind lidar and the wind energy industry, held monthly public webinars about wind lidar research and development themes, and published several white papers. These and more can be found on our web site. Tasl 32 collaborates extensively with other IEA Wind Tasks including Task 19 (Cold Climates), Task 37 (Systems Engineering), Task 43 (Digitalisation) and Task 44 (Flow control). We also work closely with industry bodies including CFARS and IEC TC88. Our virtual events were attended by many different stakeholders, with around 65% industry participation. Despite our success, wind lidar has still only reached a few percent of the total market. Task 32 will reach the end of its current phase at the end of 2021. We plan to apply for a new Task to support the large-scale deployment of wind lidar from 2022.



NORTHERN GANNET (SOURCE: ISTOCK)

TASK 34 REPORT 2020

Working together to resolve environmental effects of wind energy (WREN)

Environmental impacts associated with commercial land-based and offshore wind energy can delay construction or curtail operations.

CRIS HEIN,
National Renewable Energy Laboratory, United States

In response to these ongoing concerns, the International Energy Agency (IEA) Wind Technology Collaboration Programme (TCP) initiated Task 34 or Working Together to Resolve Environmental Effects of Wind Energy (WREN) in October 2012. WREN serves as an international forum providing relevant, scientific data for government agencies, private industry, conservation organizations, and academia to inform siting and operational decisions. To help accomplish this, WREN conducts engagement and outreach activities to key stakeholder groups and develops state-of-the-science materials, including webinars,

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READ TASK 34

TASK 34 SUMMARY

Cris Hein, NREL

Working together to resolve environmental effects of wind energy (WREN)

Task 34 or Working Together to Resolve Environmental Effects of Wind Energy (WREN) facilitates international cooperation that advances global understanding of the environmental effects of land-based and offshore wind energy development and creates a shared knowledge base of recommended practices for monitoring and mitigation that meet both conservation and wind-generated electricity objectives. Reducing the impact of wind energy development on wildlife requires scientifically robust, cost-effective solutions to inform sound wind siting, construction, operations, and decommissioning decisions. The global nature of the wind energy industry, combined with the understanding that many affected species cross jurisdictional boundaries, highlights the need to collaborate internationally.

In 2020, WREN published a journal article entitled 'Enabling Renewable Energy While Protecting Wildlife: An Ecological Risk-Based Approach to Wind Energy Development Using Ecosystem-Based Management Values' and hosted a webinar called 'Experiences from conducting environmental research at land-based and offshore wind energy facilities'. WREN continued to manage the Tethys knowledge base (https://tethys.pnnl.gov), which serves as a collaborative outreach and engagement platform to disseminate the latest research. WREN held two virtual member meetings and initiated a 4-year extension to operate through 30 September 2024.

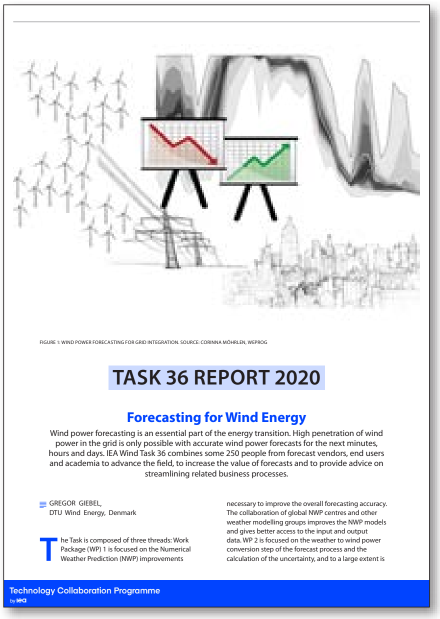

FIGURE 1: WIND POWER FORECASTING FOR GRID INTEGRATION. SOURCE: CORINNA MÖHRLEN, WEPROG

TASK 36 REPORT 2020

Forecasting for Wind Energy

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

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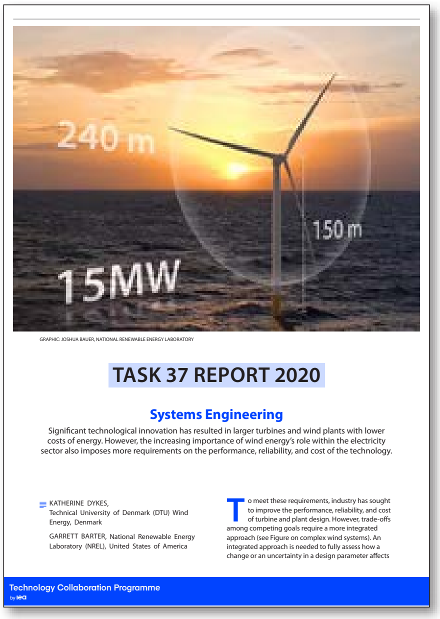
READ TASK 36

TASK 36 SUMMARY

Gregor Giebel, DTU

Forecasting for Wind Energy

Task 36 Forecasting 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, including to demonstrate the value of forecasts, especially of probabilistic forecasts. The Task had a workshop on the value of forecasting in Glasgow, just before Covid-19 hit. An interesting development was the gamification of our education effort to promote probabilistic forecasts. Based on a relatively simple game where users got both deterministic and probabilistic forecasts, users saw that the probabilistic forecasts both gave more confidence in the forecasts and higher results, i.e. better decisions. Additionally, the Task worked on a Technical Report on renewable energy forecasting together with the IEC, standardization 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.



GRAPHIC: JOSHUA BAUER, NATIONAL RENEWABLE ENERGY LABORATORY

TASK 37 REPORT 2020

Systems Engineering

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, Denmark

GARRETT BARTER, National Renewable Energy Laboratory (NREL), United States of America

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

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READ TASK 37

TASK 37 SUMMARY

Katherine Dykes, DTU, and Garrett Barter, NREL

Systems Engineering

Over the last few decades, wind energy has evolved into a large international industry involving major players in the manufacturing, construction, and utility sectors. Coinciding with industry growth, significant technology innovation has resulted in larger turbines and wind plants with lower associated costs of energy. However, the increasing importance of wind energy's role within the electricity sector imposes more requirements on the technology in terms of performance, reliability, and cost.

To address these changing expectations, the industry has made efforts to achieve a variety of goals, including reducing installed capital costs for the turbine and plant, decreasing the downstream costs for operation and maintenance (O&M), increasing energy production, and minimizing negative external environmental impacts such as noise emission or habitat disruption.

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

PHOTO CREDIT: ANDREA VIGNAROLI

TASK 39 REPORT 2020

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 (Technical University of Denmark), Denmark

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 emission, propagation, and ultimately its perception by residents in term of annoyance, but also acceptance. 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

TASK 39 SUMMARY

Franck Bertagnolio, DTU

Quiet wind turbine technology

Wind turbine noise is recognized 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 emission, propagation, and ultimately, its perception by residents as well as their attitude toward noise. The approach is twofold. 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 endeavor 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.

The initial phase of the Task 39 has ended in 2020, and a new work programme for the second phase of the Task is being established. During this second phase, there will be an increased focus on the psychology of noise and how it is perceived by residents, including external factors not related to noise.

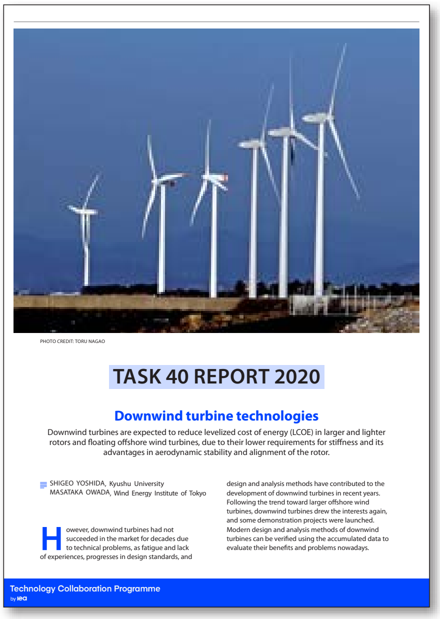

PHOTO CREDIT: TORU NAGAO

TASK 40 REPORT 2020

Downwind turbine technologies

Downwind turbines are expected to reduce levelized cost of energy (LCOE) in larger and lighter rotors and floating offshore wind turbines, due to their lower requirements for stiffness and its advantages in aerodynamic stability and alignment of the rotor.

SHIGEO YOSHIDA, Kyushu University
MASATAKA OWADA, Wind Energy Institute of Tokyo

However, downwind turbines had not succeeded in the market for decades due to technical problems, as fatigue and lack of experiences, progresses in design standards, and 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.

Technology Collaboration Programme
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READ TASK 40

TASK 40 SUMMARY

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

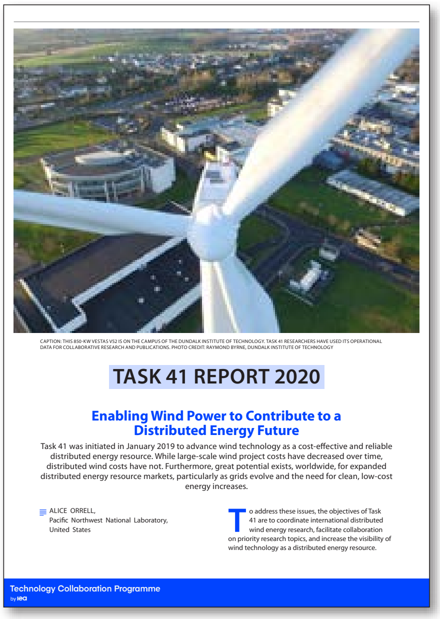
Downwind turbine technologies

Following the trend toward larger and floating offshore wind turbines, downwind turbines drew the interests of…[something missing here]. Modern design/analysis methods and accumulated data can solve the problems and promote the benefits of downwind turbines. IEA Wind TCP Task 40 was conducted for modelling and perspectives of downwind turbine technologies between March 2018 and February 2021. Outcomes of Task 40 are shown below.

WP1 conducts 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 was conducted to reveal the rotor-tower aerodynamic interaction (i.e., tower shadow effect), which is one of the technical problems of downwind turbines. Three models were developed for the blade-element and momentum method and one another model for the system engineering. Tank test and CFD were conducted to verify the rotor-nacelle interaction model, and a model was developed for the BEM. Design conditions for passive yaw idling in a storm, which is promising advantage of downwind turbines, were proposed through analysis and the field measurement.

WP2 conducts design and LCOE assessment. Aeroelastic and optimization models were developed for 10 MW turbines and showed downwind rotor was shown to be promising through the system engineering approach to reduce the mass of the blades and the nacelle, as well as the LCOE for a larger rotor in higher extreme wind speed conditions.

WP3 developed Recommended Practices by integrating and summarizing the achievements in WP1 and 2.



CAPTION: THIS 850-KW VESTAS V52 IS ON THE CAMPUS OF THE DUNDALK INSTITUTE OF TECHNOLOGY. TASK 41 RESEARCHERS HAVE USED ITS OPERATIONAL DATA FOR COLLABORATIVE RESEARCH AND PUBLICATIONS. PHOTO CREDIT: RAYMOND BYRNE, DUNDALK INSTITUTE OF TECHNOLOGY

TASK 41 REPORT 2020

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 costs have not. Furthermore, great potential exists, worldwide, for expanded distributed energy resource markets, particularly as grids evolve and the need for clean, low-cost energy increases.

ALICE ORRELL,
Pacific Northwest National Laboratory,
United States

To address these issues, the objectives of Task 41 are to coordinate international distributed wind energy research, facilitate collaboration on priority research topics, and increase the visibility of wind technology as a distributed energy resource.

Technology Collaboration Programme
by iea

READ TASK 41

TASK 41 SUMMARY

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

Enabling Wind Power to Contribute to a Distributed Energy Future

IEA Wind Task 41 is an international group of researchers from eleven member countries and associations dedicated to advancing wind technology as a cost-effective and reliable distributed energy resource. Our objectives are to coordinate international distributed wind energy research, facilitate collaboration on priority research topics, and increase the visibility of wind technology as a distributed energy resource to lower its costs and deployment barriers.

In 2020, Task 41 participants continued to define updates to design and testing standards for small and mid-sized wind turbines; facilitate data sharing opportunities; develop grid integration strategies to support evolving distribution grid and microgrid systems; and facilitate collaboration opportunities amongst task members and outside university researchers.

One highlight from 2020 is that Task 41 initiated a University Research Collaboration project to expand distributed wind research and engage with the next generation of distributed wind researchers. The research topics focus on identifying opportunities to both down-scale innovations from large wind turbine design and refine small wind turbine design, with a goal of reducing the costs of distributed wind turbines.

FIGURE 1: ALPHA VENTUS WIND FARM IN GERMANY THAT IS USED TO VALIDATE METHODS FOR PREDICTING REMAINING LIFE

TASK 42 REPORT 2020

The objectives of the IEAWIND

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.

ANAND NATARAJAN, anat@dtu.dk

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 42 SUMMARY

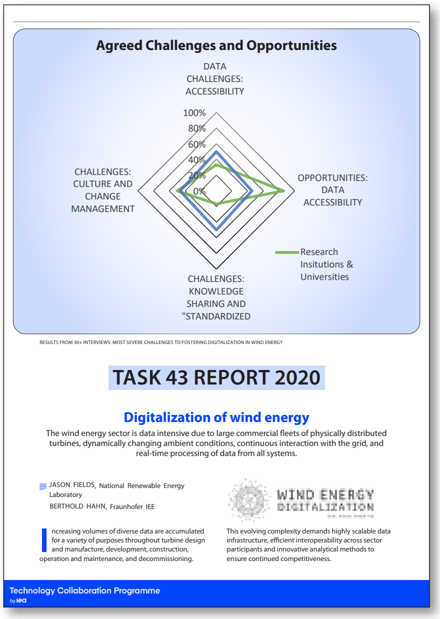
Anand Natarajan, DTU

The objectives of the IEAWIND

The objectives of the IEAWIND Task 42 on Lifetime Extension Assessment include:

- Benchmark methods for assessment of the reliability level of primary structures under relevant limit states
- The results of the Task should be utilizable in the development of standards for lifetime extension and by national bodies putting in place regulations on lifetime extension.
- Develop methods to detect damage and discuss how to categorize damages based on established knowledge
- Report on the management of data and its usefulness for life extension.
- Application to predictive maintenance and repairs
- Policy and state of the art on regulatory approaches and public perception may be included.

The Task initiated in September 2019. In the last year, a series of online meetings were held with all partners to commence the activity on benchmarking remaining life estimation methods using the data from the Alpha Ventus offshore wind farm in Germany. The prediction of remaining life using methods from the partners for the tower and the blades was made using measured loads and met-ocean conditions. Partners also made such benchmarking with other available wind farm or wind turbine measurement data. The methods included extrapolation of predicted damage equivalent loads (DEL) using several algorithms to predict DELs in the future and building load forecasting models using 10-minute measurement data statistics. Economic analysis on the potential profitability of life extension was also made with specific wind farm cost analysis.



RESULTS FROM 30+ INTERVIEWS: MOST SEVERE CHALLENGES TO FOSTERING DIGITALIZATION IN WIND ENERGY

TASK 43 REPORT 2020

Digitalization of wind energy

The wind energy sector is data intensive due to large commercial fleets of physically distributed turbines, dynamically changing ambient conditions, continuous interaction with the grid, and real-time processing of data from all systems.

JASON FIELDS, National Renewable Energy Laboratory
BERTHOLD HAHN, Fraunhofer IEE

Increasing volumes of diverse data are accumulated for a variety of purposes throughout turbine design and manufacture, development, construction, operation and maintenance, and decommissioning.

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

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 digitalizing specific segments of the wind plant life cycle, much remains to be done to increase digitalization momentum. This includes developing a holistic view and identifying wider opportunities to reduce lifecycle costs, expedite, deploy, enhance performance of assets, and integrate wind energy effectively into evolving energy grids and markets.

The scope of the Task includes digitization topics across the following dimensions:

- Lifecycle stages.
- Value chain components.
- Interaction between and across lifecycle and value chain players.

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 which maximize benefits from digitalization while minimizing duplicate or inefficient effort. This will be achieved by convening an international expert body that will:

- Define what is meant by wind energy digitalization
- Describe the current state of digitalization capability and practice within the wind energy sector
- Identify and prioritize value-add opportunities enabled by further digitalization
- Develop recommended digitalization practices for the wind energy sector.

Since the topic of digitalization is quite broad, the task has broken up into several work packages. Now, the teams are working in parallel on both the technical issues and on the crosscutting topics. Additionally, based on the outcomes of a number of interviews with external experts from research and industry and on the results of the technical discussions, Task 43 strives to develop a roadmap for digitalization in wind energy.

Country Reports - Overview

IEA Wind Member countries and EU and WindEurope have a 2020 report (available in Oktober 2021) with progress & achievements, outcomes & significance and next steps.

PHOTO CREDIT: BERNHARD FÜRNSINN

AUSTRIA

Austria has set ambitious renewable energy and climate protection targets of reaching 100% renewable electricity by 2030. Nevertheless, the year 2020 marked a further decline in the expansion of wind power. Continuing political uncertainties and administrative barriers are slowing down the expansion significantly.

BERNHARD FUERNSINN, PATRIK WONISCH, Austrian Windenergy Association and ANDREAS KRENN, Energiewerkstatt, Austria

In 2020, Austria installed seven turbines with a capacity of 25 MW, compared to 59 turbines in 2019. By the end of 2020, more than 3,120 MW were installed. As a result comparing installed and decommissioned turbines in Austria gained a net reduction of existing wind power plants. [1]. The estimated feasible potential until 2030 is at 7,500 MW with 22.5 TWh p.a. [2].

READ COUNTRY REPORT - AUSTRIA

BELGIUM

in 2004 created a 156-km² area in the Belgian Exclusive Economic Zone (EEZ) in international waters for wind farms. The first wind turbines were installed in this area in 2009. At the end of 2020, 399 offshore wind turbines were operational—producing 8 TWh/yr.

JAN HENSMANS and PIETER JAN JORDAENS

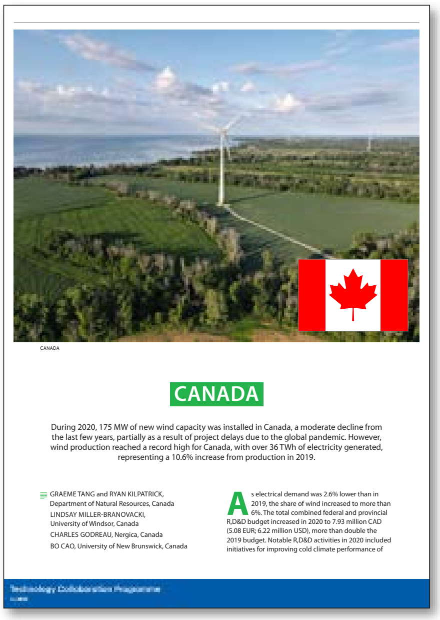
Belgium is a frontrunner for installed capacity relative to the available space, the bathymetry, and the distance from shore. Prominent researchers and research institutions place Belgium as a leader in offshore wind power.

Market development

National targets and policies supporting development

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

READ COUNTRY REPORT - BELGIUM



CANADA

CANADA

During 2020, 175 MW of new wind capacity was installed in Canada, a moderate decline from the last few years, partially as a result of project delays due to the global pandemic. However, wind production reached a record high for Canada, with over 36 TWh of electricity generated, representing a 10.6% increase from production in 2019.

GRAEME TANG and RYAN KILPATRICK, Department of Natural Resources, Canada
LINDSAY MILLER-BRANOVACKI, University of Windsor, Canada
CHARLES GODREAU, Nergica, Canada
BO CAO, University of New Brunswick, Canada

As electrical demand was 2.6% lower than in 2019, the share of wind increased to more than 6%. The total combined federal and provincial R,D&D budget increased in 2020 to 7.93 million CAD (5.08 EUR; 6.22 million USD), more than double the 2019 budget. Notable R,D&D activities in 2020 included initiatives for improving cold climate performance of

READ COUNTRY REPORT - CANADA

WIND FARM IN CHINA (PHOTO CREDIT: CWEA)

CHINA

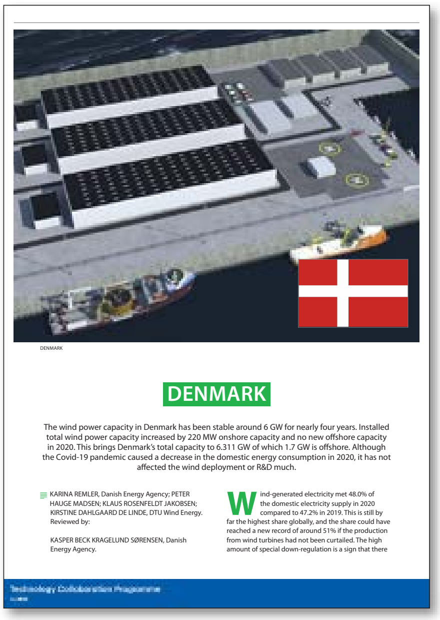
China continues to have the highest wind power capacity in the world. The wind power capacity growth presented a higher rate, and 54,427MW of new wind power capacity was installed, representing a 103.2% increase in growth from last year.

NIHE DEXIN, Du Guangping, and LYU BO, Chinese Wind Energy Association (CWEA), China

Accumulated capacity increased to 290,747MW. Grid-connected capacity increased to 281,000 MW with the addition of 71,670 MW installed in 2020. New wind power capacity accounted for 12.8% of installed power capacity nationwide.

Wind power remains the third largest generation source in China, following thermal and hydro-electricity sources. The average full-load-hour of wind power was 2,097 hours in 2020, an increase of 15 hours from 2019.

READ COUNTRY REPORT - CHINA



DENMARK

DENMARK

The wind power capacity in Denmark has been stable around 6 GW for nearly four years. Installed total wind power capacity increased by 220 MW onshore capacity and no new offshore capacity in 2020. This brings Denmark's total capacity to 6.311 GW of which 1.7 GW is offshore. Although the Covid-19 pandemic caused a decrease in the domestic energy consumption in 2020, it has not affected the wind deployment or R&D much.

KARINA REMLER, Danish Energy Agency; PETER HAUGE MADSEN; KLAUS ROSENFELDT JAKOBSEN; KIRSTINE DAHLGAARD DE LINDE, DTU Wind Energy. Reviewed by:

KASPER BECK KRAGELUND SØRENSEN, Danish Energy Agency.

Wind-generated electricity met 48.0% of the domestic electricity supply in 2020 compared to 47.2% in 2019. This is still by far the highest share globally, and the share could have reached a new record of around 51% if the production from wind turbines had not been curtailed. The high amount of special down-regulation is a sign that there

READ COUNTRY REPORT - DENMARK

PHOTO BY ZBYNEK BURIVAL ON UNSPLASH.

EUROPEAN COMMISSION

The European Union will have at least 32% of its energy demand (heat and power) from renewable sources by 2030, meeting an estimated 50% of the power demand. Notably, in 2020, renewable energy production surpassed for the first time that of fossil fuel sources [1].

THOMAS TELSNIG, European Commission – Joint Research Centre, the Netherlands
IVAN KOMUSANAC, WindEurope, Belgium
CARLOS EDUARDO LIMA DA CUNHA, European Commission – DG Research and Innovation, Belgium

In November, the European Commission published the Offshore Renewable Energy Strategy [2], which highlights the role that every offshore technology will have in supporting the key ambition of the European Green Deal—carbon neutrality by 2050. Thus, considering the European Green Deal long-term vision of climate neutrality through a new growth strategy [3], the EU is currently in the process of reviewing these targets, aiming at a 55% GHG reduction target by 2030. Together, these goals, new and ongoing alike, represent a powerful driving force for renewables, particularly wind energy.

READ COUNTRY REPORT - EU

THE BÅTSKAR WIND FARM IS THE FOCUS OF A MEASUREMENT CAMPAIGN IN PROJECT TUTTE, AIMING AT UNDERSTANDING THE WIND INFLOW AND WAKE INTERACTIONS. THE WIND FARM IS BUILT ACROSS FOUR ISLETS IN ÅLAND ISLANDS. PHOTO CREDIT: MANU HUTTUNEN

FINLAND

Year 2020 was remarkable for wind energy. Amidst the pandemic, installations continued to grow and higher-than-normal wind conditions took the wind share to 9.6% of electricity consumption [1].

RAUL PRIETO, NIINA HELISTÖ AND TIMO KARLSSON, VTT Technical Research Centre of Finland
EVGENY ATLASKIN , Finnish Meteorological Institute
AILA MAIJANEN, Business Finland

Wind power in Finland has rapidly consolidated an unsubsidized model. All the wind power projects that completed in 2019 and 2020 were constructed without subsidies, and more are under construction.

New wind power of 302 MW capacity was installed in Finland. By the year's end, installed wind power capacity amounted to 2,586 MW with 7.8 TWh of production—a 30% increase from 2019. Renewables provided about 42% of the country's electricity consumption in 2020:

READ COUNTRY REPORT - FINLAND

FRANCE

FRANCE

In 2020, over 1.1 GW new onshore wind was built in France. This number shows a third consecutive year of decrease, well below the average of 1.5 GW over the previous years. It should in the future increase to 2 GW per year to reach the newly set targets for 2023.

DANIEL AVERBUCH,
IFPEN Energies nouvelles, France.

This brings the total wind power capacity to 17.6 GW. Wind and solar now jointly represent 50% of France renewable installed power capacity, while wind alone represented 30% of the total renewable electricity production and 8.8 % of the national electricity demand in 2020. Total annual electrical energy output from wind was 39.7 TWh, a significant increase from 2019. This increase is the result of higher installed power capacity, in conjunction with a capacity factor of 26.5 %, substantially higher than the year before.

READ COUNTRY REPORT - FRANCE

"OFFSHORE WIND TURBINES IN AN OFFSHORE WIND FARM". SOURCE: ©AGRARMOTIVE - STOCK.ADOBE

GERMANY

Wind energy plays an important role for the successful energy transition to renewable energies in Germany. In 2020 wind energy had the biggest contribution to power generation from renewables. With an amount of 131 TWh electricity from wind power has reached an all-time record (126 TWh in 2019). Special attention should be drawn to February 2020, where more than 20 TWh of wind energy power have been generated, what excels the previous record from March 2019 (15,5 TWh). [6]

FRIEDERIKE BARENHORST and FRANCISKA KLEIN, Forschungszentrum Jülich GmbH - Project Management Jülich (PtJ); STEPHAN BARTH, ForWind - Center for Wind Energy Research, Germany

Market Development

Targets and Policy

- With the amendment of the Renewable Energy Sources Act 2021 (EEG 2021) which was adopted in December 2020, renewable energy targets were updated to reach 65 % of electricity share by 2030. To

READ COUNTRY REPORT - GERMANY

WIND FARM IN EVIA, CENTRAL GREECE (SOURCE: CRES)

GREECE

The previous year, wind energy in Greece continued its dynamic expansion with annual new installations exceeding long-term average. 525 MW of new wind farms were completed and connected to the grid in 2020 corresponding to a 13% increase in installed wind capacity.

NIKOLAOS STEFANATOS AND KYRIAKOS ROSSIS, Center for Renewable Energy Sources and Saving (CRES), Greece.

As a result of a decision to speed up the switch to carbon free system, significant installed capacity of lignite plants was shut down, resulting in a drastic reduction of lignite share in electricity production (12.1% compared to 18% in 2019). Although natural gas remains the main energy source for the Greek electricity grid, RES is steadily increasing its share on track to become the major component by 2030.

READ COUNTRY REPORT - GREECE

WIND TURBINE TEST STATION, KAYATHAR.

INDIA

As per estimates, India has a wind potential of more than 695.50 GW at a hub height of 120 metres, and the country currently has the fourth-highest wind installed capacity in the world with total installed capacity of 38.62 GW as on 31 December, 2020 and 60.42 billion units were generated from wind power during the year 2020.

DR. K. BALARAMAN, DIRECTOR GENERAL
National Institute of Wind Energy, India

India's Nationally Determined Contributions (NDC) under the Paris Agreement for the Period 2021 - 2030 include:

- To reduce the emissions intensity of its GDP by 33 to 35% by 2030 from 2005 levels; and
- To achieve approximately 40% cumulative electric power installed capacity from non-fossil fuel-based energy resources by 2030 with the help of transfer of technology and low-cost international finance.

READ COUNTRY REPORT - INDIA

IRELAND

IRELAND

Wind energy deployment, to meet national targets, continued in 2020, albeit at a lower rate due to a changeover in support schemes.

JOHN MC CANN, SEAI, Ireland

The implementation of the Climate Action Plan measures to achieve ambitious 2030 targets ramped up, including measures facilitating the offshore wind sector. The new Government brought increased climate and renewable energy ambitions, particularly for offshore wind.

READ COUNTRY REPORT - IRELAND

OPENING PHOTO: BLADE TRANSPORT WITH INNOVATIVE BLADE LIFTER SYSTEM THROUGH A SMALL VILLAGE IN LIGURIAN REGION TO THE SITE OF INSTALLATION OF ROCCHE BIANCHE WIND PLANT .(CREDITS: PHOTOGRAPH MARCO RIMONDI AND COPYRIGHT FERA SRL, WWW.FERASRL.IT)

ITALY

In 2020 Italy was one of the first countries strongly affected by the COVID pandemic and consequent lockdowns. This caused delays in all the sectors, including wind park installations and wind energy related research activities. The new yearly power capacity, around 100 MW, represents the minimum value in the last fifteen years. However, three joint PV wind tenders to access the incentives took place and wind farms won 87% of the whole 1 GW capacity. The renewable penetration registered very relevant peaks.

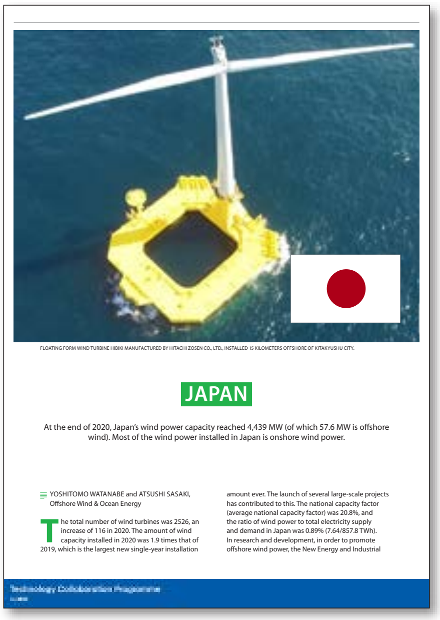
LUCA GRECO, National Research Council, CNR, Italy
LAURA SERRI, Ricerca sul Sistema Energetico, RSE S.p.A., Italy.

Market Development

Targets and Policy

In 2009, Italy set a binding national target of 17% of overall annual energy consumption from renewable energy sources (RES) in 2020, which included a target of 12.68 GW (12.0 GW land-based and 0.680 GW

READ COUNTRY REPORT - ITALY



FLOATING FORM WIND TURBINE HIBIKI MANUFACTURED BY HITACHI ZOSEN CO., LTD., INSTALLED 15 KILOMETERS OFFSHORE OF KITAKYUSHU CITY.

JAPAN

At the end of 2020, Japan's wind power capacity reached 4,439 MW (of which 57.6 MW is offshore wind). Most of the wind power installed in Japan is onshore wind power.

YOSHITOMO WATANABE and ATSUSHI SASAKI, Offshore Wind & Ocean Energy

The total number of wind turbines was 2526, an increase of 116 in 2020. The amount of wind capacity installed in 2020 was 1.9 times that of 2019, which is the largest new single-year installation amount ever. The launch of several large-scale projects has contributed to this. The national capacity factor (average national capacity factor) was 20.8%, and the ratio of wind power to total electricity supply and demand in Japan was 0.89% (7.64/857.8 TWh). In research and development, in order to promote offshore wind power, the New Energy and Industrial

READ COUNTRY REPORT - JAPAN

SOUTHWEST OFFSHORE WIND FARM, JELLABUK-DO, KOREA, DOOSAN HEAVY INDUSTRY 3 MW WTGS, SOURCE: KOREA OFFSHORE WIND POWER CO., LTD.

KOREA

Having installed 191 MW capacity of wind turbines in 2019 and 160 MW in 2020, the accumulated capacity in Korea reached 1650 MW at the end of 2020. A 60 MW offshore windfarm was constructed in 2020 resulting in 132 MW offshore wind power capacity in Korea.

SEUNG-HO SONG, Kwangwoon University, Republic of Korea

In 2017, the renewable energy target was raised to 20% of the electricity generation by 2030. In October 2020, president Moon Jae-in announced that the Republic of Korea aims to achieve carbon neutrality by 2050. The wind energy sector in Korea, which has shown slower deployment than the photovoltaics, is preparing large-scale installation of wind energy, especially in offshore wind for the energy transition.

READ COUNTRY REPORT - KOREA

OPENING PHOTO: (PHOTO CREDIT: © INEEL)

MÉXICO

In 2020, the wind power sector in Mexico had added 574 MW of new wind power to the national electricity grid, bringing the total capacity to 6,681 MW [1]. The growth rate for annual additions was 9% with respect to 2019, and representing about 8.6% of total installed capacity [1].

JOSÉ MANUEL FRANCO-NAVA, National Institute of Electricity and Clean EnergieS (INEEL Mexican Wind Energy Innovation Center (CEMIE-Eólico), México.

The new capacity represents 0.66% of the total new wind onshore world capacity for 2020 of 86.9 GW [2]. In the next four years, new policies will support an accelerated transition towards the generation, transmission and use of renewable and clean energy, as long as social inclusion is contemplated [3]. Three auctions performed so far resulted in 3,407 MW of wind power contracted; these projects should be installed before 2021.

México's R&D focus is on small and medium-size turbines. In 2020, efforts included design and

READ COUNTRY REPORT - MEXICO

SOURCE: SIMON OLDANI_NVE

NORWAY

Wind power in Norway continued with a high level of deployment and increased by 1532 MW in 2020, resulting in a net total installed capacity of 3,977 MW at the end of the year. The production of wind-based electrical energy in 2020 was 9.9 TWh, an increase of 80% from the year before. Decreasing LCOE for wind power projects and the end of the electricity certificate scheme drives the high level of wind power deployment in Norway in recent years.

ANN MYHRER ØSTENBY, Norwegian Water Resources and Energy Directorate, and HARALD RIKHEIM, Research Council of Norway.

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READ COUNTRY REPORT - NORWAY

CREDITS: LÍDIA LEAL. LEGEND: WINDFLOAT ATLANTIC OFFSHORE WIND FARM

PORTUGAL

In 2020, no new wind farms were installed in Portugal. However, additional capacity was added to existing wind farms and corresponded, in total, to 41 MW. In this sense, by the end of 2020, 5,478 MW was operating in the country, corresponding to 38% of the national total renewable operational capacity. The wind-based electrical energy in 2020 was 12.36 TWh, meeting [25%] of the Portugal's electricity demand.

PAULA COSTA, TERESA SIMÕES, ANTÓNIO COUTO, ANA ESTANQUEIRO, Laboratório Nacional de Energia e Geologia – LNEG, Portugal.

Considering the overall renewable power capacity installed in Portugal, the electricity production in 2020 reached 64% of the national consumption, a small decrease compared to the previous year. On 25 October 2020, between 03:00 and 08:15 a.m., continental Portugal met 100% of its electricity needs with wind energy during several periods. The instantaneous electricity demand met by wind energy during this period was 105%.

READ COUNTRY REPORT - PORTUGAL

WHY WE ARE SUSTAINABLE? (PHOTO CREDIT: JOSE LUIS RODRIGUEZ)

SPAIN

Renewable sources-based power supply in Spain reached 44% of total power consumption in 2020. (Total power demand declined by 5.6%).

IGNACIO CRUZ and LUIS ARRIBAS, Centro de Investigaciones Energeticas Medioambientales y Tecnologicas (CIEMAT) in collaboration with the Spanish Wind Energy Association (AEE) Spain.

Throughout 2020, wind power was the second largest source of electricity generation in Spain, with a relative generation growth of up 5.8%.

According to the Spanish National Integrated Energy and Climate Plan 2021-2030 (NECP) the government is committed to reach about 50,258 GW of installed wind capacity which means about 28.86 billion EUR (35.29 billion USD) to meet European targets for 2030.

The Spanish wind sector installed 1,720 MW during 2020 [1], which is accounts for10% of all new wind

READ COUNTRY REPORT - SPAIN

PROTOTYPE TURBINE AT SWPTC WITH WOODEN TOWER FROM MODVION ON BJÖRKÖ (GOTHENBURG), NACELLE HEIGHT 30 M, ROTOR DIAMETER 16 M. (SOURCE: MODVION).

SWEDEN

In 2020, Sweden installed 1,403 MW of new wind energy capacity (1,588 MW were installed in 2019). At the end of the year, the country's total installed capacity was 10,084 MW from 4 333 wind turbines.

ANDREAS GUSTAFSSON and PIERRE-JEAN RIGOLE, Swedish Energy Agency, Sweden.

Through the EU burden-sharing agreement, Sweden has a goal of greenhouse gas emission reduction of 40% in 2030 in relation to 2005 levels. At the national level, Sweden is to have no net emissions of greenhouse gases into the atmosphere by 2045 and should thereafter achieve negative emissions. To achieve zero net emissions, emissions from activities in Swedish territory are to be at least 85% lower than emissions in 1990. Another national goal is to reach 100% renewable electricity production in 2040. The Swedish Energy Agency estimates that the country will

READ COUNTRY REPORT - SWEDEN

FIGURE 1 SAN GOTTARDO SITE (WWW.AET.CH)

SWITZERLAND

By the end of 2020, Switzerland had 42 large wind turbines in operation with a total rated power of 87 MW. These turbines produced 146 GWh of electricity in 2020. The construction of a new wind farm with a capacity of 12 MW began in 2019; it will be operational by end of 2020, increasing the total wind power capacity by 15%.

KATJA MAUS, Swiss Federal Office of Energy, Switzerland
LIONEL PERRET and MATTHIEU DUCRET, Planair SA, Switzerland

A cost-covering feed-in tariff (FIT) for renewable energy in Switzerland has been in place since 2009 [1]. This policy promotes wind energy and has led to an increase in new wind energy projects. Financing is currently requested for an additional 3.3 TWh under the FIT scheme

Internationally cross-linked research activities in 2020 focused on cold climates, complex terrain, aviation cohabitation, and social acceptance.

READ COUNTRY REPORT - SWITZERLAND

HIGH VOLTAGE OFFSHORE SUBSTATION IN BORSSELE WIND FARM, AUGUST 2020, WIND FARM OPERATOR BLAUWWIND. PICTURE SOURCE: RVO

THE NETHERLANDS

In 2020, the total installed wind power capacity was 6.6 GW, which is considerably more than the 4.5 GW in 2019. This is mainly due to the increase in offshore wind power from 1 GW to 2.5 GW in line with the planned rollout of the Borssele wind farms.

RUUD OERLEMANS, Rijksdienst Voor Ondernemend Nederland (www.RVO.nl). The Netherlands. ruud.oerlemans@rvo.nl.

At the end of 2024, about 4.5 GW wind power should be installed in the Dutch part of the North Sea according to the first road map. Until 2030, another 6 GW is currently under development according to the second road map bringing total offshore capacity to 11 GW in the Dutch part of the North Sea.

The commissioning of the onshore wind farms is going slowly, but steadily towards the 6 GW goal of 2020. In

READ COUNTRY REPORT - NETHERLANDS

7 MW LEVENMOUTH DEMONSTRATION TURBINE (SOURCE: ORE CATAPULT)

UNITED KINGDOM

High winds in spring 2020 combined with low energy demand due to COVID-19 allowed renewable energy to outpace annual fossil fuel generation for the first time. Electricity demand was at its lowest level in over a decade with 281 TWh final consumption, a 4.7% decrease from 2019.

ANGELIKI SPYROUDI, AMANDA GRAHAM, Offshore Renewable Energy Catapult, United Kingdom

Industrial and non-domestic consumption dropped by 10% in contrast to domestic use which increased by 4%.[1] Wind energy provided over 56% of the total annual electricity generation from renewables (26% onshore and 30% offshore).[2]

The UK maintained its dominant position in offshore wind with installations growing 412 MW to 10.4 GW in 2020. Onshore wind capacity only increased by 157 MW, but this is set to accelerate with onshore wind projects allowed to compete in the same pot as solar energy in upcoming auctions.

The UK Government announced a ten-point green recovery plan in 2020 which included a rise in the

READ COUNTRY REPORT - UNITED KINGDOM

THE 8,000-ACRE LOS ANGELES DEPARTMENT OF WATER AND POWER PINE TREE WIND AND SOLAR FARM IN THE TEHACHAPI MOUNTAINS NORTH OF MOJAVE, CALIFORNIA, FEATURES 80 1.5-MEGAWATT (MW) GENERAL ELECTRIC WIND TURBINES AND IS ONE OF THE LARGEST MUNICIPALLY OWNED WIND FARMS IN THE UNITED STATES. *PHOTO BY DENNIS SCHROEDER, NATIONAL RENEWABLE ENERGY LABORATORY (NREL)*

USA

Wind power capacity in the United States grew at a record pace in 2020, adding 16.8 gigawatts (GW)[1]. Wind continues to be the top source of renewable energy production in the United States[2]. The U.S. Energy Information Administration (EIA) states that wind accounted for 9.2% of U.S. electric sales or 8.3% of U.S. generation in 2020[3].

U.S. DEPARTMENT OF ENERGY'S WIND ENERGY TECHNOLOGIES OFFICE, NATIONAL RENEWABLE ENERGY LABORATORY

The United States had 121,985 megawatts (MW) of operating wind power capacity [1], with 67,814 wind turbines operating across 42 states and two U.S. territories at the end of 2020 [5]. Wind energy companies employed 116,817 workers in 2020 [6]. Project developers and power purchasers reported power purchase agreement activity totaling 5,444 MW in 2020 [4].

At the end of December, the Bureau of Ocean Energy Management (BOEM) had issued 15 active commercial

READ COUNTRY REPORT - UNITED STATES

PHOTO: COLOURBOX

Table 4. National statistics of the IEA Wind member countries 2020

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	3.1	-39	7.0	60	11.7%
Belgium	4.7	836	12.9	79	16.3%
Canada	13.6	175	36.3	578	6.3%
China	290,7	54427	466,65	7522	6.2%
Denmark	6.2	159	16.3	35	46.9%
Finland	2.6	302	7.8	81	9.6%
France	17.6	1105	39.7	449	8.8%
Germany	62.2	1438	131.0	553	23.7%
Greece	4.1	525	9.3	55	16.9%
Ireland	4.3	125	11.5	32	36.3%
India	39.2	1504	60.4	1385	4.4%
Italy	10.6	102	18.5	303	6.1%
Japan	4.4	507	7.6	858	0.9%
Korea	1.7	154	3.1	516	0.6%
México	6.8	664	16.7	318	8,1%
Netherlands	6.6	1990	13.9	106	13.1%
Norway	4.0	1532	9.9	134	7.4%
Portugal	5.5	41	12.4	50	24.5%
Spain	27.4	1720	53.6	239	22.4%
Sweden	10.1	1403	27.5	136	20.2%
Switzerland	0.1	12	0.2	55	0.3%
United Kingdom	24.7	570	75.6	331	22.8%
United States	121,9	16800	337.5	3664	9.2%
Totals	**670.3**	**81025**	**1375.3**	**17616**	**7.8%**
Non-IEA Wind TCP countries	*107.7*	*11 975*	*214.7*	*8 234*	*2.6%*
World total	***778.0***	***93000***	***1 590.0***	***25850***	***6.2%***

Bold italic indicates estimates

Table 5. Potential capacity increases beyond 2020 in reporting member countries

Country	Planning approval[a] (MW)		Under construction[b] (MW)		Total (MW)
	Land-based	Offshore	Land-based	Offshore	
Austria	1,185	---	---	---	1,185
Belgium	---	---	---	---	---
Canada	1,996	---	715	---	2,711
Denmark	---	---	---	605	605
Finland	3,607	---	2,435	---	6,042
France	---	3,036	---	1 473	4,509
Germany	2,672	---	3,600	---	6,272
Ireland	---	---	---	---	---
Italy	---	30	---	---	30
Korea	3,200	2,385	450	---	6,035
México	---	---	384	---	782
Norway	2,435	---	1,154	---	3,589
Netherlands	769	700	1,800	1,500	4,769
Spain	24,629	---	2,364	---	26,993
Sweden	---	---	---	---	---
Switzerland	---	---	---	---	---
UK	4,666	11,745	1,372	3,689	21,472
United States	---	---	---	---	---

--- = 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, % Increase, relative to country size, Average size of turbines and Average capacity factor

	Cumulative capacity (end of 2020)		New capacity 2020		Increase in cumulative capacity		Capacity relative to country size		Average capacity new land-based turbines		Average capacity all turbines		Average capacity factor	
	Country	**MW**	**Country**	**MW**	**Country**	**%**	**Country**	**kW/ km²**	**Country**	**MW**	**Country**	**MW**	**Country**	**%**
1	China	290,747	China	54,427	Norway	63%	Germany	174	Finland	4.51	Norway	3.42	Norway	37%
2	USA	121,985	USA	16,836	Netherlands	43%	Netherlands	159	Denmark	4.23	Finland	3.15	UK	35%
3	Germany	62,167	Netherlands	2,060	China	23%	Belgium	155	Norway	4.21	Netherlands	2.52	Finland	35%
4	India	39,248	Spain	1,720	Belgium	22%	Denmark	143	Canada	4.17	Austria	2.39	Belgium	34%
5	Spain	27,445	Germany	1,650	Sweden	16%	UK	102	Sweden	3.93	Sweden	2.33	USA	34%
6	UK	24,665	Norway	1,532	Switzerland	16%	Ireland	61	Netherlands	3.62	UK	2.26	Sweden	31%
7	France	17,610	India	1,504	Greece	15%	Portugal	59	Austria	3.57	Korea	2.23	Ireland	31%
8	Canada	13,588	Sweden	1,403	Finland	13%	Spain	54	Spain	3.46	Switzerland	2.07	Canada	31%
9	Italy	10,619	France	1,105	USA	16%	Austria	37	Germany	3.41	Germany	2.00	Denmark	30%
10	Sweden	10,084	Belgium	836	Japan	13%	Italy	35	Japan	3.11	Canada	1.99	Netherlands	28%
11	Mexico	6,681	Mexico	574	Mexico	11%	France	32	Korea	2.70	Portugal	1.97	Greece	28%
12	Netherlands	6,600	UK	570	Korea	10%	Greece	31	Italy	2.67	USA	1.81	France	27%
13	Denmark	6,218	Greece	525	France	7%	China	30	Greece	2.63	Japan	1.74	Portugal	26%
14	Portugal	5,478	Japan	516	Spain	7%	Sweden	23	Switzerland	2.35	Greece	1.56	Austria	26%
15	Belgium	4,700	Finland	302	India	4%	Korea	16	USA	2.80	Italy	1.49	Germany	24%
16	Japan	4,439	Denmark	220	Ireland	3%	USA	12	Portugal	2.26	Spain	1.28	China	24%
17	Ireland	4,300	Canada	175	Denmark	3%	Japan	12	UK	2.23	Denmark	1.10	Spain	23%
18	Greece	4,114	Korea	160	Germany	2%	India	12			India	1.02	Korea	23%
19	Norway	3,977	Ireland	125	UK	2%	Norway	10					Switzerland	21%
20	Austria	3,120	Italy	102	Canada	1%	Finland	8					Japan	21%
21	Finland	2,586	Portugal	41	Italy	1%	Mexico	3					Italy	20%
22	Korea	1,650	Austria	25	Portugal	1%	Switzerland	2					India	18%
23	Switzerland	87	Switzerland	12	Austria	-1%	Canada	1						

Table 7. Targets Reported for IEA Wind TCP Member Countries

Country	Official Target Renewable Energy Sources (RES)	Official Target Wind Energy	2020 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	290747MW, 6.2%, 466.65TWh (281 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	65 % RES Share of gross domestic consumption by 2030; source: EEG 2021 (Renewable Energy Act 2021)	EEG 2021 - Renewable Energy Sources Act: Targets of yearly gross addition of wind power capacity (amendment adopted in December 2020): Onshore: 71 GW land-based wind energy by 2030 Offshore: 20 GW by 2030 and 40 GW by 2040 (according to WindSeeG, Wind Sea Act, amendment adopted in December 2020)	62 GW (7.7 GW offshore, 54.3 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).	121,985 MW 9.2%

--- = No official target available

Table 8. Average capacity of turbines 2020

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	1,307	2.4	2.4	---	3.6	3.6
Belgium	---	---	---	8.7	---	---
Canada	6,813	2.0	2.0	---	4.2	4.2
China	155,255	---	---	---	---	2,67
Denmark	5,657	1.1	0.9	---	4.2	4.2
Finland	821	3.1	3.1	---	4.5	4.5
France	---	---	---	---	---	---
Germany	31,109	2.0	1.9	6.8	3.4	3.7
Greece	2,635	1.6	1.6	---	2.6	2.6
Ireland	---	---	---	---	---	---
Italy	7,137	1.5	1.5	---	2.7	2.7
Japan	2,554	1.7	1.7	---	3.1	3.1
Korea	741	2.2	2.2	3.0	2.7	2.8
México	3,175	2.7	2.7	---	1.8	1.8
Netherlands	2,618	2.5	1.9	9.0	3.6	6.6
Norway	1,164	3.4	3.4	---	4.2	4.2
Portugal	2,779	2.0	2.0	8.4	2.3	4.1
Spain	21,419	1.3	1.3	---	3.5	3.5
Sweden	4,333	2.3	2.3	---	3.9	3.9
Switzerland	42	2.1	2.1	---	2.4	2.4
United Kingdom	10,906	2.3	1.6	7.0	2.2	4.4
United States	67,814	1.8	1.8	0	2.8	2.8
Average		2.1	2.0	7.0	3.3	3.7
Maximum		3.4	3.4	9.0	4.5	6.6
Minimum		1.1	0.9	3.0	2.2	2.3

--- = no data available

Table 9. Estimated average turbine cost and total project cost for 2020 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	---	---	1,305	---
China	588	953	1,071	2,448
France	---	---	---	---
Germany	---	---	1,684	---
Ireland	---	---	---	---
Italy	---	---	1,468	---
Korea	950	1,500	1,700	4,160
Mexico	---	---	1,500	1,500
Norway	834	---	1,178	---
Portugal	---	---	---	---
Spain	880	---	1,050	---
United States	800	---	1,460	---

--- = 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, United States
	Auctions for premium	Competitive bidding procurement processes for electricity from wind energy or where wind energy technologies are eligible.	Finland, France, United States
	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, United States
	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 2020

Country	Capacity	Estimated number of jobs	Economic impact
	MW		million USD[a]
China	290,747	795,000	---
United States	121,985	116,817	
Germany	62,167	---	6,030
Spain	27,445	30,000	6,078
United Kingdom	24,665	15,205	---
France	17,610	20,200	---
Canada*	13,588	796	279
Italy	10,619	16,000	4,228
Sweden	10,084	---	---
Mexico	6,681	16,000	---
Denmark	6,218	33,000	---
Portugal	5,478	3,250	---
Netherlands	6,600	---	---
Ireland	4,300	---	---
Japan	4,439	---	---
Belgium	4,700	---	---
Greece	4,114	5,100	---
Austria	3,120	3,500	5
Norway	3,977	---	---
Finland	2,586	---	---
Korea**	1,650	1,800	1,003
Switzerland	87	---	---
Total	**631,097**	**638,851**	**56,502**

*Canada annual wind power investment. **Korea domestic manufacture only. [a] Applicable conversion rate EUR to USD: 1.223

Table 12. National R&D budgets for reporting countries, 2010–2020

Country	2010 budget	2011 budget	2012 budget	2013 budget	2014 budget	2015 budget	2016 budget	2017 budget	2018 budget	2019 budget	2020 budget
	million USD	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	6.2
China	---	---	---	---	---	11.7	1.4	---	8.8	9.4	9,2
Denmark[a]	24.2	1.0	11.5	24.2	---	---	15.4	---	26.8	22.2	18.6
European Commission	47.0	36.7	80.9	90.5	29.9	315.0	68.5	32.7	81.1	62.1	69.7
Finland	5.2	12.9	2.8	4.3	1.2	1.9	1.9	0	1.7	0.4	3.2
France	---	---	---	---	---	---	---	---	---	---	---
Germany	71.2	105.1	103.2	50.6	46.6	99.1	93.4	109.9	103.8	90.7	79.9
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	76.5
Korea	38.1	37.7	44.7	49.1	---	---	30.0	---	40.0	36	43
México	---	---	---	---	2.1	---	---	2	---	0.3	---
Netherlands	51.1	9.2	11.6	7.0	4.5			14.7	33.8	40.4	25.7
Norway	16.7	19.7	22.7	18.2	15.0	10.2	10.8	7.3	6.4	5.1	5.1
Portugal	---	---	---	---	---	---	---	---	---	---	---
Spain	115.9	115.9	158.2	117.8		94.0	85.5	11	17.2	26.3	132
Sweden	14.5	14.5	14.2	14.9	7.8	7.7	7.7	5.5	6.3	5.9	5.9
Switzerland	0.5	0.5	0.5	0.5	0.5	0.6	0.7	0.8	0.8	5.4	6.3
United Kingdom	---	---	---	---	---	---	---	---	---	---	---
United States	80.0	80.0	93.5	68.2	52.2	107.0		---	92	92	104

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

Table 13. Examples of test and demonstration facilities in IEA Wind TCP member countries

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.

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Table 13. Examples of test and demonstration facilities in IEA Wind TCP member countries

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 HAPT project ((Highly Accelerated Pitch bearing Test) aimed 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 was designed and manufactured. In the follow-up project HAPT 2 the application of roller bearings as pitch bearings is investigated by examining characteristics, especially damage mechanisms, of this bearing for oscillating movement and by developing and comparing simulation models with experimental data. That shall allow to design and validate roller bearings as pitch bearings.
	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 at CEMIE-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	DOE and NREL commissioned the Distributed Integrated Energy Laboratory for the Advanced Research on Integrated Energy Systems (ARIES) research platform, which will enable the scientific community to address the fundamental challenges of integrated energy systems at the 20-MW scale

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)

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