Technology Collaboration Programme
by iea

Annual Report 2021

IEA Wind TCP

Stephan Barth *Photo: ForWind*

Message from the Chair

Annual Report 2021

The world has seen how digital cooperation works, and for all the obvious disadvantages that purely virtual meetings bring, they also offer advantages. Higher flexibility, lower hurdles for integrating new participants, and a reduction of CO2 emissions by avoiding flights are only some examples. In doing so, the IEA Wind TCP has been able to continue its important work in 2021 successfully. Both the ExCo and, in particular, the Tasks have deployed the new tools wisely and effectively.

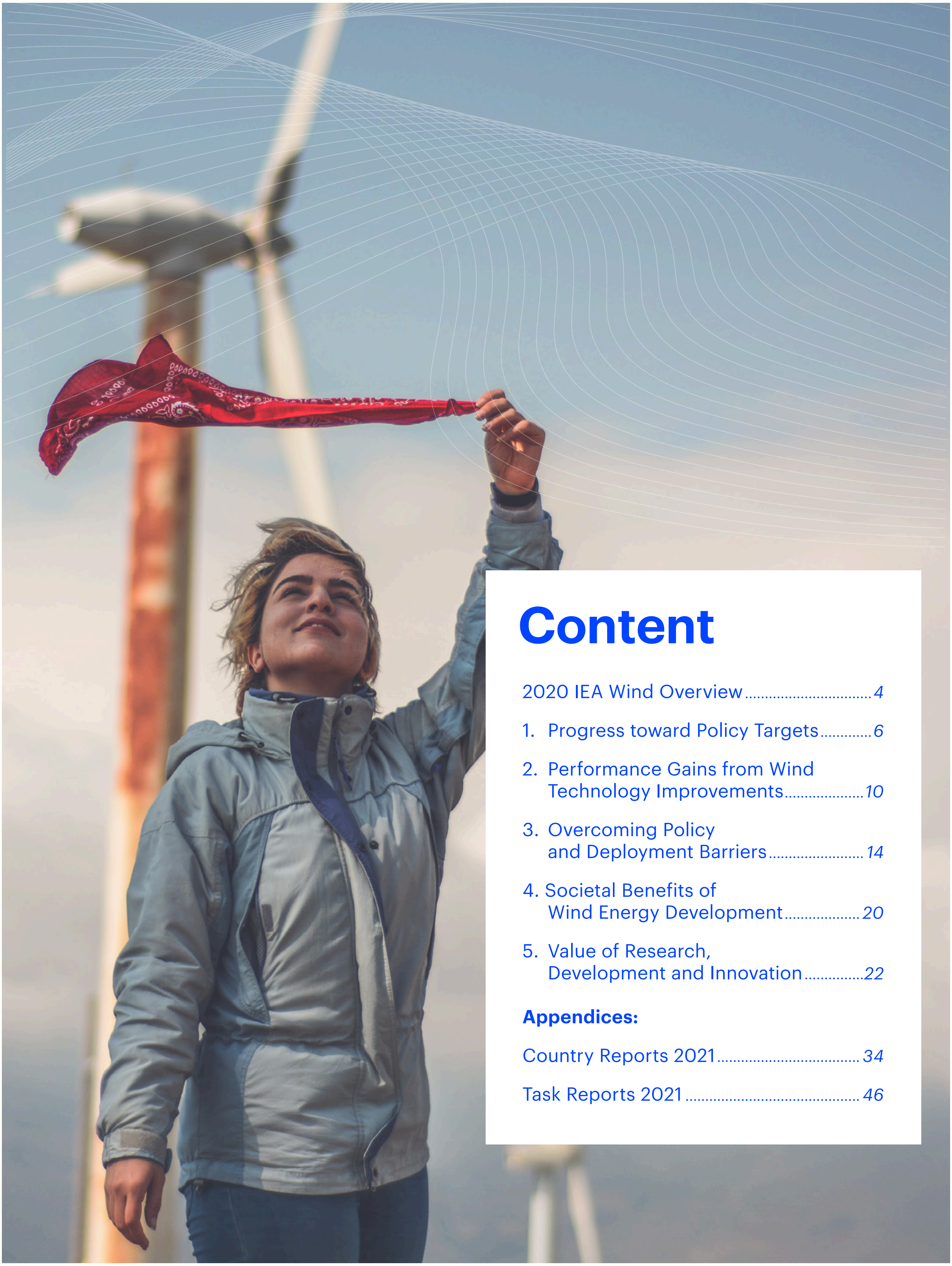
The year 2021 also demonstrated that the decrease in global CO2 emissions during the pandemic was only a short-term effect. It is therefore vital that we should make every possible effort to switch to climate-neutral forms of energy as quickly as possible. Wind energy technology is of outstanding importance in this context. The potentials on land and at sea, the beneficial properties for operating a holistic energy system, and the small footprint alone, are the advantages that clearly justify the intensive support for this technology through research and development.

I am very proud to see that new technical concepts are thought up and tested, successful measures and technologies are optimized even further, and findings and solutions are shared collaboratively. This Annual Report shows how innovative the ExCo Member Countries are in their efforts. It is equally impressive that numerous IEA Wind TCP Tasks are successfully planned and increasingly interlinked. The exchange of expertise and the progress built on each other's results across institutional, national, and continental borders shows how unique and valuable the Wind TCP is for accelerating further development of wind energy technology.

The aggregation of knowledge into Recommended Practices continues to be a very successful way of sharing knowledge and experience, not only with each other but also with those still in the early stages of using wind energy. Very much in the spirit of the IEA, which is based on the premise that successful energy transitions must be fair and inclusive, offering a helping hand to those in need and ensuring the benefits of the new energy economy are shared widely.

Yours Sincerely,

Stephan Barth,
Chairman of the IEA Wind TCP



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Content

2021 IEA Wind TCP *Overview*

The year 2021 saw newly added wind power capacity almost at the record year 2020 levels: global wind power installed capacity increased by 93 gigawatts (GW) to 837 GW, and offshore wind capacity made a new record reaching 57 GW total capacity by the end of the year [1]. The wind power industry continued to show good resilience, only slightly affected by the global pandemic. The demand for wind and renewables is surging as renewable energy addresses environmental and energy crises. A leap in yearly deployment numbers is needed to reach new targets set for 2030 and beyond.

Auctions for land-based and offshore capacity were complemented by the private sector announcing investment decisions for new subsidy-free wind power plants through Power Purchase Agreements (PPAs). Increases in energy prices supported these auctions. Wind energy installations contributed to a growing industry with economic benefits, including direct and indirect job creation.

The environmental and energy crises have accelerated and increased the trend of ambitious targets for renewables. These targets translate to doubling the wind power capacity from current numbers by 2030, even tenfold for offshore. There are challenges to overcome to achieve the new wind energy targets, like speeding up permitting by simplifying the authorisation procedures while ensuring public acceptance for wind will stay high. In addition, competitive tenders increase pressure for cost reductions in the whole value chain. At the same time, raw material prices and interest rates increase.

Investments in wind energy research, development, and demonstration (RD&D) are needed across the whole value chain from basic research to testing and demonstration and include multiple disciplines. Within total public energy RD&D funding of 38.4 billion USD, renewable energy RD&D public funding constituted only 15% of total public energy RD&D. This 15% includes 438.7 million USD wind energy RD&D funding, which is a decrease from 2020 funding levels.

This summary of the *Annual Report 2021* presents the deployment and R&D highlights and trends from 21 countries, as well as the European Union, WindEurope, and Chinese Wind Energy Association. Data for 2021 will be published towards the end of 2022, with graphics showing the evolution of trends from previous International Energy Agency Wind Technology Collaboration Programme (IEA Wind TCP) documents (1995-2020).

The annual report is freely downloadable at www.iea-wind.org

The environmental and energy crises have accelerated and increased the trend of ambitious targets for renewables.

Photo: Robert Witold / DTU Wind and Energy Systems

1. Progress toward Policy Targets

Both climate and energy crises add urgency to renewable targets for 2030 and beyond. As a result, 2021 saw an increased ambition, setting more significant wind energy targets in many countries.

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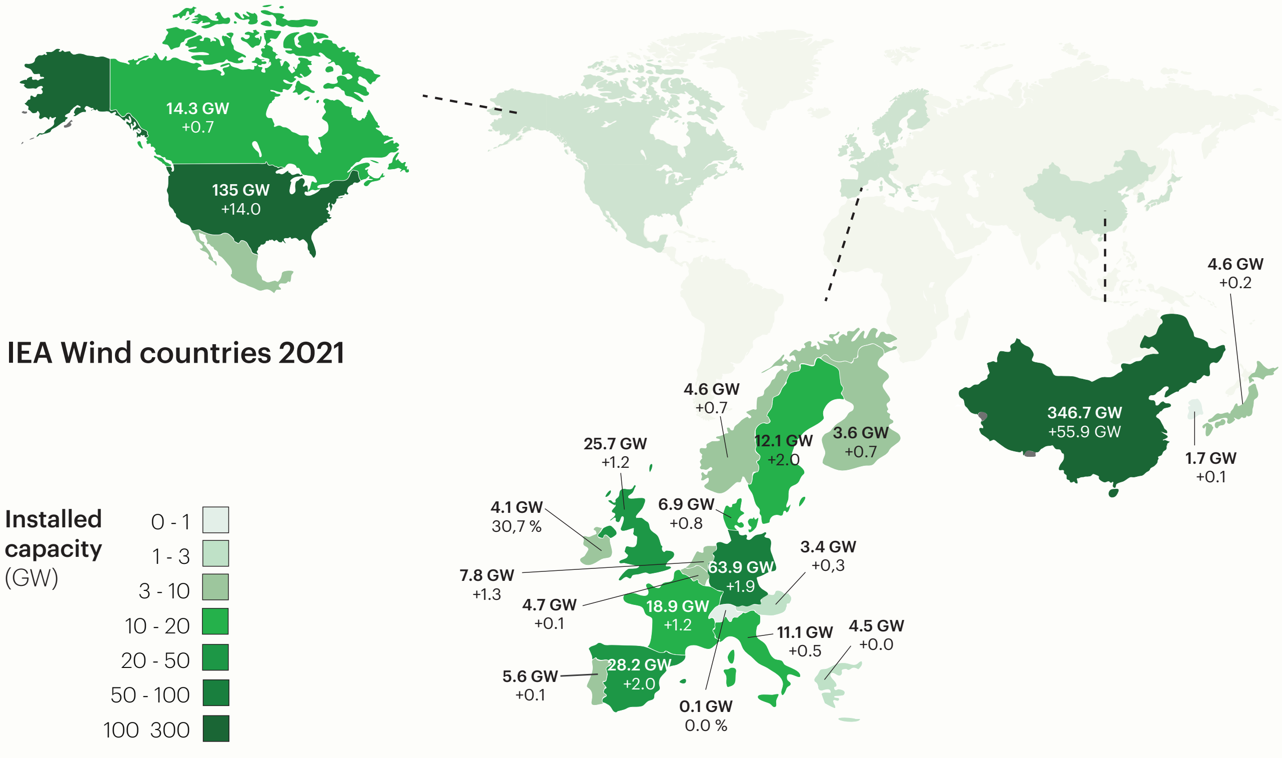

Figure 1. Total and newly installed wind power capacity end of the year 2021 in IEA Wind TCP countries.

New Records Set, Deployment Stepped Up in Many Countries

The biggest star of 2021 was China, with 56 GW newly built and 47.5 GW grid-connected capacity, of which a remarkable 14.5 GW was offshore. The global lead surpassed 350 GW grid-connected capacity, of which 26 GW was offshore. Europe had a record year of installations with 17 GW of new wind: Denmark, Sweden, and Finland made all-time records in annual installed capacity, and the Netherlands set the record for new land-based wind. India surpassed 40 GW installed capacity, and the United Kingdom achieved a 25 GW landmark. The United States installed 14 GW, Sweden more than 2 GW, France, Germany, India, and the Netherlands more than 1 GW.

Even if wind energy has proved its resiliency by continuing high development rates during the COVID-19 pandemic on a global scale, permitting and global supply chain issues have slowed down the estimated growth in many countries. It has also become clear that the installed capacity should increase considerably to reach the demand for clean power in the targets set for 2030 and 2050

Wind power continues to steadily increase its share of the electricity mix, even if some countries reported lower numbers than in 2020 due to a low wind year and increased electricity demand. The highest share in 2021 was in Denmark, where 44% of the electricity demand was met by wind energy, followed by Ireland at 29%, Portugal at 26%, Spain at 23%, and the United Kingdom at 23%. Sweden surpassed the 20% landmark. Denmark and Portugal report instant shares of more than 100% wind for one hour. Spain, Greece, and Ireland had new records for wind generation in one hour, reaching 84%, 73%, and more than 75% of demand, respectively (for Greece, this was 92% for variable generation share in demand).

China saw a leap in wind-generated electricity: from 466 to 656 TWh (40% increase to cover 8% of demand), and the Netherlands jumped from 14 to 18 TWh. Record generation with landmarks surpassed was reported by Spain (60 TWh), Greece, and Norway (10 TWh). In Spain, wind energy generation became the largest source of electricity generation for the first time.

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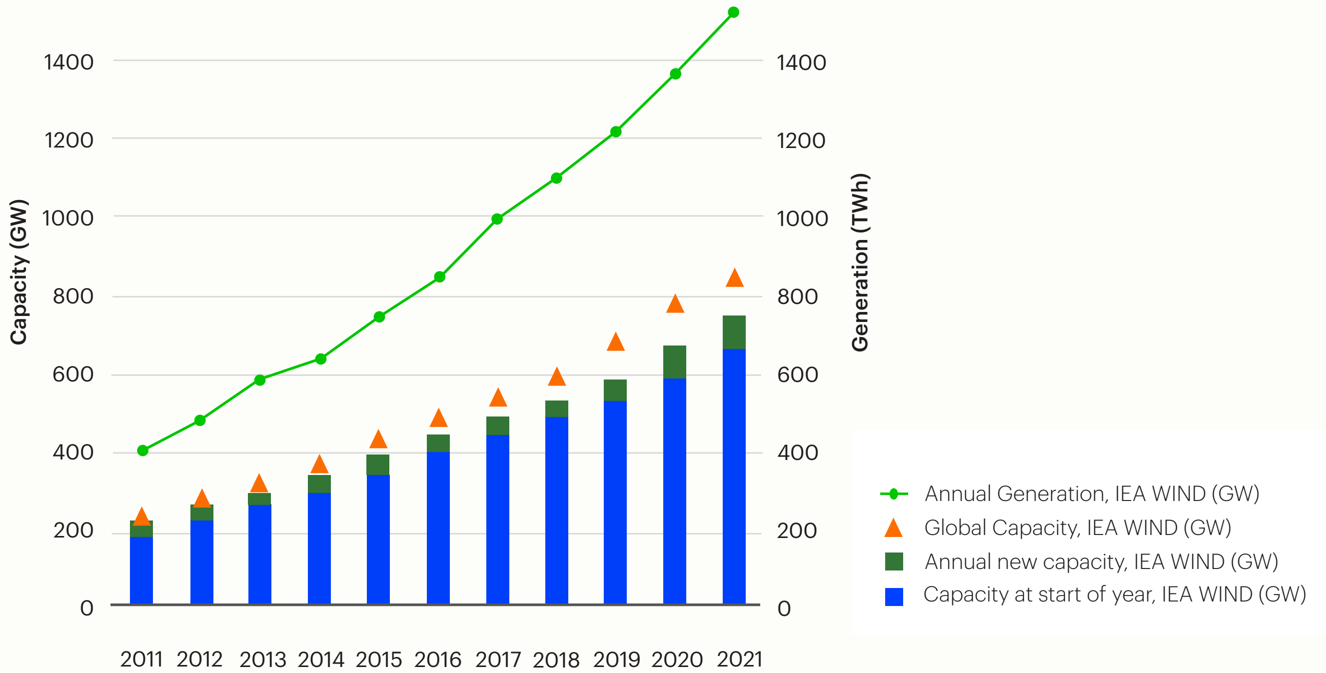

Figure 2. The trend of wind deployment for 2011-2022 in IEA Wind TCP countries and globally.
(Note that 2021 does not include Mexico, which has withdrawn from the TCP. For India and the United States, the year 2020 generation has been used).

Offshore Increasing Momentum also for Floating Projects

Offshore wind power installations made a new record of 21 GW in 2021, representing more than 20% of the annual global market. The cumulative capacity reached a total of 57 GW. China saw a massive increase in offshore capacity to benefit the last year of the subsidy scheme: 14.5 GW. The United Kingdom and Denmark installed more offshore than onshore capacity in 2021. Offshore projects under construction are reported from the United Kingdom (13-15 GW), the Netherlands (2.2 GW), Denmark, France, the United States, Korea, and Italy (first offshore wind power plant 10x3MW).

The United Kingdom Scottish auction saw 25 GW of new capacity allocated. Government plans for the fourth round of Contract for Difference were announced, securing more capacity than the three previous rounds combined. In France, two tender processes are ongoing for fixed-bottom and floating offshore. In 2022, Hollandse Kust West (1.5 GW) auction in the Netherlands and the first offshore auction in Ireland will take place. Belgium aims to open an auction in 2023 for the second-largest offshore zone. In Portugal and Spain, auctions for offshore are anticipated.

The United States offshore wind energy project development and operational pipeline grew to a potential generating capacity of 40 GW in 2021. In Korea, the so-called Electricity Business Licenses reached 13.6 GW at 54 locations at the end of 2021. Italy has registered 64 projects, including more than 40 floating ones.

Offshore areas are designated in China (5), Norway (2), and Japan (4), and three more sites were added in the Netherlands. The Sweden offshore plan map, including offshore wind areas for 23-31 TWh yearly generation, is in process. A decision to remove grid connection costs from projects to compensate for offshore costs being higher than onshore was made in 2021. Canada is preparing a new regulatory framework for offshore wind, and regional assessments have been announced for the Atlantic provinces of Nova Scotia and Newfoundland/Labrador.

The United Kingdom is a world leader in floating wind surpassing 100 MW total capacity. The Scottish auction in 2021 allocated 14.5 GW floating (of a total of 25 GW). In addition, floating offshore demos have been built in France, Portugal, China, and Norway (see the section for demos). The new 3 GW target in the offshore wind roadmap in Spain is all floating wind. In Korea, the Ulsan site targets 6 GW floating offshore; in Norway, the areas designated for offshore include floating.

Plans for offshore energy islands were advancing in 2021. The energy islands will be hubs that can create a better connection between energy from offshore wind and the energy systems in the region. Denmark continued planning for one in the

North Sea and one in the Baltic Sea. Cooperation on energy islands with Denmark, Germany, and Belgium was declared in 2021, fulfilling the political wish that the energy islands be grid-connected to several countries.

Wind Energy Plays a Critical Role in National Climate Targets

Carbon neutrality targets were set first for 2050 (the United States, Canada, Japan, Korea, and Europe) and 2060 (China and India). Announcements to advance the target have been reported from Germany (by 2030), Austria (by 2040), Finland (by 2035), and Sweden (by 2045).

In 2021 more urgency was pressed, with higher or earlier targets for renewable energy, striving to see progress by 2030. The new national climate target in the United States included 100% clean electricity by 2035. China increased the targeted share of non-fossil energy to 20% of demand in their 5-year plan. In Canada, a funding program to support reaching net zero was announced in response to increased stringency for emission reductions. In Europe, growing renewable targets for 2030 were seen in the "Fit-for-55" package (55% greenhouse gas reduction target) and further boosted by the GreenPowerEU plan.

Electrification of industry, transport, and buildings sectors creates demand for additional renewable power capacity. The clean electricity targets translate further to wind power as one of the primary means to achieve decarbonisation. In the EU, wind energy installations over the next five years are expected to be 18 GW per year (up from 11 GW in 2021), which needs to significantly increase to 32 GW per year to reach the EU's 2030 energy and climate goals.

The EU targets have increased to almost triple the current wind installations from 190 GW today to 510 GW in 2030 – for offshore wind capacity from its current level of 16 GW to at least 60 GW by 2030. Several member countries have wind-specific targets doubling the land-based wind capacity from 2020 to 2030 (Austria, Greece, Italy, Spain, France, and Ireland). In Denmark, more efforts to tackle the energy crisis have resulted in quadruple land-based and offshore wind targets in 2030. The new German target of 30 GW for offshore wind is more than triple the current offshore capacity. In the United Kingdom, the new target is a fivefold increase from 2021 (50 GW in 2030, adding 4 GW/year to the 10.5 GW offshore installed today and including 10 GW floating wind). In the Netherlands, the target for 2030 was increased from 11 to 21 GW, a more than eight-fold increase. New targets were also announced for countries not yet developing offshore wind: Ireland (from 3.5 to 5 GW for 2030) and Greece (2 GW by 2030).

In the United States and India, the offshore targets for 2030, aiming for 30 GW wind capacity, present a huge leap starting from very little today, as well as the targeted 12 GW for Korea. The development of offshore wind farms is a crucial component of the Korean Green New Deal investment to create jobs in new and renewable energy sectors.

Opportunities for Repowering

An increasing proportion of installed capacity will reach its end of life between 2021 and 2030. To address this challenge, the IEA Wind TCP started in 2020 a new Task 42 on Lifetime Extension in 2020.

Italy and Portugal report repowering as a way to meet future targets for wind energy. In Italy, repowering is included in the auctioning system. Portugal is launching new regulations to enable repowering. Spain is anticipating 10-15 GW of repowering in the next decade.

Out of the 13.8 GW of onshore wind installed in 2021 in Europe, 515 MW were through repowering projects from a decommissioned capacity of 393 MW. The majority came from Germany and Austria. In Europe, about 11.4 GW could be decommissioned over the next five years. About 2.9 GW of this could be repowered, leading to 5.7 GW of repowered capacity. By 2030, 50% of the current installed capacity in Europe will have reached the end of its operational life.

> **Electrification of industry, transport and building sectors creates demand for additional renewable power capacity.**

2. Performance Gains from Wind Technology Improvements

The trend towards larger turbines continued in 2021. Capacity factors saw improvements in some countries, whereas in others were somewhat lower in 2021 than in the high-wind year 2020. Cost reductions from auctions have brought an increasing amount of subsidy-free wind projects through power purchase agreements.

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Turbines and Wind Farms Continue to Increase in Size

The average power rating of new onshore turbines in Europe was 4 MW. For offshore wind turbines, it was 8.5 MW. In the United Kingdom, the average rating of new offshore turbines installed was 9.3 MW, an increase of over 2 MW from 2020.

In Norway, the average size of new land-based turbines in 2021 surpassed 5 MW. In Sweden and Finland, this was 4.7 MW. The industry has overcome size and logistics challenges for the giant turbines with 150 m towers and 150 m rotor diameters to suit the landscape with forested areas in flat terrain and gentle hills. Austria, the Netherlands, Germany, and the United Kingdom also had an average size of close to 4 MW or more.

The trend of increasing size is reported in the country chapter for Sweden.

Also, the project size is growing – in the United States, 70% of projects in development have more than 200 MW of capacity. The largest to-date wind power plant in New Mexico started operation: 1.055 GW. In the United Kingdom, Hornsea Two saw the first power generated in December 2021 from the offshore power plant, which will become the largest in the world once fully operational, with 165 x 8 MW turbines supplying 1.3 GW.

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 47 on Aerodynamics, as well as Tasks 30, 37 on model tool development, Task 43 on digitalisation, Task 44 on wind farm flow control, and Task 46 on erosion of blades).

The year 2021 was reported to be lower than the average wind year in Nordic countries, Germany, the United Kingdom, Ireland, and France, average in Portugal. High capacity factors in 2021 for land-based wind turbines were reached in Norway and Finland (33%) and Canada (30%). High capacity factors for the offshore fleet were recorded in Denmark (43%) and the Netherlands (39%). Moderate performance compared to high records in 2020 was reported in the United Kingdom (37%, down from a record 45% in 2020), Germany (35%, down from 40% in 2020), and Belgium (35%, down from 41% in 2020).

Cost Reductions from Auctions Leading to Increasing Subsidy-Free Projects

The wind power industry continues to improve its competitiveness. See also Task 53 Wind Energy Economics.

The shift to tendering from fixed guaranteed price support has prompted increasingly competitive prices for wind energy. IEA Wind TCP member countries had reported decreasing auction prices since 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 2020, Finnish technology neutral tender (1.4 TWh/a) winners were all wind power plants with an average subsidy of 2.5 EUR/MWh, payable only when the spot price is less than 30 EUR/MWh.

Offshore wind power has seen a dramatic price reduction in the tendering process. In the United

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Kingdom, the average price of bids in Contract for Difference auctions has reached a tipping point where projects start even if left out of the auction (no-subsidy merchant projects). The average bids accepted were GBP 39/MWh (in 2020, 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).

In 2021, more than 12 GW of wind power capacity was secured in auctions through seven countries in the EU, of which 2 GW was to offshore wind energy:

- Two Spanish auctions saw wind farms secure 998 MW at 25.2 EUR/MWh and 2258 MW at 30.2 EUR/MWh.

- In France, an average price of 60.8 EUR/MWh was reached for the 6th onshore tender period ending in April 2021. Ten new tendering processes for onshore wind were launched up to 2026 for a total amount of 9 to 10 GW.

- In Italy, joint tenders for onshore wind and PV were published, but the available quota was not saturated. The winning wind capacity was 41 MW, 23 MW, and 393 MW, equal to 56%, 40,% and 40% of the total winning capacity, respectively.

- In Ireland, the first auction of the new Renewable Electricity Support Scheme was held in 2020 (close to 0.5 GW, 1.5 TWh/a wind contracts). A schedule of renewable auctions was published in 2021 for years 2022-24 (indicatively 4-14 TWh/a), including two offshore auctions (22-35 TWh/a).

- In Greece, no new wind won support in auctions in 2021; however, since the beginning of the auction system in 2018, a total of 1.4 GW of wind farms and 1.3 GW of PV systems have been awarded.

- In the 2021 Denmark Thor 1 GW offshore site auction, the bidders were required to pay back part of the market revenue when the market price was above the bid (until a set amount). Still, the auction winner had to be determined by lottery as several bids were received at the lowest price.

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 United States for years and in Europe, growing steadily since 2015. In Finland, all new capacity has been without subsidy since 2019, with an increasing number of projects in construction (4.2 GW). In Spain, the PPA and merchant markets are booming, allowing annual volumes to exceed the yearly auctioned capacity of 1.5 GW. Currently, a record amount of 5.5 GW is under construction.

3. Overcoming Policy and Deployment Barriers

Member countries work together in the context of the IEA to tackle deployment constraints because many countries experience similar growth impediments. Moreover, policy actions can often help overcome or even remove these barriers. The main work to remove barriers reported in 2021 includes speeding up permitting procedures and increasing social acceptance.

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Seeking Ways to Improve Public Acceptance

Social acceptance continues to be a key constraint on the development of wind energy projects. Thus, increasing public acceptance will help member countries meet their renewable energy obligations. See also IEA Wind TCP Task 28, which focuses on the social science of wind energy acceptance, and Task 34 on studies conducted on environmental impacts in several countries.

Wind energy generally has a high public acceptance in the surveys conducted. For example, in 2021, about 80% of the Austrian population supported a further wind power expansion – a continuing trend since 2011. Also, in Finland and Switzerland, wind energy gets good public support in national energy attitude polls. However, opposition often exists locally to any new wind power plant proposed, even if the general public supports wind energy. In Norway, the local opposition from the deployment boom around the country turned the general public acceptance to a low level in 2019. It impacted the decision to stop licensing new sites. In Korea, there is low acceptance of both land-based and fixed-bottom offshore wind power. For the Netherlands, 7 GW wind power has been considered the maximum land-based target mainly due to spatial and social issues. However, recent growing awareness concerning climate change shows that public acceptance is improving for wind. As reported by Canada, Belgium, Ireland, and Switzerland, appeals against permitting wind energy facilities may take years to resolve. However, 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 Canada, research proposed enhanced social acceptance by including intra-community communication, community ownership, clear and up-to-date communication on projects, and attending to Indigenous models and choices of societal development.
- In Finland, the property tax from wind power plants for small municipalities has received positive publicity.
- In Ireland, the new auction mechanism includes measures supporting community acceptance of renewable energy projects, including a mandatory 2 EUR/MWh community benefit payment and a reserved auction category for community-owned projects.
- In Korea, government-led collaborative initiatives include siting and streamlined permitting and encouraging stakeholder acceptance. In collaboration with local residents and the fishing industry, the plan for offshore wind power generation sets out specific measures to trickle down benefits to local stakeholders.
- Moving to new desert areas like Gobi with less population in China has started. The first 97 GW batch is almost built, and planning for the second batch of 350 GW has been accelerated.

Mitigating Administrative Barriers

EU (and Austria, Belgium, Germany, Greece, Italy, Ireland, and Sweden) report that to achieve the new challenging wind energy targets for 2030, speeding up permitting with a simplification of the authorisation procedures is required. Mitigation possibilities reported include:

- **A "one-stop-shop"** simplifying and speeding up licensing procedures has mitigated the complexity of permitting processes in Sweden and France and has been adopted in Belgium.
- **Setting regional targets:** In Sweden, regional targets for wind power deployment were pointed out in the 2021 report on tools for

planning and guidance. Greece also highlighted national targets divided into regions to inform local authorities that they must give permits. In the Netherlands, regional energy strategies make local authorities, communities, industry, farmers, and citizens devise plans to achieve a fossil-free energy system in 2050. Regional and local targets have also been reported as mitigation measures from Austria, Ireland, and Switzerland.

- In Germany, the new Summer package aiming at high increases in renewables has launched the principle that using renewable energy is in the overriding public interest and serves public security. The planned "Wind Energy Area Requirement Act" aims to allocate 2% of the German land area to onshore wind turbines by 2032. To achieve this, wind turbines shall be, in principle, permissible within landscape conservation areas. A key issues paper highlights that wind turbines shall be approved swiftly and legally watertight, ensuring European ecological standards of protection to solve the conflict of objectives between energy transition and species conservation. Permitting procedures are simplified by establishing national, consistent criteria for bird collision risk significance assessment within the Federal Act for the Protection of Nature.

- In Greece, the first phase of measures to reduce permitting from 7+ to 2 years completed in 2021 includes additional staff for authorities and systems to share information between authorities to speed up the process.

- In the Netherlands, a collaboration of authorities overseeing the permitting has been required for some time. However, it is still a very long process.

- In Switzerland, a new simplified process has been introduced. Some Cantons (states) opened a combined land use planning and building permitting procedure. Also, the role of the cantonal authorities in the planning process was better defined to enable assisting project developers and communes.

Spatial planning limitations and a need for more sufficient eligible wind zones are reported from Austria, Belgium, Germany, Italy, and the Netherlands. 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 China, several clean energy bases with multiple and complementary energy sources have been introduced: nine clean energy bases, five offshore wind power bases, and several transmission channels, also situated in the desert and other less inhabited areas.

Specific offshore considerations are reflected in the revision of the EU Renewable Energy Directive: improvements on cross-border renewable energy projects, the planning of offshore wind per sea basin, the consideration for combining offshore wind with interconnectors across borders, and the facilitation of corporate Power Purchase Agreements (PPAs). Germany is launching a new simplified offshore permitting process, including grid permits. The United Kingdom targets consenting time for offshore wind farms to decrease from 4 years to 1 year. Ireland is progressing on the consenting, leasing, grid connection, and support scheme for offshore wind to reach newly made offshore targets for 2030.

Supporting Further Cost Reductions and Competitiveness in Electricity Markets

Incentivising wind power investment has been a primary tool used to improve deployment. In 2021, many schemes were expiring – the United States PTC (up to 0.19 USD/MWh or 0.17 EUR/MWh), Norway and Sweden green certificates, and China offshore (land-based wind power subsidies ended in 2020).

Some schemes continued, like the United States Investment Tax Credit. Also, in the United States, five states updated or adopted clean energy standards in 2021, which thirty-one states and the District of Columbia had in place. Korea has a technology-neutral and market-based RPS (renewable portfolio standard). Austria, Italy, and Japan have been lowering their Feed-in-Tariff subsidy levels (FITs). Switzerland is moving from FIT to an investment subsidy scheme in 2022.

Government-backed revenue stabilisation mechanisms are still the preferred support scheme by the industry. At the same time, Power Purchase Agreements in some countries have a more prominent role in securing the financing of wind energy projects. Competitive auctions have proved to be efficient in lowering the cost of wind energy. However, hitting low prices when commodities are on the rise – and not enough sites developed due to lengthy permitting – are challenges resulting in undersubscribed auctions (Germany, Greece, Italy). In Greece, all capacity auctioned in 2021 was for solar PV plants, and minimum technology quotas are to be set in 2022 to provide a balanced energy mix.

To overcome the challenges of manufacturers operating at a loss due to high material prices and disturbed supply chains, auctions could add other criteria than price, such as risk assessments, environmental, and support to the grid. These are discussed in Denmark and Germany, and grid support criteria are planned for the Netherlands' next offshore auction for Hollandse Kust West. Building energy markets that support the long-term sustainability of wind deployment will be necessary. Wind energy can be a hedge towards high prices in electricity markets, as was seen in 2021 when prices were very high. In Greece, 114 million EUR / 119 million USD was returned to consumers from a surplus of special RES funds – similar rules apply in

Photo: Niclas Demehl / Unsplash

Switzerland. Ireland sustained high wholesale prices in 2021/22, resulting in a negative levy to support renewable electricity in 2022/23. Wind energy also helped in reducing the high price peaks. From the side of Greece, it was estimated that electricity prices would have been 40% higher without wind. In Spain, wind generation during high market prices in 2021 increased the value of wind to the electricity system. In 2021, this was estimated to be 4,757 million EUR (5,413 million USD).

Electrification and energy systems coupled with electricity, gas, transport, industry, as well as heating and cooling, help bring new demand to markets during surplus wind generation to avoid hitting low prices.

In addition, 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 United States. For example, 16.7 GW of the total 27.4 GW wind power capacity installed in Spain had successfully passed the Operational Capability Tests at the end of 2020. In 2021, wind technology provided around 28% of the overall upward and approximately 23% of the overall downward regulation at the Spanish net deviations markets.

In the United States, there is a trend to add battery storage to wind power plants. In addition, there is increasing interest in hybrid

Social acceptance continues to be a key constraint on the development of wind energy projects.

Photo: Robert Witold / DTU Wind and Energy Systems solutions combining wind and solar with storage also in other countries. For example, in India, 2,550 MW capacity of transmission-connected wind-solar hybrid projects has been awarded in 3 auctions since India launched the system in 2018. In Spain, the first hybrid wind farm (32 MW) with batteries (5 MW, 1 hour) has been carried out. In Germany, a new auction segment will be introduced to innovative trial concepts for renewable energy with local hydrogen-based electricity storage. In Greece, the legislative framework for hybrids is gradually taking shape.

See Task 51 on developing short-term forecasting for electricity markets and Task 50 on hybrid power plants.

Reducing Wind Power Curtailment

Research from the IEA Wind TCP Task 25 on grid integration shows that a high curtailment rate signals 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 successfully reduced the curtailed energy to less than 3% (20 TWh) in 2021, compared to more than 10% (almost 42 TWh) in 2018. in the order of 3% to 7% (in Ireland, the curtailments decreased from the year 2020, and in Denmark, the curtailments mainly result from cross-border arrangements with Germany). Portugal still reports no curtailments for integrating a 26% share of wind energy.

Grid Integration and Adequacy of Transmission Infrastructure

The significant increase in wind capacity will need to be followed with a ramp-up of grid build-out, both onshore and offshore. Sweden, the United Kingdom, and the United States report concerns about inadequate transmission becoming a limit in the future if no reinforcements are made.

- In Greece and the greek islands, the grid is being strengthened; the Crete connection to the main grid was commissioned in 2021.
- In Spain, the backlog of more than 430 GW worth of requests for grid access in 2020 resulted in new laws requiring projects to proceed within five years to release grid capacity taken by speculative projects. There is a growing concern from developers regarding project due dates with limitations of the administration to manage a large number of requests and claims over time. To help congested grids, a budget to support the self-consumption and storage of renewable energy was approved, some of which include wind energy specifically.
- In Portugal, new legislation is being prepared to ease repowering and overplanting more MW to wind power plant sites than initially permitted to connect to the grid. Hybrid plants using the same grid connection is one opportunity.
- In Austria, high grid costs (a so-called G-component per MWh) will be harmonised with a new support scheme.
- In China, the grid is under enormous strain with the high installation rates of wind power. As a result, a set of policies and measures have been issued to ensure grid integration and consumption of renewable energy.
- In the United Kingdom, grid integration includes plans for green hydrogen. In Germany and Denmark, national hydrogen and power-to-X strategies have been published. Green hydrogen will be key in enhancing and completing the energy transition by being an energy storage medium or enabling sector coupling.

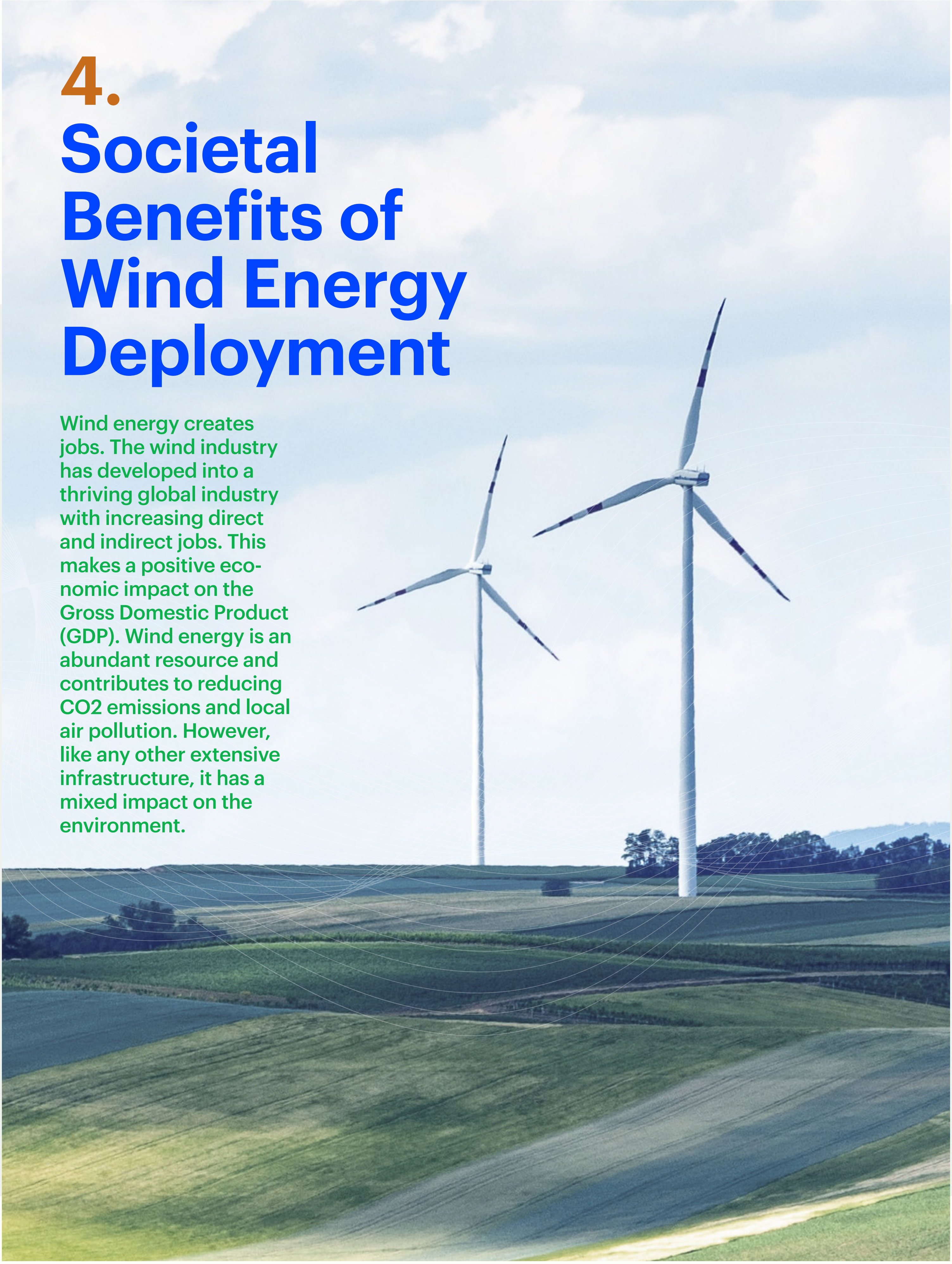
Transition towards New Regulatory Frameworks

The ambitious targets for 2030 and beyond require new regulatory frameworks. Therefore, 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 being lower than expected in some countries, like Austria, Germany, and Ireland. Government action is needed to ensure the confidence of investors in during regulatory changes.

In China, the tariffs for wind were aligned with coal tariffs in 2021 for land-based wind energy and 2022 for offshore wind. The alignment of tariffs allowed voluntary participation in market transactions to better reflect the green power value of wind power generation. In Sweden, green certificate allocation regulations took place to tackle the price erosion of green certificates.

The significant increase in wind capacity will need to be followed with a ramp-up of grid build-out, both onshore and offshore.



4.
Societal Benefits of Wind Energy Deployment

Wind energy creates jobs. The wind industry has developed into a thriving global industry with increasing direct and indirect jobs. This makes a positive economic impact on the Gross Domestic Product (GDP). Wind energy is an abundant resource and contributes to reducing CO_2 emissions and local air pollution. However, like any other extensive infrastructure, it has a mixed impact on the environment.

Photo: Dimitri Anikin/Unsplash

Economic Impact, Industry Revenues and Jobs

Jobs are created during the entire lifetime of wind energy plants, from project planning, manufacturing, operations, maintenance, decommissioning, and encompass a variety of technical and professional skills. As of 2020, 1.25 million direct jobs were attributed to the wind industry [1]. Furthermore, IRENA estimates that wind energy installations will increase tenfold to 8,000 GW capacity and create 5.5 million jobs to reach net-zero emissions by 2050 [2].

Countries report on job creation in the wind energy sector. China estimates that 15 jobs are created per 1 MW installed wind power, which adds up to 838,000 jobs. Denmark reports no significant changes in the number of positions, with 90,400 full-time jobs – 1/3 direct jobs and 2/3 indirect jobs. The sector contributed 4% of the GDP in 2020. In Spain, the industry employs 27,500 people, and estimates are that the industry contributes 0.30% of GDP. Ireland expects much from the wind energy sector, not least for its small and medium-sized enterprises (SMEs), which are expected to provide a range of products, services, and skills to the offshore wind sector. A study estimates that by 2030 the domestic offshore wind industry could create 11,000 to 20,500 jobs.

Even if wind energy has proved its resiliency by continuing high development rates during the COVID-19 pandemic on a global scale, the pandemic underscored the need to build robust supply chains and manufacturing capabilities.

There is pressure for cost reductions in the whole value chain from competitive tenders. At the same time, the raw material price and interest rates increase. The industry also competes aggressively to win auctions in European waters and elsewhere. Germany reports that the OEMs are very international and hence locate manufacturing and, in some cases, also R&D departments in proximity to the markets. German blade manufacturing facilities are all reported closed in 2021, resulting in a loss of ~4,000 jobs.

Emission Reduction and Other Environmental Impacts

It is hard to find assets greener than wind energy plants. Wind energy will keep growing in influence in a low-carbon future where every kWh of clean power counts in the fight against climate change.

According to Bernstein Research, wind energy has a lifetime carbon footprint of 98% less than natural gas and 75% less than solar, producing 11 grams of CO2 per kWh. As countries have different power systems, wind power production will create emission savings by replacing different energy mixes. There are divergent ways of calculating CO2 emissions replaced by wind energy: Denmark uses 139 g/kWh from wind-generated electricity. In comparison, Switzerland reports 378 g/kWh saved by producing wind-generated electricity, Portugal 430 g/kWh, and Italy 536 g/kWh. The energy transition will also impact the raw material CO2 intensity for wind power plants and how CO2 emissions from wind energy technologies are calculated throughout the supply chain, including, for example, steel, vessels, and blade recycling. A recent report, "The Emerging Sustainability Information Ecosystem," highlights the challenges in quantifying environmental and social impacts and the lack of transparency and consistency around the Environmental, Social, and Governance (ESG) rating systems, which use complex, opaque weighting methodologies balancing different environmental, social and governance factors [3].

2021 was a special year for wind energy. Several European countries reported a drop in renewable energy generation and emission savings of wind energy due to low wind resources.

With even more ambitious targets for renewable energy and wind energy to tackle climate change and the evolving energy crisis, the impact on the environment increases considerably and, thereby, the deployment challenge. As described elsewhere, the German plan to have 2% of its land available for onshore wind turbines is accompanied by strict implementation of nature conservation and ecological standards, for example, by establishing consistent criteria for bird collision risk.

A positive impact on the environment is reported by Belgium, which highlights that offshore wind turbine foundations improve the biodiversity and fish population in the water as they form artificial reefs where mussels, sea coral, and sea plants grow.

Even if wind energy has proved its resiliency by continuing high development rates during the COVID-19 pandemic on a global scale, the pandemic underscored the need to build robust supply chains and manufacturing capabilities.

5. Value of Research, Development, and Innovation

National RD&D investment in wind energy produces academic and industrial results and shows a remarkable acceleration over time. RD&D highlights span all four IEA Wind strategic areas.

Photo: Timusic Photographs/Unsplash

National RD&D Funding and Initiatives

Wind energy RD&D funding decreased slightly in 2021 compared to 2020, reaching 438.7 million USD (Table 1). Of the 16 countries reporting RD&D budgets in 2021, two reported for the first time in 10 years (France and Ireland). The United States is by far the largest investor, with 110 million USD, followed by Germany with 61.5 million USD and Japan with 61.2 million USD. The total public energy RD&D expenditures have increased from 22.5 billion USD to 38.4 billion USD, of which the renewable energy RD&D constitutes 15%, including wind [4]. The EU Commission launched the new Horizon Europe programme for research and innovation in mid-2021 which will first impact the RD&D expenditures in 2022.

Investments in wind energy RD&D require a long-term dedicated effort across multiple disciplines and institutional borders. A recent bibliometric global network analysis of wind energy RD&D illustrates developments in research areas, their interconnectedness, and geographical distribution.

National R&R Budgets for Reporting Countries, 2010 - 2021

Country	2010 Budget Mio. USD	2011 Budget Mio. USD	2012 Budget Mio. USD	2013 Budget Mio. USD	2014 Budget Mio. USD	2015 Budget Mio. USD	2016 Budget Mio. USD	2017 Budget Mio. USD	2018 Budget Mio. USD	2019 Budget Mio. USD	2020 Budget Mio. USD	2021 Budget Mio. 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	6,2
China	–	–	–	–	–	11,7	1,4	–	8,8	9,4	9,4	9,4
Denmark*	24,2	1,0	11,5	24,2	–	–	15,2	–	26,8	22,2	18,6	18,2
European Commission	47,0	36,7	80,9	90,5	29,9	315,0	68,5	32,7	81,1	62,1	41,6	33,6
Finland	5,2	12,9	2,8	4,3	1,2	1,9	1,9	–	1,7	0,4	3,2	0,7
France	–	–	–	–	–	–	–	–	–		–	17,1
Germany	71,2	105,1	103,2	50,6	46,6	99,1	93,4	110,0	103,8	90,7	79,9	61,5
Greece	–		–	–	–	–	–	–	–	2,1	–	–
Ireland	0,4	0,4	1,1	–	–	–	–	–	–	–	–	10,1
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	66,0	76,5	62,1
Korea	38,1	37,7	44,7	49,1	–	–	30,0	–	40,0	36,0	43,0	45,0
Mexico	–	–	–	–	2,1	–	–	2,0	–	0,3	–	–
Netherlands	51,2	9,2	11,6	7,0	4,5			14,7	33,8	40,4	25,7	23,9
Norway	16,7	19,7	22,7	18,2	15,0	10,2	10,8	7,3	6,4	5,1	5,1	9,6
Portugal	–	–	–	–	–	–	–	–	–	–	–	–
Spain	115,9	115,9	158,2	117,8		94,0	85,5	11,0	17,2	26,3	132,0	16,6
Sweden	14,5	14,5	14,5	14,9	7,8	7,7	7,7	5,5	6,3	5,9	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	8,8
United Kingdom	–	–	–	–	–	–	–	–	–	–	–	–
United States	79,0	79,0	91,8	86,0	87,0	106,0	95,5	90,0	92,0	92,0	104,0	110,0

"–" Indicates no data available

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

* Projects supported by public funds

Bold Italic indicates estimates

1. Dataverz prepared the Worldwide RD&D Mapping for DTU 4th July 2022. The research outputs originate from the last ten years (2011-2022), with metadata of sufficient quality and based on records that include in the title or the abstract "wind energy", "wind power", or "wind turbine" plus a set of keywords provided by DTU/IEA Wind TCP to contextualise the results further. The raw data sources for academic outputs included Crossref (which covers most of the indexed academic production with over 120 million records) and CORE (the world's largest aggregator of open-access research papers). The data for patents was gathered from World Intellectual Property Organisation (WIPO), the European Patent Office (EPO) and the U.S. Patent and Trademark Office (USPTO). It resulted in 77,576 scientific publications, 32,100 patents and more than 50,000 R&D organisations.

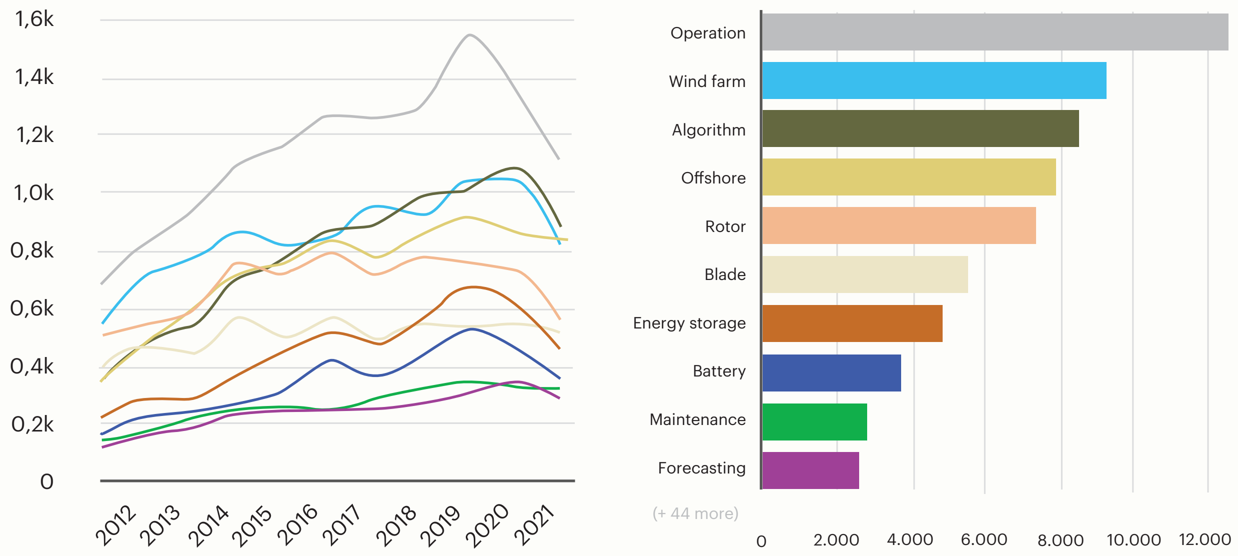


Figure 3. Topic research areas. Number of publications. 2011-2022

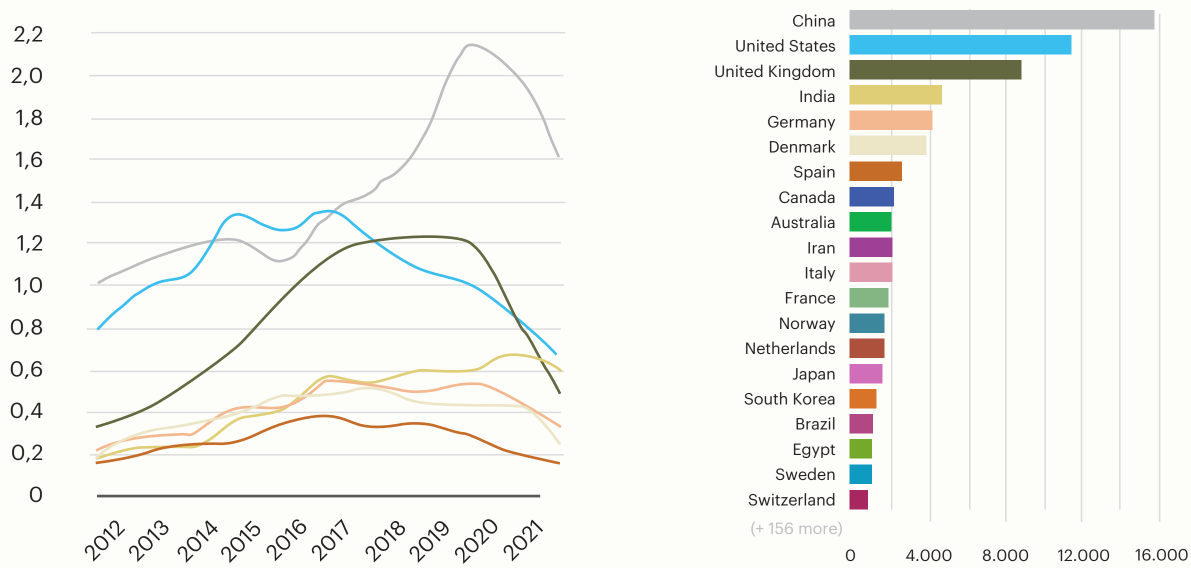


Figure 4. Publications per country. 2011-2022

Figure 3 illustrates that operation tops the list of publication topics. Keywords such as rotor and blade proportionally experience a decrease in total share, while keywords such as algorithm and offshore experience an increase in total share. Operations and wind farms are stable keywords with a relatively sizeable proportional share. The decrease in publications in 2022 and 2021 might be connected to COVID-19 as conference proceedings experience the most significant drop.

During the studied period, China overtook the United States in the number of publications and is close to producing more publications than Europe, see Figure 4. Apart from China, India experienced the second-largest increase in yearly publications.

Despite the significant increases in academic production of China and India, the United States, the United Kingdom, Denmark, and a few other western countries still have substantially higher average citations per publication.

Research Initiatives and Results

Member countries highlight key topics driving ongoing and future RD&D activities, many 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:

- Resource, Site Characteristics, and External Conditions
- Advanced Technology (Components, Offshore, Life Extension)
- Energy Systems with High Amounts of Wind
- Social, Environmental, and Economic Impacts

Resource, Site Characteristics and External Conditions

- As part of the Italian R&D programme on Electric Energy from the Sea, RSE has developed the new Italian Wind Atlas -Atlante EOLico ItaliANo AEOLIAN- to describe wind conditions from 1990 to 2019. It has a spatial resolution of about 1 km for heights ranging from 50 to 150 m a.s.l/a.g.l. Moreover, it is based on a novel approach combining the Weather Research and Forecasting (WRF) numerical modelling with the Analog Ensemble (AnEn) statistical technique. A preliminary techno-economic assessment of combined wind and wave production in a site of the Sicily Channel is provided.
- The Swiss MaxWEP project explores the wind's potential in the Alps' complex terrain throughout the year. Driving a high-resolution numerical weather model (WRF) with the COSMO model as an input, the researchers create a map of the spatial pattern of the local wind speed potential. They further provide predictions of a vertical wind speed profile using a machine learning algorithm driven by a combination of ground-based scanning LIDAR measurements, 3D ultra-sonic anemometer data, and data from the surrounding operational weather station network of MeteoSwiss.
- An updated weather model in the United States was developed to identify cold-pool events affecting wind power plant production. The project is part of the Atmosphere to Electrons, a multi-year, multi-stakeholder United States Department of Energy (DOE) research and development initiative. The project aims to improve wind plant performance and reduce the cost of wind energy production.

Advanced Technology – Components

- The Austrian project N.Ice researches and tests wind energy utilisation in cold climates. The second and last field test was made in the winter of 2021-22. An ultra-short pulse laser generates nanostructures in the sub-m range on technical surfaces (like rotor blades) to avoid or prevent the adhesion of ice or at least reduce the lifespan of ice shells. Individual samples are used in field tests on a small wind turbine and are exposed together with reference samples. The laser-processed samples are monitored continuously, together with unprocessed reference samples. The ice formation on the sample surface is registered quantitatively to enable assessment of the degree of ice formation and the duration of icing.
- BLATIQUE-2 is a large R&D Danish project supported by EUDP and led by DTU Wind in close cooperation with a.o. LM, Ørsted, and DNV. BLATIGUE-2 aims to develop fast and efficient fatigue testing methods for large wind turbine blades, develop intelligent equipment to excite the blades under such tests, and increase the value of blade testing through digitalisation, eventually transforming state-of-the-art technologies to turn-key solutions for market entry. The project will further improve multi-axial fatigue test methods and develop user-friendly tools that make fatigue exciters smarter by integrating hardware and software. Furthermore, methods to dramatically reduce the fatigue test time of large blades will be developed through testing blade segments. In addition, digital image correlation, drone technology and computer-vison-based image analysis techniques, and non-contact measurement and inspection systems will be designed to reduce the labour-intensive and time-consuming industrial processes during the blade fatigue test.
- The EU FIBREGY project (6.5 million EUR (7.3 million USD)) aims for the extensive use of Fibre Reinforced polymer (FRP) materials in the structure of the next generation of large Renewable Energy Offshore Platforms. The idea is to replace steel, which is more prone to degradation in offshore environments. The project includes the testing of different prototypes and the building of a real-scale demonstrator. The FIBREGY's activities focus on Enerocean's W2Power twin wind turbine platform.
- Modvion is a Swedish company developing modular towers in laminated wood. The tower is produced at a low cost due to its simple and modular construction. It reduces CO2 emissions by 90% compared to steel. The company has received an EU grant to build the first commercial wooden turbine tower of 100 m. In 2021, Vestas Ventures invested in Modvion to strengthen its engagement in further developing modular wooden towers. In 2022, Modvion inaugurated the world's first factory for wooden wind turbines in Gothenburg.

Photo: Mario Caruso / Unsplash

Advanced Technology – Offshore Wind

- FOX (Floating Offshore installation Offshore XXL wind turbines) is a demonstration project in the Netherlands. The current way of installing offshore wind turbines is time-consuming as the various wind turbine parts (mast, nacelle, and blades) must be assembled precisely during calm weather. This limits the available installation time. In 2021, larger components like a complete assembly of nacelle and rotor were installed successfully in one go using slip joints. This decreases installation time, and cheaper heavy lift vessels can be used instead of jack-up vessels. DOT, Heerema, and TU Delft execute the project.

- CYBERLAB is a large research project funded by the Norwegian Energix programme (2021-2025) and managed by SINTEF Ocean. The aim is to enable low-carbon offshore power grids in large lattices of marine structures. The expected results and industry benefits are to (a) Develop cyber-physical empirical methods to calibrate models of large lattices of marine structures. These methods will be applied to component (cell) characterisation and full system (lattice) verification; (b) Maximise the information gained from cyber-physical testing by using Optimal Experimental Design. OED provides a mathematically sound framework to optimally set the parameters of an experiment before its execution adaptively and automatically; (c) Contribute to the understanding of the dynamic behaviour of lattices of marine structures; d) Demonstrate the effectiveness of the proposed approaches for a specific offshore power grid application, such as a floating wind or solar park with shared mooring.

- Technology, Innovation & Green Growth for Offshore Renewables (TIGGOR) is a British 3.5 million

GBP programme designed to boost offshore renewable supply chain growth and productivity. By June 2021, 1.7 million GBP was used to match-fund five North East England firms (Transmission Dynamics, Kinewell Energy, SMD, Trident Dynamics, and Unasys) to accelerate technology concepts in areas such as remotely operated vehicles, digital twins, cable arrays, and sensors. They now demonstrate their technologies to major stakeholders such as Equinor and EDF Renewables.

Advanced Technology – Life Extension, Recycling and Decommissioning

- The German project InGROW focuses on repowering as an alternative to decommissioning offshore wind turbines. It consolidates and strengthens the existing structure to develop a new, bigger, more efficient wind turbine with an additional 20-25 years of operational time. Experimental model tests and numerical simulations have been carried out to comprehend the results of the hybrid structural system, and a certifier has examined and confirmed the possibility of a future certification.
- SusWIND is a British initiative led by The National Composites Centre and delivered in partnership with the Offshore Renewable Energy Catapult. The initiative aims to accelerate technology processes and material development, addressing the recyclability/future development of composite wind turbine blades. Year one highlights include an interactive digital map of expected volumes and localities of categorised blade waste streams with time in the United Kingdom. In addition, relevant recycling methodologies have been identified, along with a Life Cycle Assessment of current blade materials, including CO2 emissions and alternative blade material variants.

Energy Systems with High Amounts of Wind

- NRCan and WEICan's Utility Forum is a multi-year initiative to convene Canadian utilities to address issues with operating electric grids with high levels of Non-Synchronous Generation and Inverter-Based Resources. Two Tasks were performed: 1) Wind Farm Enhanced Capability Demonstration Project: Nova Scotia Power Inc. (NSPI) examined the technical ability of the provinces' wind generator fleet in providing various grid ancillary services – fast-frequency response, power-frequency response (similar to droop-frequency control) and automatic generation control; 2) Canadian Provincial Grid Code Study: GE was contracted to recommend opportunities to harmonise grid codes across Canada as a means to lower the barriers to entry for further renewables deployment.
- The EU OYSTER project aims to develop and demonstrate a compact electrolyser solution designed to integrate offshore wind turbines. PEM electrolyser manufacturers ITM Power, offshore wind developer Ørsted and turbine manufacturer Siemens Gamesa Renewable Energy will develop and test a shore-side pilot MW-scale electrolyser at Grimsby (United Kingdom). Project partners aim for hydrogen to be produced from offshore wind at a competitive cost with natural gas (with a realistic carbon tax), thus unlocking bulk markets for green hydrogen. EU support: 5.0 million EUR (5.6 million USD).
- The Swedish Wind Power Technology Centre manages research on frequency services from wind power in the Swedish power system. The project will develop, simulate and test frequency control with wind turbines. The standard built-in frequency control will be tested in commercial wind farms and participate in bidding ancillary services on the frequency regulation market for the first time in Sweden. In addition, the technical function and demand for wind turbines to control the frequency in the electricity grid will be verified and evaluated. This also includes an analysis of wear and how the lifetime of the pitch system and gearbox is affected.
- The United States Department of Energy published the Atlantic Offshore Wind Transmission Literature Review and Gaps Analysis, summarising the current publicly available transmission analyses along the Atlantic Coast, as well as gaps in existing studies.

Social, Environmental and Economic Impacts

- Controversies in the green transition (Co-Green): In the case of wind turbine sound and its politicisation, Co-Green is a research project financed by the Independent Research Council of Denmark and led by DTU Wind. The researchers use the sound from wind turbines, commonly referred to as problematic 'wind turbine noise', as an exemplary case to examine how a technical understanding of sound ignores all the aspects that cannot be measured but which nonetheless create uncertainty and controversy. The project investigates how wind turbine sound is understood and the various types of expertise that try to explain it. This more profound understanding of sound is used to examine how sound from wind turbines is often politicised and

> **Investments in wind energy RD&D require a long-term dedicated effort across multiple disciplines and institutional borders.**

Photo: Ralph Ravi Kayden / Unsplash

problematised in wind power deployment and sometimes leads to controversy and delayed projects.

- The German WERAN plus project uses new forecasting methods for the impact of wind turbines on radio navigation and omnidirectional radio beacons, opening up the possibility of reducing the required distance from wind turbines by 50%. A new method – the so-called "Doppler cross bearing method" - determines the location of potential disruptors and the intensity with which any given object is reflecting radio signals. The identified objects can be localised on a map and a complete "clutter map" visualises the disruptions. New wind energy installations can be added to the map, making the impact assessment on aviation safety easier. Also, it is possible to predict any potential disruptions to the radio signals from VHF omnidirectional radio beacons. This enables wind energy installations in the surroundings of omnidirectional radio beacons without posing a threat to aviation security.

- French ADEME launched a call featuring the topic of Wind and Biodiversity and awarded a portfolio of projects SEMMACAP, OPRECH, ORNIT-EOF, ECOSYSM-EOF, EOL-BIO, and MAPE, which address the impact of wind turbines on mammals, bats, and birds, in different situations, including the specifics of floating wind.

- The Gentle Driving of Piles (GDP1.2) is a Dutch project that develops a technique where vertical and torsional vibrations are induced in a monopile to fluidise the seabed. This makes the installation less noisy, and due to less fatigue load on the monopole, it can be constructed lighter. The development project investigates the impact of vibrations on the effectiveness of clay, power consumption, and optimal frequencies and amplitudes. The project is executed by the Technical University of Delft and its partners.

- Siting and environmental challenges: The United States Department of Energy's research priorities for land-based and offshore wind energy include wildlife and environmental impacts and solutions, radar impacts and solutions, and mitigation of use conflicts. Current research in this area consists of a real-time acoustic monitoring platform to detect vocalisations by right whales and a system designed to reduce wind energy's impact on bats while increasing energy production compared to blanket curtailment.

Test Facilities and Demonstration Projects

- In China, the full-scale test of a 102 m blade was conducted, including the static and fatigue test. After that, the blades will be applied to 10 MW wind turbines.

- At the Belgium wind farms – Northwester and Norther – tests are made to validate advanced structural health strategies using IOT sensors and optical fibres. This is part of the ICON Supersized 4.0 project.

- The German WINSENT is a wind energy test site in complex mountainous terrain that will be fully operational in 2022. The WINSENT test site offers both a virtual and a natural environment. The open platform supports the use of wind energy in complex terrain through improved prediction of performance and turbine load as well as yield increase and load reduction. The main features include: (i) Construction, erection, and operation of the four met masts and the two 750 kW research turbines, including measurement data collection and storage. (ii) Microclimate assessment by characterising the complex test site before and after the erection of the two research turbines. (iii) Adaption of the two research turbines by processing the geometric and structural turbine data as well as designing a new wind turbine controller.

- A blade test laboratory Korea Institute of Materials Science (KIMS - WTRC)' was recognised as one of the RE Testing Laboratories of IECRE in 2019. The KIMS-WTRC can accommodate and test 8 MW blades as the dimension of the blade test building is large enough and equipped with static and fatigue test equipment for blades.

- In Spain, two offshore floating prototypes are demonstrated and tested: 1) The DemoSATH Project, developed by SAITEC Offshore Technologies, with a full scale 96 m diameter of a 2 MW wind turbine, based on hybrid lines for the mooring system and drag anchors, which will be tested at BIMEP Test Facility (85 m sea depth) in the Basque Country in 2022; 2) The PivotBuoy concept, developed by X1 Wind, with a partial scale 1:3, 29 m rotor diameter of a 225 kW downwind wind turbine with 3 TLP single point mooring and gravity anchors. This prototype was assembled at Las Palmas Port in late November 2021. It will be tested at PLOCAN Test Facility 50 m sea depth) in the Canary Islands in 2022.

A list of test and demonstration facilities in the IEA Wind TCP member countries is presented in Table 2.
See next page →

Table 2.
Examples of test and demonstration facilities in IEA Wind TCP member countries

COUNTRY	FACILITY DESCRIPTION
Belgium	*Sirris/OWI-Lab large climatic test chamber: New humidity testing feature and icing spray test array installed as part of EU H2O2 Newskin project.* *Ongoing tests on the Belgium windfarms, Northwester, and Norther: validation of advanced structural health monitoring strategies using IOT sensors and optical fibres in the DBC ICON Super-sized project framework.* *Ongoing measurement campaigns within the Northwester 2 and Rentel wind farms for improving the soil-structure interaction model s/digital twins in the framework of the ETF project Windsoil and DBC SBO Soiltwin project.*
Canada	*WEICan 10-MW test site includes energy storage that demonstrates secondary frequency regulation.* *The Nergica test facility in Gaspé, Quebec, a region of complex terrain and cold climate, comprises two 2.05 MW turbines equipped with Rotor-mounted ice monitoring cameras and ice detectors.*
China	*The National Offshore Wind Power Equipment Quality Supervision and Inspection Center invested by CGC in Yangjiang: In 2021 the static and fatigue testing of the longest blade of 102m made by Shuangrui was conducted, and readyness for testing of blades up to 150m. The test benches for generators and gearboxes of 10+MW wind turbines were constructed by the relevant manufacturers.*
Denmark	*Test Centre Høvsøre, West Jutland: seven testing sites for international companies test their wind turbine concepts and collect data from tests on the turbines. It is possible to test and document safety, the turbine's performance, and noise emission with up to 200 metres in overall turbine height.* https://wind.dtu.dk/facilities/hoevsoere *Test Centre Østerild, West Jutland: up to nine wind turbines, of which Vestas owns two, Siemens Gamesa two, and DTU Wind Energy the remaining five. Five test sites It is possible to test turbines up to 330 metres in five of the test sites and for the remaining up to 250 m. It is being investigated how to increase the max height to 400 meters.* https://wind.dtu.dk/facilities/oesterild *The Large-Scale Facility, DTU Risø Campus: test hall with three test stands capable of testing 45 m, 25 m, and 15 m blades or other slender structures.* https://wind.dtu.dk/facilities/large-scale-facility
Denmark (Continued)	*Poul la Cour Wind Tunnel, DTU Risø Campus: closed-return type wind tunnel, reaching a maximum test section velocity of about 105 m/s.* https://wind.dtu.dk/facilities/poul-la-cour-wind-tunnel *Composite Laboratories, DTU Risø Campus: for R&D within composite processing techniques, preparation of test specimens, accredited mechanical testing to meet industrial standards, X-ray computed tomography, electron microscopy, plasma treatment and surface chemistry, sensor instrumentation, and signal analysis.* https://wind.dtu.dk/facilities/material_testing *The research wind turbine V52 DTU Risø Campus: a variable speed-pitch adjusted wind turbine that works as the main part of the large modern megawatt wind turbines.* https://wind.dtu.dk/facilities/the-research-wind-turbine-v52 *WindScanner: remote sensing-based wind scanners able to map the entire 3D wind fields around today's huge wind turbines, wind farms, bridges, buildings, forests, and mountains.* https://wind.dtu.dk/facilities/windscanner *AC/DC Wind Power Laboratory: four 10 kW custom-built converters to investigate power electronic controls and controller interactions in low-inertia systems.* *The Hybrid Wind Power Plant Facility, DTU Risø Campus: 2 x 225 kW wind power plants connected to the grid with storage technologies and a ~200 kW solar PV plant. Two wind turbines are retrofitted with a power converter and an open research controller. It also includes a switchboard and a Controllable Grid Interface (CGI).* *Lindø Offshore Renewables Center (LORC): 14MW and 16MW test facilities in one test hall and the 25 MW test facility in the second test hall.* https://www.lorc.dk/test-facilities
France	*SEMREV test site on the Atlantic Coast.* https://sem-rev.ec-nantes.fr/ *Mistral floating wind test site on the Mediterranean will be developed by Valeco/EnBW in cooperation with France Energies Marines. It targets the first demonstrator with the HexaFloat technology from SAIPEM in 2023.*

COUNTRY	FACILITY DESCRIPTION
Germany	*DFWind: research platform for wind energy with two 4.2 MW wind turbines (Enercon E-115 EP3 E4), including a met-mast array for in-depth wake research. The primary research topics are control methods, condition monitoring, meteorology, acoustics, aerodynamics, aeroelasticity, support structures, geotechnics, and wind energy systems.* *WINSENT: a wind energy test site in complex mountainous terrain will be fully operational in 2022, with both a virtual and a real environment. The open platform supports the use of wind energy in complex terrain through improved prediction of performance and turbine load as well as yield increase and load reduction. The main features include: (i) Construction, erection, and operation of the four met masts and the two 750 kW research turbines, including measurement data collection and storage. (ii) Microclimate assessment by characterising the complex test site before and after the erection of the two research turbines. (iii) Adaption of the two research turbines by processing the geometric and structural turbine data as well as designing a new wind turbine controller.*
Greece	*The GREEN ISLAND demonstration project, Agios Efstratios, aims at transforming a small isolated island grid into a RES-powered system. The system will include an 800-900kW 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. Construction work starting in 2022.*
Ireland	*An airborne wind energy test site in County Mayo received planning permission in 2021. The facility will be owned and operated by RWE.* *SEAI Atlantic Marine Energy Test Site (AMETS) is in the process of extending the consent to include floating offshore wind turbines.* *Lir NOTF has an access programme for Irish Offshore Renewable Energy device developers to enable the testing and progression of ORE technologies through the early development stages in advance of open sea testing. It is supported by SEAI and is open to any ORE technology (wave, wind, tidal, floating solar) that can be tested at the Lir NOTF (21).*
Italy	*MaRELab (Marine Renewable Energy LABoratory), a laboratory at sea managed in cooperation with the University of Campania "Luigi Vanvitelli" for testing novel marine energy harvesting systems. Since 2021, the first prototype at sea of Hexafloat (patented by Saipem SpA), an innovative platform concept for floating wind turbines, has been installed at MaRELab by CNR in cooperation with*
Italy (Continued)	*Saipem. The prototype, with a scale factor 1:6.8 of a 5 MW machine, hosts a 10kW turbine provided by Tozzi Green SpA and is moored with three synthetic lines reducing the environmental footprint. Energy production, platform motions, and loads on the mooring lines, as well as local meteorological and oceanic conditions, have been measured, generating a valuable set of experimental data.*
Korea	*A blade test laboratory at the Korean Institute of Materials Science (KIMS-WTRC) can accommodate and test 8-MW blades. It is equipped with static and fatigue test equipment for blades.*
Spain	*WINDBOX test facility incorporates five test benches: hydraulic pitch test, generator slipping rings test, blade and hub bearings test, yaw system test, and specific junctions test.* *Two floating wind test facilities: BIMEP Test Facility (85 m sea depth) in the Basque Country and PLOCAN Test Facility (50 m sea depth) in the Canary Islands.*
Sweden	*A test centre in Uljabuouda, in Arjeplog, was established in 2019 to provide an opportunity to test wind turbines up to a height of 330 meters in cold and icy conditions (RISE Research Institute of Sweden and Skellefteå Kraft).*
United Kingdom	*The Blade Erosion Test Rig (BETR) facility by ORE Catapult.* *United Kingdom Floating Offshore Wind Turbine Test Facility (UKFOWTT) - expected completion in 2022 by the University of Plymouth, enabling systematic physical modelling experiments with wind, wave, and currents simultaneously.*
United States	*DoE announced 15 million USD (13.2 million EUR) in funding for two projects supporting offshore wind technology demonstration: one to develop a full-scale design of a floating offshore wind platform capable of supporting a turbine of 10+ MW; and another to design, demonstrate, and validate a synthetic rope mooring for floating offshore wind turbines, which is expected to reduce the impact of offshore wind development on commercial fishing and reduce costs.* *National Rotor Testbed, an open-source wind turbine designed at Sandia National Laboratories, will help wind power plant operators understand how they can lower energy costs using wake control approaches.*

Photo: Ave Calvar / Unsplash

Next Term

The near future for wind energy is bright and yet challenging. On the one hand, considerable growth in deployment rate and technological advances is expected. 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 provide the skilled workforce required for increased deployment and operation of wind power plants.

Even if continued growth is seen for wind markets, it is not yet at a level demanded to reach the 2030 climate goals: for example, in Europe, the annual market should be 33 GW (25 GW land-based and 8 GW offshore) per year, from the total 17 GW new capacity seen in 2021 and 23 GW/year anticipated for next five years. Even this 23 GW/year will be compromised if Governments do not deliver on the commitments they have made to improve permitting. They continue to restrict spatial and planning requirements for wind farms, resulting in closer to the current 17 GW/year level over the period from 2022 to 2026.

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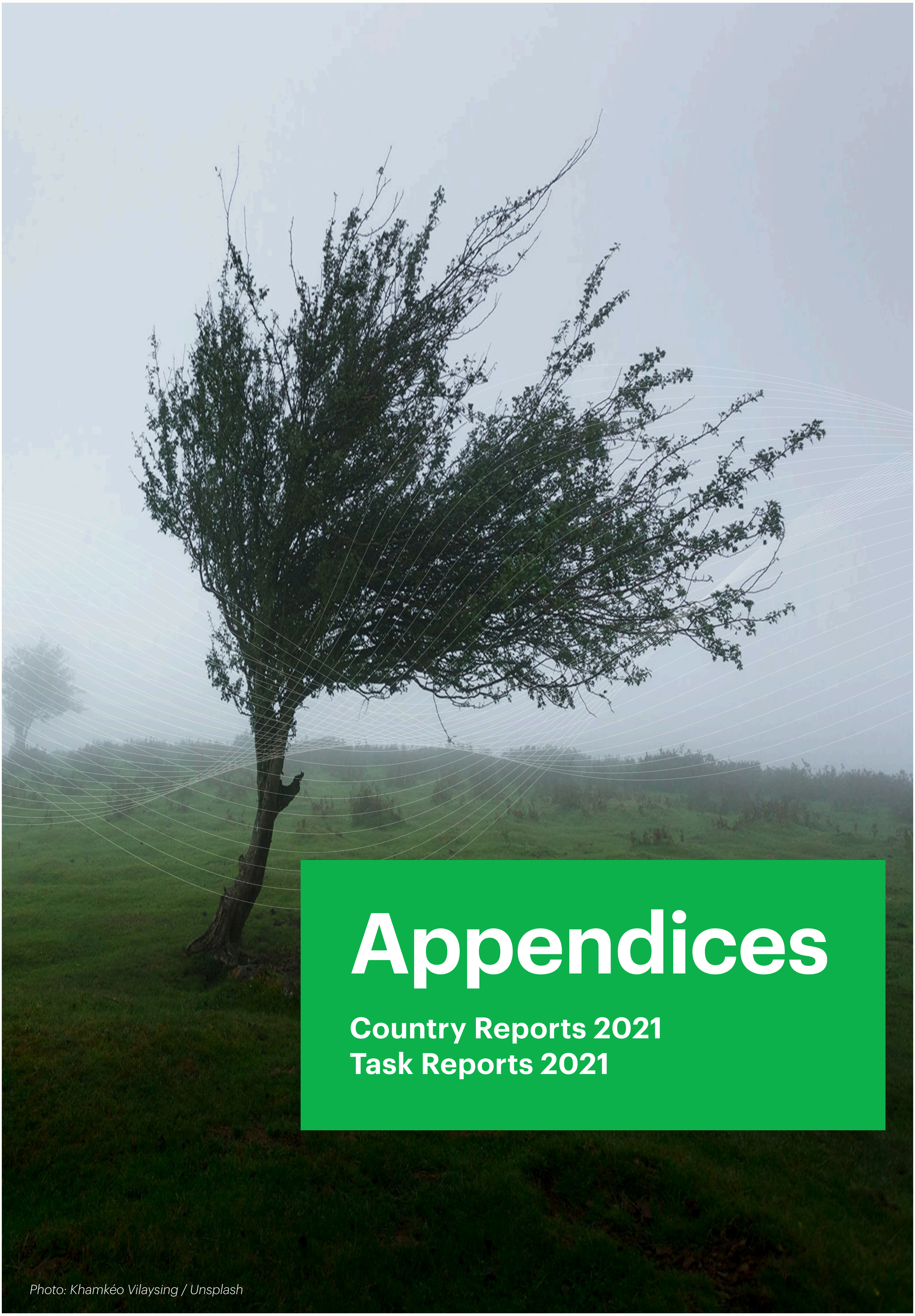

Appendices

Country Reports 2021
Task Reports 2021

Photo: Khamkéo Vilaysing / Unsplash

Read Country Report Austria

Read Country Report Belgium

Austria

Bernhard Fuernsinn, Patrik Wonisch, AWA
Andreas Krenn, Energiewerkstatt, Austria

Introduction

Austria has set ambitious renewable energy and climate protection targets, reaching 100% electricity generation from renewables by 2030. The year 2021 marked a moderate expansion of wind power. Austrian wind power increased by 298 MW. Many projects are part of a queue caused by inadequate support scheme conditions in recent years and lengthy approval procedures.

In 2021, Austria installed 69 turbines compared to 7 turbines in 2020. By the end of 2021, there was more than 3,300 MW installed capacity, while 57 turbines with 103 MW were decommissioned. As a result, comparing established and decommissioned turbines in Austria, there was a slight net increase in existing wind power plants. [1] The estimated feasible potential until 2030 is at 7,500 MW with 22.5 TWh p.a. [2]

Belgium

Jan Hensmans, FPS Economy, SMEs, Self-Employed and Energy, General Directorate Energy, Belgium

Introduction

The federal government began planning the first Belgian offshore wind farm in the North Sea in 2003, and 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. By the end of 2020, 399 offshore wind turbines are operational—producing around 7 TWh/yr.

In 2021, Belgium had the sixth-highest offshore wind capacity in the world and was pushing for additional development. However, Belgium has limited territorial waters, and offshore wind must compete with numerous other uses and respect environmental constraints.

Construction works are expected to remain at a standstill for a few years while awaiting the official tender procedure for new developments in the more western Princess Elisabeth Zone, where space is already allocated for doubling wind capacity at sea to 4.5GW.

Development beyond the second offshore wind zone will be difficult, and Belgium is exploring the option of interconnection with or developing new offshore wind capacity in the waters of other countries

In February 2021, Belgium and Denmark signed a memorandum of understanding for developing an electricity interconnector from an energy island Denmark plans to build in the North Sea. The interconnector could connect Belgium to large offshore wind farms off the Danish coast. Power from the wind farms would be transmitted to both countries.

Technology Collaboration Programme
by iea

Report 2021
Canada

102 MW wind farm in Bear Mountain, BC. Wind Turbine Model E-82, *Source: ENERCON Canada Inc.*

Authors *Christa Wakim and Ryan Kilpatrick, Department of Natural Resources, Canada*

During 2021, 677 MW of new wind capacity was installed in Canada.

This is a significant increase from last year's installed capacity (175 MW), partially because many projects are ramping up due to the post-pandemic economic recovery. Wind production reached over 36 TWh of electricity generated, representing a 0.2% decrease from production in 2020.

Highlight(s)

- 677 MW of new capacity online in 2021 – a high increase from 2020, almost reaching the record level of 2016.
- Stricter GHG targets and support to reach carbon neutrality announced in 2021
- At least 2,000 MW of wind energy capacity are anticipated this year.

Read Country Report Canada

Technology Collaboration Programme
by iea

Report 2021
CWEA

The Yangjiang Nanpeng Island offshore wind farm. *Source: MingYang Smart Energy*

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

China continues to have the highest wind power capacity in the world. The wind power capacity growth presented a higher rate, and 55,919MW of new wind power capacity was installed, representing a 2.74% increase in growth from last year.

Accumulated capacity increased to 346,666MW. Grid-connected capacity increased to 328,480 MW with the addition of 47,570 MW installed in 2021. The new added and cumulative grid-integrated wind power capacities, respectively, accounted for 27% and 13.8% of installed power capacities nationwide in 2021.

Wind power remains the third largest generation source in China, following thermal and hydroelectricity sources.

The average full-load-hour of wind power was 2,246 hours in 2021, an increase of 149 hours from 2020. Wind-generated electricity totaled 655.6TWh, an increase 40.5% over the previous year. Wind-generated electricity accounted for 7.9% of the total electricity generation, an increase of 1.7 percentage points over 2020. The average wind curtailment rate was 3%, at the same level as 2020.

Read Country Report CWEA

Canada

Christa Wakim and Ryan Kilpatrick,
Department of Natural Resources, Canada

Introduction

During 2021, 677 MW of new wind capacity was installed in Canada. This is a significant increase from last year's installed capacity (175 MW), partially because many projects are ramping up due to the post-pandemic economic recovery. Wind production reached over 36 TWh of electricity generated, representing a 0.2% decrease from production in 2020.

Chinese Wind Energy Association

He Dexin, Du Guangping, and Lyu Bo, CWEA, China

Introduction

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In 2021, the Chinese government issued a series of policies and regulations to implement the grid parity of the wind power project, reduce wind curtailment, promote the development of distributed wind power, and push developing of wind power in desert and Gobi areas. In addition, Chinese companies made progress in R&D, including wind energy developments in low wind-speed areas and offshore wind energy generation. 2021 is the last year for offshore wind power to enjoy government subsidies, and the installed offshore wind power capacity has increased significantly.

Read Country Report Denmark

Read Country Report EC/WE

Denmark

Birte Holst Jørgensen, DTU Wind and Energy Systems
Karina Remler, Danish Energy Agency
Peter Hauge Madsen, DTU Wind and Energy Systems
Reviewed by:
Kasper Beck Kragelund Sørensen, Danish Energy Agency

Introduction

Denmark continues to be a global leader in variable renewable integration. Due to a poor wind year, wind-generated electricity fell to 44% but is expected to increase significantly in the years to come. The energy islands in the Danish waters are advancing with various site investigations, necessary legislation, and market design. R,D&D priorities reflect wind energy being a dominant part of the energy system, focusing on appropriate test facilities, system integration, power-to-x (PtX), and social perception.

European Commission and WindEurope

Matthijs Soede, European Commission, Belgium
Thomas Telsnig, European Commission, Joint Research Centre, the Netherlands
Ivan Komusanac, WindEurope, Belgium
Ivan Pineda, WindEurope, Belgium

Introduction

Wind installations in the European Union have seen moderate growth on 2020 as permitting and global supply chain issues slowed down the estimated growth. After installing 11 GW in 2021, the EU-27 is expected to install 18 GW per year over the next five years. However, this will need to be further increased in order to reach the EU's energy and climate goals.

Electrification of industry, transport, and buildings sectors is creating demand for additional renewable power capacity. Government-backed revenue stabilization mechanisms are still the preferred support scheme by the industry, while Power Purchase Agreements in some countries are having a larger role in securing financing of wind energy projects.

The European Commission continued to support wind energy research and development via their funding programs like Horizon 2020, its successor, Horizon Europe, and the European Regional Development Fund.

Read Country Report Finland

Read Country Report France

Finland

Raul Prieto, Niina Helistö and Timo Karlsson,
VTT Technical Research Centre of Finland
Evgeny Atlaskin, Finnish Meteorological Institute
Jussi Mäkelä, Business Finland

Introduction

The year 2021 showed a sustained boom in wind power installations. The boom of wind deployment in Finland continues with 671MW new capacity in 2021, more than doubling the capacity additions from the previous year. The cumulative wind capacity at the end of 2021 increased by 26%, reaching 3,257MW ([1] Finnish Wind Power Association (2022). https://tuulivoimayhdistys.fi/en/).

The wind share of electricity consumption stayed at 9.3%, similar to the previous year's 9.6% ([2] Finnish Energy (12.01.2022) "The energy year 2021". Energiateollisuus). Wind generated electricity reached 8.2TWh, a 5% increase compared to the previous year despite the 26% increase in capacity. The reason is the relatively normal year in terms of wind power index (0.98, close to the long term average of 1.00), compared to the exceptional previous year (index 1.17, meaning 17% over the long term average), which has compensated for the new wind capacity made available ([3] Finnish Meteorological Institute (5.4.2022), Wind and wind power indices in Finland for 2016-2021 based on ERA-5 100-meter wind speed.).

In 2021 Finland consumed 86.5 TWh of electricity, similar to pre-pandemic 2019 (86.1TWh). This represents a recovery from the 6% drop in electricity demand registered in 2020 due to the pandemic.

France

Daniel Averbuch, IFPEN Energies nouvelles, France

Introduction

In 2021, over 1.2 GW of new onshore wind was built in France. This number lies slightly above the 2020 figure but well below the average of 1.5 GW over the 2016-2019 period. It should in the future increase to 2.6 GW per year to reach the newly set targets for 2023.

This brings the total wind power capacity to 18.9 GW. Wind and solar now jointly represent 53% of France's renewable installed power capacity, while wind alone represented one-third of the total renewable electricity production and 7.8% of the national electricity demand in 2021. Total annual electrical energy output from wind was 36.8 TWh, a significant decrease from 2020. This decrease results from an exceptional capacity factor of 26.5% reached in 2020.

During 2021, new measures have been put in place, including the start-up of the definition of specific areas suited to the development of onshore wind.

The four awarded offshore projects from the 2012 tender are now under construction, while two procedures of competitive dialogue are ongoing for bottom-fixed and floating offshore wind.

Read Country Report Germany

Read Country Report Greece

Germany

Friederike Barenhorst and Franciska Klein, PtJ, Forschungszentrum Jülich, Germany
Stephan Barth, ForWind, Germany

Introduction

With the new Federal Government formed in December 2021, wind energy continues to play a major role in the successful energy transition to renewable energies supply in Germany. With the so-called "Easter Package", the Federal Ministry for Economic Affairs and Climate Action (BMWK) reforms several important laws to massively speed up the expansion of renewable energies, particularly solar and wind power. It declares that for Germany, the build-up of renewable energies is of great public interest, and plans to provide at least 80% of its energy consumption from renewable sources by 2030 [1]. Research projects that are directly related to increasing the speed of the extension of wind energy production and deployment have come to the fore from 2022 on. Furthermore, the offshore expansion will be significantly increased in the future; by 2030, there shall be 30 GW of installed offshore capacity, 40 GW by 2035 and 70 GW by 2045 (starting from 7,8 GW in 2022).

Greece

Nikolaos Stefanatos and Kyriakos Rossis, CRES, Greece

Introduction

The total installed wind power capacity in Greece at the end of 2021 reached 4456 MW [3] (an 8% increase compared to the end of 2020). The total new capacity installed in Greece in 2021 was 338 MW lower than the all-time record of 2019 (752 MW), but still higher than the 10 year average (284 MW). A total of 128 new wind turbines with an average nameplate capacity of 2.67MW were installed.

Aside from natural gas, wind energy remains the biggest domestic energy source for the Greek Electricity system, providing 18.9% of total demand. During the year, variable RES penetration to the electricity system reached values as high as 92% of total demand (1 hour average), without any negative side effects on the operation and stability of the system.

Read Country Report India

Read Country Report Ireland

India

National Institute of Wind Energy, India

Introduction

The Government of India has announced an achievable Renewable Energy target of 500 GW of clean energy sources by year 2030, out of which 140 GW will be coming from wind power. The wind energy potential in India is very high, estimated at 695.5GW at 120m in height.

Renewable Energy Sources (excluding large Hydro) currently account for 27.5% (109,885 MW) of India's overall installed power capacity of 399,496 MW (31.03.2022). Wind Energy holds the major portion of 36.7% of total RE installed capacity. The country currently has the fourth-highest wind installed capacity in the world, with total installed capacity of 40.358 GW as of March 2022.

India is blessed with a coastline of about 7600 km and has good prospects of harnessing offshore wind energy. Gujarat and the Tamil Nadu States have identified a high potential for an offshore generation. Ministry of New and Renewable Energy, Govt. of India (MNRE) has set a target of 30 GW offshore installations by 2030.

In India, most of the leading wind turbine manufacturers have established their facilities. India has a strong supply chain of wind turbine component manufacturers, and Indian wind turbine manufactures have already started focusing on the export market demand, apart from meeting the domestic market demand.

Ireland

John Mc Cann, SEAI, Ireland

Introduction

While new records for wind energy output were set and significant new policies supporting wind energy were announced, 2021 was not an auspicious year for wind energy deployment in Ireland. Despite ambitious 2030 renewable energy targets, only 9.3MW of new capacity was installed. This was due to a gap between the termination of the legacy REFIT support scheme and the commencement of installation of capacity under the new Renewable Electricity Support Scheme (RESS). There is a pipeline of fully consented onshore projects for the latter, and a surge in construction is expected in 2022 for wind farms awarded support under the 1st RESS auction. Significant progress was made on the consenting, leasing, grid connection, and support scheme for offshore wind in 2022, the earliest date for commencement of operation of new offshore wind farms is 2027.

A significant number of wind energy research projects were successful in obtaining funding under SEAI's 2022 RD&D funding call. Irish entities were also successful partners in funding awards for EU wind energy research projects. Ireland also increased its participation in IEA Wind Tasks to an all-time high of 17 after a 2021 SEAI call for participants.

Read Country Report Italy

Read Country Report Japan

Italy

Introduction

In 2021 the effects of the COVID pandemic decreased, and the new capacity increased at the levels of 2018-2019: 470 MW, the total installed capacity surpassing 11 GW. The year 2021 has seen the closure of many relevant research projects, the proposal and start of new ones, and an increasing number of participants in the IEA WIND Tasks.

Japan

Yoshitomo Watanabe, Offshore Wind & Ocean Energy, New Energy Technology Department, New Energy and Industrial Technology Development Organisation, Japan

Introduction

At the end of 2021, Japan's wind power capacity reached 4,581 MW (Figure 1). Most of the wind power installed in Japan is onshore wind power. The total number of wind turbines was 2,574, an increase of 87 in 2021. The new single-year installation amount of wind power capacity in 2020 was the highest ever, but in 2021 it was 28% of that. This is because the number of large-scale projects carried out was low. In addition, decommissioned wind power generation capacity has increased to 68.2 MW. It is thought that this is due to the increase in the number of wind turbines that have been in operation for a long time. The national capacity factor (average national capacity factor) was 21.5%, and the ratio of wind power to total electricity supply and demand in Japan was 1%.

The proportion of wind power is small, but it is increasing. In research and development, in order to promote offshore wind power, the New Energy and Industrial Technology Development Organisation (NEDO) is conducting several national projects with the aim of reducing the cost of offshore wind power. In addition to this, the Green Innovation Fund Project (GI Project) began in 2021, and specific projects will have been adopted and started by April 2022. Also, based on the Act of Promoting Utilization of Sea Areas in Development of Power Generation Facilities using Maritime Renewable Energy Resources(effective April 2019), companies were selected for offshore wind power generation projects with a total capacity of approximately 1.7 GW in four sea areas in 2021.

Read Country Report Korea

Read Country Report Netherlands

Korea

Seung-Ho Song, Kwangwoon University, Republic of Korea

Introduction

Having installed 64 MW capacity of wind turbines in 2021, the accumulated capacity in Korea reached 1713 MW at the end of 2021. In 2017, the renewable energy target was raised to 20% of the electricity generation by 2030. In October 2020, it was 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 for large-scale installation of wind energy, especially in offshore wind, for the energy transition.

Netherlands

Ruud Oerlemans, Rijksdienst Voor Ondernemend Nederland, The Netherlands

Introduction

Compared to last year, the onshore wind capacity increased faster. Now 5.3 GW is installed, which is 1.2 GW more than last year, which means the Netherlands is 0.7 GW away from the 6 GW onshore target. For the Netherlands, 7 GW of onshore wind power seems to be the maximum onshore, mainly due to spatial and social issues. However, this may change because of the growing awareness concerning climate change, high energy prices, and dependency on fossil fuels originating from countries having autocratic regimes.

The rollout of the current offshore wind road map for 2030 is progressing steadily. In 2020 1.5 GW of offshore wind power was added, and 2.2 GW of wind power of this road map is under construction and is expected to be operational in 2023.

Last year around €12.5 million subsidy was awarded for nine innovative offshore R,D&D projects. The research and development of the rewarded projects concerned, amongst others: offshore foundations developments, storage, and flexibilization of electricity production, installation techniques, precipitation atlas, and improved installation of wind turbines.

Read Country Report Norway

Read Country Report Portugal

Norway

Magnus Wold, NVE, Norway
Christine Birkeland, NVE, Norway
Harald Rikheim, Norwegian Resource Council, Norway
Ann Myhrer Østenby, NVE, Norway

Introduction

Wind power in Norway continued with a fairly high level of deployment, resulting in 706 MW of new installed capacity in 2021 and a net total installed capacity of 4649 MW at the end of the year. The electrical energy produced by the 64 active wind farms in 2021 was 11.8 TWh. That is an increase of 19% from the year before, despite lower-than-normal wind resource availability. Decreasing LCOE of wind power projects, favorable depreciation rules, and the end of the electricity certificate scheme have driven the latest years' high level deployment of wind power in Norway.

There is significant activity in the regulatory space for both onshore and offshore wind power. Several processes are ongoing for the improvement of the licensing scheme for onshore wind power. Simultaneously the framework for offshore wind is under development. Neither of these processes were completed in 2021.

Portugal

Paula Costa, Teresa Simões, António Couto and Ana Estanqueiro, LNEG, Portugal

Introduction

In 2021 a total of 126 MW was installed in Portugal through two new wind farms and overplanting capacity procedures. By the end of 2021, 5,628 MW was operating in the country, corresponding to 37% of the national total renewable operational capacity. The wind-based electrical energy in 2021 was 13.27 TWh, meeting 26% of the country's electricity demand.

Renewable electricity production in 2021 reached 65% of the national consumption, a small increase when compared to the previous year. On 31 October 2021, between 01:00 to 07:45h, Portugal (Mainland) met 100% of its electricity needs with wind energy during several periods. The instantaneous electricity demand met by wind energy during this period was 108%. Values above 100% were also observed for some hours on 27th December 2021.

The main R&D project tasks were ongoing as expected. Project Carbo4Power provided an innovative design of a modular rotor offshore blade, while project PivotBuoy unveiled the new prototype of the floating offshore wind turbine. Project Atlantis performed the first scenario test on using robotics to inspect a turbine tower and blades at Viana do Castelo.

Read Country Report Spain

Read Country Report Sweden

Spain

Ignacio Cruz and Luis Arribas, CIEMAT in collaboration with the Spanish Wind Energy Association (AEE) Spain

Introduction

Renewable sources-based power supply in Spain reached 46.7% of total power consumption in 2021 (Total power demand increased by 2.5%).

Throughout 2021, wind power was Spain's largest source of electricity generation, with a relative generation growth of 2.7%. According to the Spanish National Integrated Energy and Climate Plan 2021-2030 (NECP), the government is committed to increase the wind capacity to 50 GW, which means about 28.86 billion EUR (35.29 billion USD) to meet European targets for 2030.

The Spanish wind sector installed 842.61 MW during 2021 [1]. Wind power has become in Spain the number one technology (25.7%) regarding installed power capacity on the Spanish peninsula. Spain was the number seven in Europe in new investments with 1.5 billion EUR (1.83 billion USD) investment decisions in new onshore wind farms.

The Spanish government approved the first Offshore Wind Roadmap in 2021. It aims to kick-start the deployment of offshore wind with a view to having up to 3 GW operating by 2030. Given Spain's geography, it will all be floating offshore wind. Ports and shipyards across Spain already play a key role in the rest of Europe. The new Roadmap will stimulate the further development of Spain's floating wind supply chain.

National investments for wind-related R&D totalled around 12 million EUR (16.56 million USD) in 2021.

Sweden

Andreas Gustafsson and Pierre-Jean Rigole, Swedish Energy Agency, Sweden

Introduction

In 2021, Sweden installed 2 042MW of new wind energy capacity (1403 MW were installed in 2020). At the end of the year, the country's total installed capacity was 12 116 MW from 4 679wind turbines.

Through the EU burden-sharing agreement, Sweden has a goal of greenhouse gas emission reduction of 40% in 2030 in relation to the 2005 level. 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 percent 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 need to install an additional 2.5 to 6 TWh of renewable power capacity per year between 2030 and 2040 to reach that goal and that wind power will provide a large part of it.

As Sweden's primary wind power R,D&D funding agency, the Swedish Energy Agency finances research conducted by universities and industries in several research programs. The overarching goals of wind power R,D&D are to help Sweden reach its targets and national objectives for a renewable energy system, contribute to business development and increase jobs and exports.

Read Country Report Switzerland

Read Country Report United Kingdom

Switzerland

Katja Maus, Swiss Federal Office of Energy, Switzerland
Lionel Perret, Planair SA, Switzerland

Introduction

By the end of 2021, Switzerland had 42 large wind turbines in operation with a total rated power of 87 MW. These turbines produced 146 GWh of electricity in 2021. The construction of a new wind farm with a capacity of 14 MW began in 2021; it will be operational by the end of 2022, increasing the total wind power capacity by 16%.

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 despite the long authorization process, many projects are still in development. Financing is currently requested for an additional 3.2 TWh under the FIT scheme

Internationally cross-linked research activities in 2021 focused on cold climates, complex terrain, aviation cohabitation, and social acceptance.

United Kingdom

Stephen Wyatt, Offshore Renewable Energy Catapult

Introduction

Less favourable weather conditions during 2021 contributed to renewable energy generation falling by 9.5% from 2020 to 121.9 TWh in 2021, although this figure is still the second highest on record. Renewables share of total energy generation fell from 43% to 39% from 2020 to 2021. In general, total energy production fell to its lowest level in over 50 years due to maintenance in the North Sea and disruptions in nuclear output. Energy demand increased by 5.4% from 2020 as COVID-19 restrictions were eased. However, this figure was still down 8% from 2019. Of the total annual electricity generated from renewables, wind energy provided 53% (29% offshore & 24% onshore).

Offshore wind capacity grew by 873 MW in 2021 to 11.2 GW of cumulative capacity. In terms of onshore capacity, 372 MW was added in 2021, taking the total to 14.5 GW. Despite a greater annual growth in offshore capacity than onshore, only onshore wind saw a corresponding increase in generation from Q4 2020 to Q4 2021 [1].

Research in the wind sector is focused on driving efficiency in O&M through collaboration between industry, academia, and the public sector. Tackling the challenge of grid integration will be vital as wind energy grows beyond 40GW. In addition, it will be vital to develop the local supply chain, deliver on ambitious targets, and maximise the benefit of the sector to the UK economy.


Technology Collaboration Programme by iea

Report 2021
USA

In 2021, the Biden administration established a new target to deploy 30 gigawatts of offshore wind power capacity by 2030. In this photo, a wind turbine installation vessel floats beside a 6-megawatt turbine that's part of Dominion Energy's Coastal Virginia Offshore Wind pilot project located 27 miles off the coast of Virginia Beach, Virginia. *Photo by Lyfted Media for Dominion Energy*

Authors *U.S. Department of Energy's (US DOE) Wind Energy Technologies Office and National Renewable Energy Laboratory (NREL), United States*

Wind energy plays a critical role in national climate targets established in 2021. These include reducing greenhouse gas emissions by at least 50% from 2005 levels by 2030, achieving 100% clean electricity by 2035, and reaching net-zero emissions economywide by no later than 2050 [1].

Five U.S. states updated or adopted new clean energy standards in 2021; 31 states and the District of Columbia already had such standards in place [2].

Wind power capacity in the United States continued to grow in 2021, adding nearly 14 gigawatts (GW) [3]. As the United States' top source of renewable energy production, wind power facilities accounted for 9.2% of electricity generation in 2021 [4]. As of the end of 2021, the United States had 135 GW [5] of electricity generation capacity from wind turbines. The nation's largest operating wind project, the 1,055-megawatt (MW) Western Spirit in New Mexico [5], came online in 2021, and construction began on Vineyard Wind [5], the nation's first commercial-scale offshore wind power plant.

Read Country Report USA

USA

U.S. Department of Energy's Wind Energy Technologies Office and National Renewable Energy Laboratory

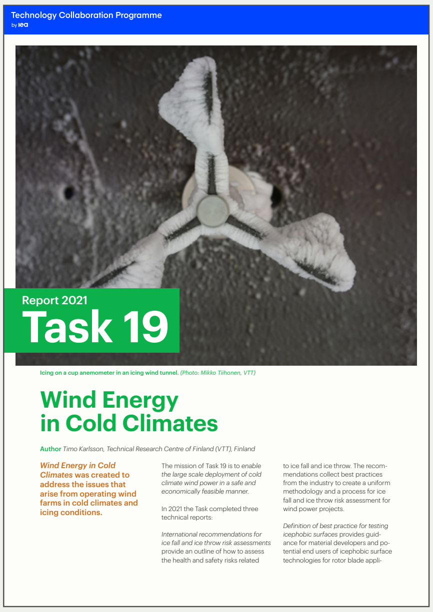
Introduction

Wind energy plays a critical role in national climate targets established in 2021. These include reducing greenhouse gas emissions by at least 50% from 2005 levels by 2030, achieving 100% clean electricity by 2035, and reaching net-zero emissions economywide by no later than 2050 [1]. Five U.S. states updated or adopted new clean energy standards in 2021; 31 states and the District of Columbia already had such standards in place [2].

Wind power capacity in the United States continued to grow in 2021, adding nearly 14 gigawatts (GW) [3]. As the United States' top source of renewable energy production, wind power facilities accounted for 9.2% of electricity generation in 2021 [4].

As of the end of 2021, the United States had 135 GW [5] of electricity generation capacity from wind turbines. The nation's largest operating wind project, the 1,055-megawatt (MW) Western Spirit in New Mexico [5], came online in 2021, and construction began on Vineyard Wind [5], the nation's first commercial-scale offshore wind power plant.

Read Task 11



Read Task 19

Task 11 Summary

Lionel Perret, Planair SA, Switzerland

Wind Scout

Task 11 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. When considered useful, a factsheet is prepared with the main results of a TEM. Task 11 also disseminates knowledge by developing Recommended Practices. Many IEA Wind Recommended Practices have served as basis for both national and international standards.

In 2021, Task 11 was strongly involved in the establishment of updated, detailed procedures to better organise the internal communication within the IEA Wind TCP, to accelerate the procedures for new task approval and provide support to the Operating Agents. In regular meetings with the Leadership Team, the aim was to increase the dynamics of the TCP Wind and define the conditions for TEMs to be organised in collaboration with other IEA TCPs. Travel restrictions have affected the organisation of Task 11 in 2021. The TEM#103 on Offshore Wind Consenting, initially foreseen for 2021, was finally made online beginning of 2022.

The reports and activities of Task 11 bring the latest knowledge to wind energy experts in the member countries, offer recommendations for the future work of the TCP and operate as a catalyst for starting new IEA Wind TCP Research Tasks. Task 11 has been active since 1978, with the participation of the majority of the IEA Wind TCP participating countries.

Task 19 Summary

Timo Karlsson, Technical Research Centre of Finland (VTT), Finland

Wind Energy in Cold Climates

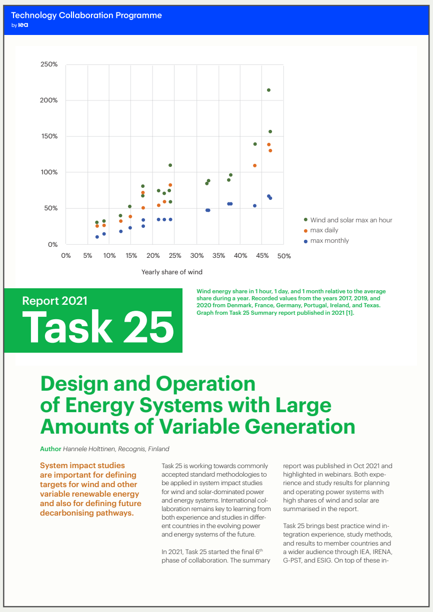
IEA Wind TCP Task 19: *Wind energy in Cold Climates* was created to address the issues that arise from operating wind farms in cold climates and icing conditions. The mission of Task 19 is to *enable the large scale deployment of cold climate wind power in a safe and economically feasible manner.*

In 2021 the Task completed three technical reports: *International recommendations for ice fall and ice throw risk assessments* provide an outline of how to assess the health and safety risks related to ice fall and ice throw. The recommendations collect best practices from the industry to create a uniform methodology and a process for ice fall and ice throw risk assessment for wind power projects.

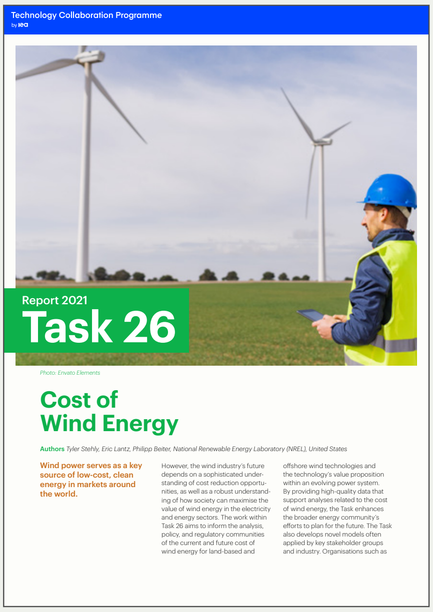
Definition of best practice for testing icephobic surfaces provides guidance for material developers and potential end users of icephobic surface technologies for rotor blade applications. This report is the first step in defining the evaluation process for icephobic surfaces and supports the identification of relevant tests for standardisation.

Ice Detection Guidelines for Wind Energy Applications provide background information on ice detection and its practical applications in wind energy and propose a classification of available methods and their suitability for different ice detection applications. It also proposes a standard set of metrics for performance evaluation of ice detectors in laboratory and field tests.

All reports were written with the participation of volunteer experts from the industry, either as an early-stage reviewer or contributing authors.



Read Task 25



Read Task 26

Task 25 Summary

Hannele Holttinen, Recognis, Finland

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

System impact studies are important for defining targets for wind and other variable renewable energy and also for defining future decarbonising pathways. 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 learning from both experience and studies in different countries in the evolving power and energy systems of the future.

In 2021, Task 25 started the final 6th phase of collaboration. The summary report was published in Oct 2021 and highlighted in webinars. Both experience and study results for planning and operating power systems with high shares of wind and solar are summarised in the report.

Task 25 brings best practice wind integration experience, study methods, and results to member countries and a wider audience through IEA, IRENA, G-PST, and ESIG. On top of these international network stakeholders, the system operators are the main target group of Task 25 work, following Task 25 work directly and as observers.

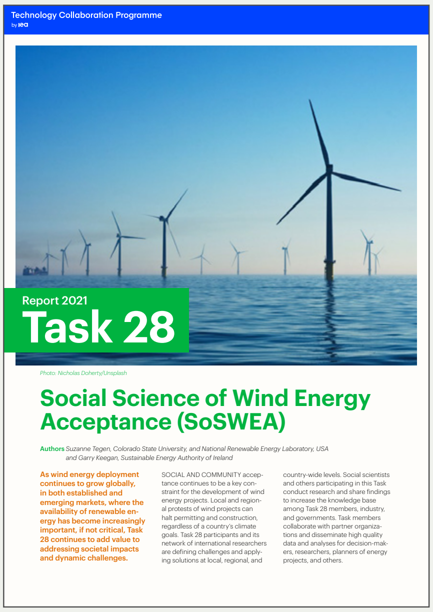
The Recommended Practices report update started in 2021, including collaboration with IEA PVPS TCP Task 14. This will be the main effort for the Task in 2022-23.

Task 26 Summary

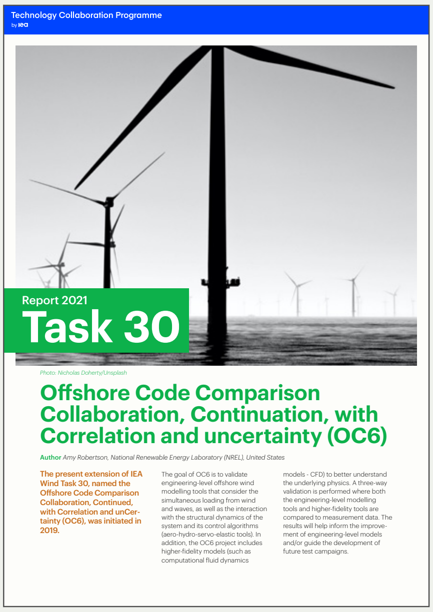
Tyler Stehly, Eric Lantz, Philipp Beiter, National Renewable Energy Laboratory (NREL), United States

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 how society can maximise the value of wind energy in the electricity and energy sectors. The work within Task 26 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 the cost of wind energy, the Task enhances the broader energy community's efforts to plan for the future. The Task also develops novel models often applied by key stakeholder groups and industry. Organisations such as IEA and the International Renewable Energy Agency have used Task 26 wind project cost, and performance statistics, and participants regularly use these data for internal and external purposes.



Read Task 28



Read Task 30

Task 28 Summary

Suzanne Tegen, Colorado State University, and National Renewable Energy Laboratory (NREL), United States
Garry Keegan, Sustainable Energy Authority of Ireland (SEAI), Ireland

Social science of wind energy acceptance (SoSWEA)

As wind energy deployment continues to grow globally, in both established and emerging markets, where the availability of renewable energy has become increasingly important, if not critical, Task 28 continues to add value to addressing societal impacts and dynamic challenges.

Social and community acceptance continues to be a key constraint for the development of wind energy projects. Local and regional protests of wind projects can halt permitting and construction, regardless of a country's climate goals. Task 28 participants and its network of international researchers are defining challenges and applying solutions at local, regional, and country-wide levels. Social scientists and others participating in this Task conduct research and share findings to increase the knowledge base among Task 28 members, industry, and governments. Task members collaborate with partner organisations and disseminate high quality data and analyses for decision-makers, researchers, planners of energy projects, and others.

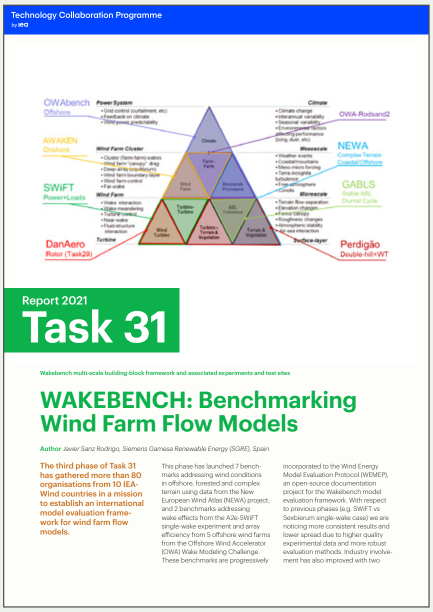
Task 30 Summary

Amy Robertson, National Renewable Energy Laboratory (NREL), United States

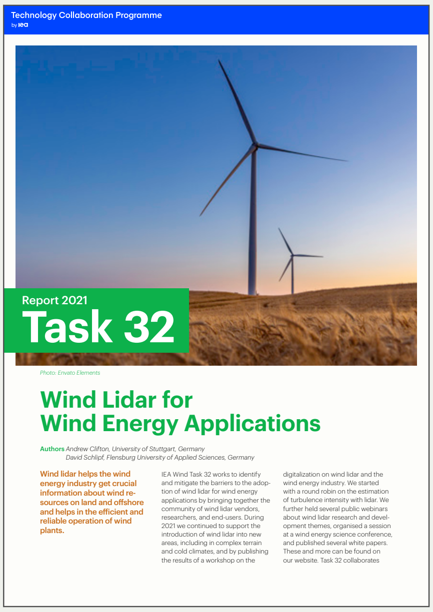
Offshore Code Comparison Collaboration, Continuation, with Correlation and uncertainty (OC6)

The present 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 help inform the improvement of engineering-level models and/or guide the development of future test campaigns.

In 2021, the remainder of activities for Phase I, focused on validating the slow-motion hydrodynamic response of a floating wind semisubmersible, was accomplished. This work included higher-fidelity simulations, which took much longer to complete than the engineering modelling work, and a new experimental campaign (labelled OC6 Phase Ib) that helped to validate these models [1]. Phase II of the project was also completed, which was focused on the implementation and verification of an advanced soil-structure interaction (SSI) model for offshore wind system design and analysis. Participants integrated an advanced macro-element capability to coupled aero-hydro-servo-elastic offshore wind turbine modelling tools and verified the implementation by comparing simulation results across the modelling tools, for an example, monopile design. The simulation results were also compared to more traditional SSI modelling approaches.



Read Task 31



Read Task 32

Task 31 Summary

Javier Sanz Rodrigo, Siemens Gamesa (SGRE), Spain

Wakebench: Benchmarking Wind Farm Flow Models

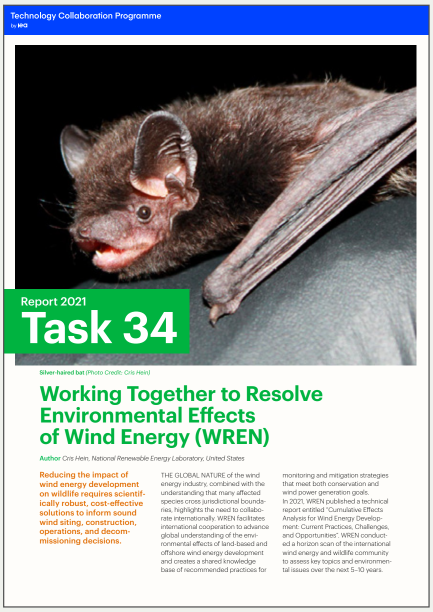
The third phase of Task 31 has gathered more than 80 organisations from 10 IEA-Wind countries in a mission to establish an international model evaluation framework for wind farm flow models. This phase has launched 7 benchmarks addressing wind conditions in offshore, forested and complex terrain using data from the New European Wind Atlas (NEWA) project; and 2 benchmarks addressing wake effects from the A2e-SWiFT single-wake experiment and array efficiency from 5 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 will be a core component of a new IEA Task for wind farm flow modelling and validation.

Task 32 Summary

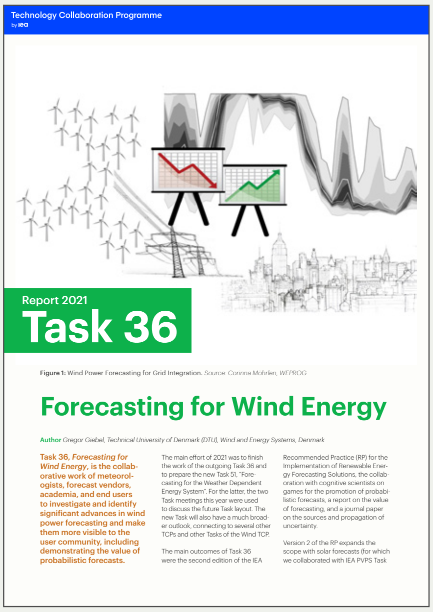
Andrew Clifton, University of Stuttgart, Germany
David Schlipf, Flensburg University of Applied Sciences, Germany

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 2021 we continued to support the introduction of wind lidar into new areas, including in complex terrain and cold climates, and by publishing the results of a workshop on the digitalisation on wind lidar and the wind energy industry. We started with a round robin on the estimation of turbulence intensity with lidar. We further held several public webinars about wind lidar research and development themes, organised a session at a wind energy science conference, and published several white papers. These and more can be found on our website. Task 32 collaborates extensively with other IEA Wind Tasks, including Task 19 (Wind Energy in Cold Climates), Task 37 (Systems Engineering in Wind Energy), Task 43 (Wind Energy Digitalisation), and Task 44 (Flow Farm Control). We also work closely with industry bodies, including CFARS and IEC TC88. Our virtual events were attended by many different stakeholders, with around 50% industry participation. Task 32 will reach the end of its current phase at the end of 2021 and will continue in Task 52 on the large-scale deployment of wind lidar from 2022. Currently, wind lidar has achieved market dominance offshore and around 5-10% onshore, with continuing rapid growth. Therefore, the new Task 52 will explore the challenges arising from the mass deployment of wind lidar and help the global wind energy industry prepare.



Read Task 34



Read Task 36

Task 34 Summary

Cris Hein, National Renewable Energy Laboratory (NREL), United States

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

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. WREN facilitates international cooperation to advance 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 strategies that meet both conservation and wind power generation goals.

In 2021, WREN published a technical report entitled "Cumulative Effects Analysis for Wind Energy Development: Current Practices, Challenges, and Opportunities". WREN conducted a horizon scan of the international wind energy and wildlife community to assess key topics and environmental issues over the next 5–10 years. A manuscript of the results entitled "International Assessment of Priority Environmental Issues for Land-based and Offshore Wind Energy Development" was submitted to the journal Global Sustainability. WREN supports the management of the Tethys knowledge base (https://tethys.pnnl.gov), which serves as a collaborative outreach and engagement platform to disseminate the latest research. WREN also published several fact sheets, developed a web-based tool summarising the research status of monitoring and minimisation technologies, and hosted a forum with subject matter experts on raptor collision risk with wind turbines.

Task 36 Summary

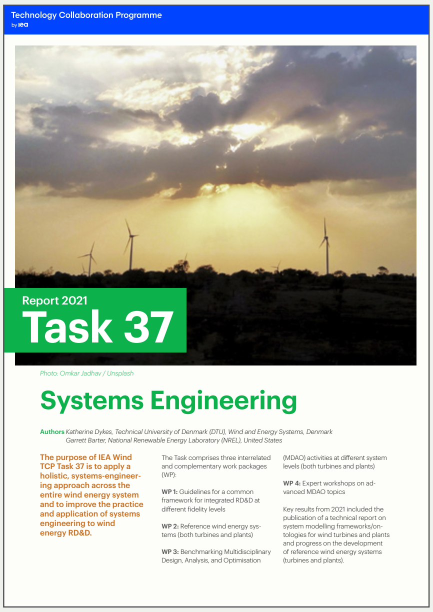
Gregor Giebel, Technical University of Denmark (DTU), Wind and Energy Systems, Denmark

Forecasting for Wind Energy

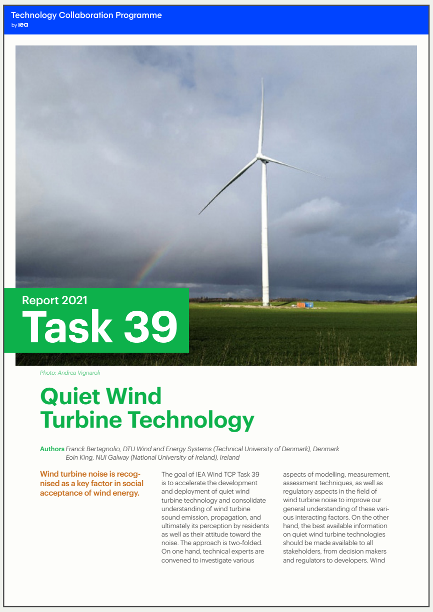
Task 36, "Forecasting for Wind Energy", is the collaborative work of meteorologists, forecast vendors, academia, and end users to investigate and identify significant advances in wind power forecasting and make them more visible to the user community, including to demonstrate the value of probabilistic forecasts. The main effort of 2021 was to finish the work of the outgoing Task 36 and to prepare the new Task 51, "Forecasting for the Weather Dependent Energy System". For the latter, the two Task meetings this year were used to discuss the future Task layout. The new Task will also have a much broader outlook, connecting to several other TCPs and other Tasks of the Wind TCP.

The main outcomes of Task 36 were the second edition of the IEA Recommended Practice (RP) for the Implementation of Renewable Energy Forecasting Solutions, the collaboration with cognitive scientists on games for the promotion of probabilistic forecasts, a report on the value of forecasting, and a journal paper on the sources and propagation of uncertainty.

Version 2 of the RP expands the scope with solar forecasts (for which we collaborated with IEA PVPS Task 16), probabilistic forecasts, and a fourth part on how to use real-time measurements, providing recommendations for the design, set-up, maintenance of meteorological and power generation data gathering systems to optimally support the production of generation forecasts. This last part also contains a description of useful data transfer standards and classifies those according to complexity.



Read Task 37



Read Task 39

Task 37 Summary

Katherine Dykes, Technical University of Denmark (DTU), Wind and Energy Systems, Denmark
Garrett Barter, National Renewable Energy Laboratory (NREL), United States

Systems Engineering

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

- **WP 1:** Guidelines for a common framework for integrated RD&D at different fidelity levels
- **WP 2:** Reference wind energy systems (both turbines and plants)
- **WP 3:** Benchmarking Multidisciplinary Design, Analysis, and Optimization (MDAO) activities at different system levels (both turbines and plants)
- **WP 4:** Expert workshops on advanced MDAO topics

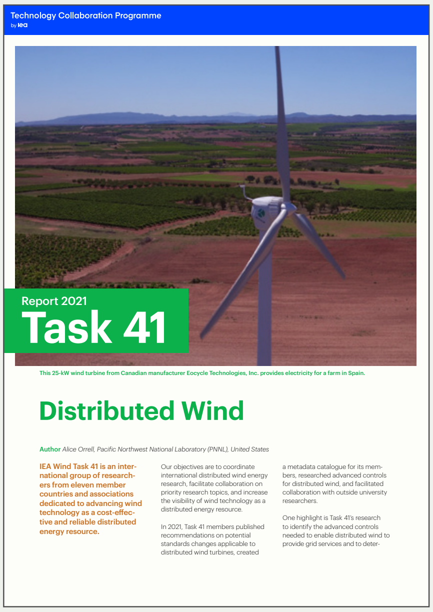
Key results from 2021 included the publication of a technical report on system modelling frameworks/ontologies for wind turbines and plants and progress on the development of reference wind energy systems (turbines and plants).

Task 39 Summary

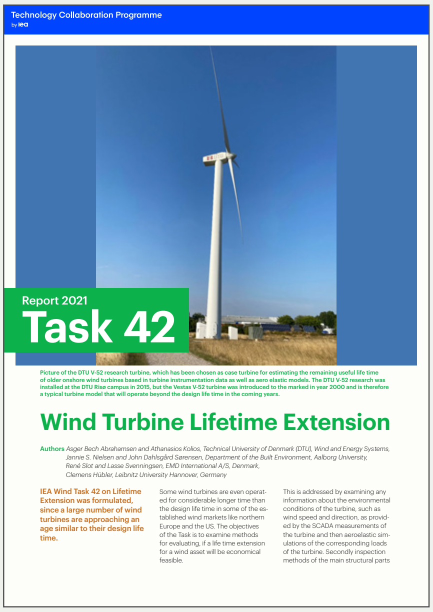
Franck Bertagnolio, Technical University of Denmark (DTU), Wind and Energy Systems, Denmark
Eoin King, National University of Ireland (NUI) Galway, Ireland

Quiet Wind Turbine Technology

Wind turbine noise is recognised as a key factor in 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 the noise. The approach is two-folded. 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 in various fields of expertise originating from different countries are active in the Task endeavor to reach these goals. The activities are distributed in 4 WPs addressing engineering aspects on one side (noise generation and noise propagation) and socio-psychological aspects on the other side (assessment of noise effects on humans and perception of noise related to other factors that noise itself). Furthermore, 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 first phase of Task 39 officially ended in 2020. The second phase of the Task is currently undergoing with an increased focus on human perception and acceptance issues.



Read Task 41



Read Task 42

Task 41 Summary

Alice Orrell, Pacific Northwest National Laboratory (PNNL), United States

Distributed Wind

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.

In 2021, Task 41 members published recommendations on potential standards changes applicable to distributed wind turbines, created a metadata catalogue for its members, researched advanced controls for distributed wind, and facilitated collaboration with outside university researchers.

One highlight is Task 41's research to identify the advanced controls needed to enable distributed wind to provide grid services and to determine what other design requirements may be needed specifically for high renewable-contribution isolated power systems. With advanced controls, distributed wind can provide additional benefits beyond electricity, such as enhancing grid reliability and resilience.

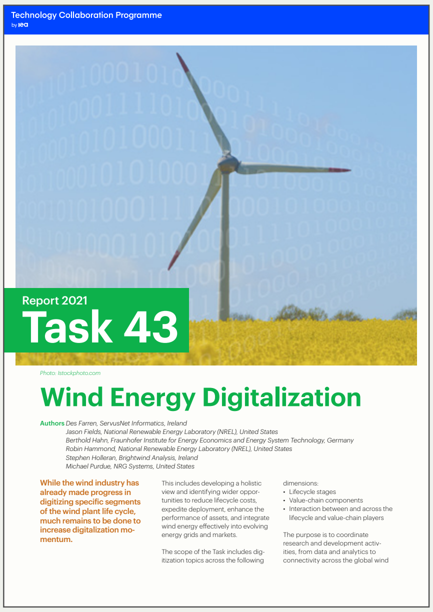
Task 42 Summary

Asger Bech Abrahamsen and Athanasios Kolios, Technical University of Denmark (DTU), Wind and Energy Systems, Denmark

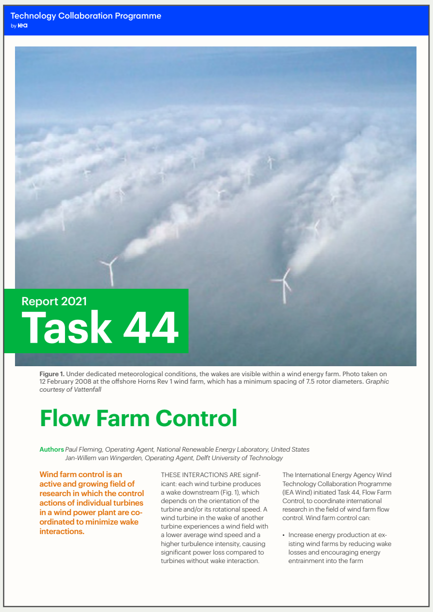
Wind Turbine Lifetime Extension

The IEA Task 42 on Life extension was formulated, since a large number of wind turbines are approaching an age similar to their design life time and some are even operated for considerable longer time than the design life time in some of the established wind markets like northern Europe and the US. The objectives of the Task is to examine methods for evaluating, if a life time extension for a wind asset will be economical feasible.

This is addressed by examining any information about the environmental conditions of the turbine, such as wind speed and direction, as provided by the SCADA measurements of the turbine and then aeroelastic simulations of the corresponding loads of the turbine. Secondly inspection methods of the main structural parts of wind turbines have been investigated in order to provide recommendations to the regulatory frame work and authorities. A recommendation on life extension procedures will be provided when the task 42 is completed.



Read Task 43



Read Task 44

Task 43 Summary

Des Farren, ServusNet Informatics, Ireland
Jason Fields, National Renewable Energy Laboratory (NREL), United States
Berthold Hahn, Fraunhofer Institute for Energy Economics and Energy System Technology,
Germany Robin Hammond, National Renewable Energy Laboratory (NREL), United States
Stephen Holleran, Brightwind Analysis, Ireland
Michael Purdue, NRG Systems, United States

Wind Energy Digitalization

While the wind industry has already made progress in digitizing 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 deployment, enhance the 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 the 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 that maximise benefits from digitalization while minimising duplicate or inefficient effort.

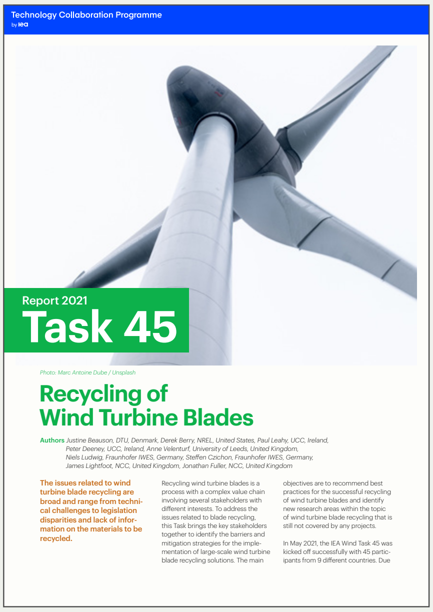
Task 44 Summary

Paul Fleming, National Renewable Energy Laboratory (NREL), United States
Jan-Willem van Wingerden, Delft University of Technology, Netherlands

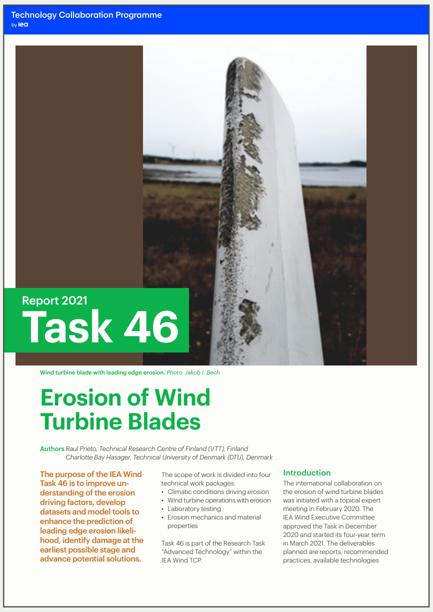
Flow Farm Control

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. WREN facilitates international cooperation to advance 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 strategies that meet both conservation and wind power generation goals.

In 2021, WREN published a technical report entitled "Cumulative Effects Analysis for Wind Energy Development: Current Practices, Challenges, and Opportunities". WREN conducted a horizon scan of the international wind energy and wildlife community to assess key topics and environmental issues over the next 5–10 years. A manuscript of the results entitled "International Assessment of Priority Environmental Issues for Land-based and Offshore Wind Energy Development" was submitted to the journal Global Sustainability. WREN supports the management of the Tethys knowledge base (https://tethys.pnnl.gov), which serves as a collaborative outreach and engagement platform to disseminate the latest research. WREN also published several fact sheets, developed a web-based tool summarising the research status of monitoring and minimisation technologies, and hosted a forum with subject matter experts on raptor collision risk with wind turbines.



Read Task 45



Read Task 46

Task 45 Summary

Justine Beauson, Technical University of Denmark (DTU), Wind and Energy Systems, Denmark
Derek Berry, National Renewable Energy Laboratory (NREL), United States
Paul Leahy, Peter Deeney, University College Cork (UCC), Ireland
Niels Ludwig, Steffen Czichon, Fraunhofer Institute for Wind Energy Systems (IWES), Germany,
James Lightfoot, Jonathan Fuller, National Composites Centre (NCC), Anne Velenturf, University of Leeds, United Kingdom

Recycling of Wind Turbine Blades

The issues related to wind turbine blade recycling are broad and range from technical challenges to legislation disparities and lack of information on the materials to be recycled. Recycling wind turbine blades is a process with a complex value chain involving several stakeholders with different interests. To address the issues related to blade recycling, this Task brings the key stakeholders together to identify the barriers and mitigation strategies for the implementation of large-scale wind turbine blade recycling solutions. The main objectives are to recommend best practices for the successful recycling of wind turbine blades and identify new research areas within the topic of wind turbine blade recycling that is still not covered by any projects.

In May 2021, the IEA Wind Task 45 was kicked off successfully with 45 participants from 9 different countries. Due to Covid restrictions, the meeting was held online and over 2 days to accommodate the different time zones. Since May 2021, the members involved in the work packages have been working on establishing the state of the art on the 3 key topics of this Task. These topics are the technical aspects of recycling, the analysis of the blade lifecycle and value chain, and the standards and legislation framing the end of life of wind turbine blades.

Task 46 Summary

Raul Prieto, Technical Research Centre of Finland (VTT), Finland
Charlotte Bay Hasager, Technical University of Denmark (DTU), Wind and Energy Systems, Denmark

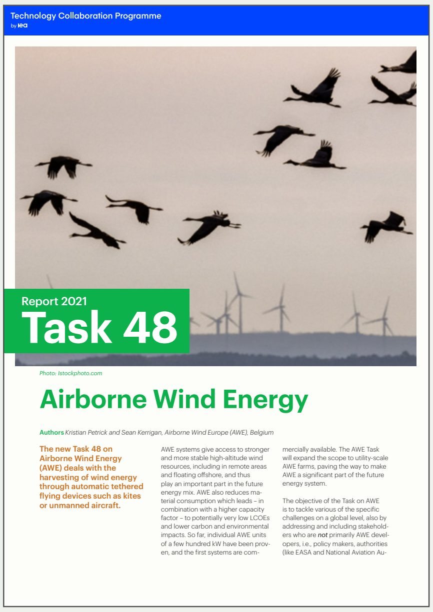
Erosion of Wind Turbine Blades

The purpose of the IEA Wind Task 46 Erosion of wind turbine blades is to improve understanding of the erosion driving factors, develop datasets and model tools to enhance the prediction of leading edge erosion likelihood, identify damage at the earliest possible stage and advance potential solutions. The scope of work is divided into four technical work packages:

- Climatic conditions driving erosion
- Wind turbine operations with erosion
- Laboratory testing
- Erosion mechanics and material properties

Task 46 is part of the Research Task "Advanced Technology" within the IEA Wind.

Read Task 47



Read Task 48

Task 47 Summary

Gerard Schepers, Koen Boorsma, Netherlands Organisation for Applied Scientific Research (TNO), Netherlands
Helge Aagaard Madsen, Technical University of Denmark (DTU), Wind and Energy Systems, Denmark

TURBulent INflow Innovative Aerodynamics (TURBINIA)

In 2021 the IEA Task 47 TURBINIA (TURBulent INflow Innovative Aerodynamics) started for a period of 4 years. The Task aims to cooperate in the field of high-quality, detailed aerodynamic measurements for MW scale turbines in the atmospheric flow. Such measurements are extremely difficult to do, and the only public example until now is the Danish DanAero experiment, which was used in the final phase of IEA Task 29.

Recently several other countries initiated new experiments for turbines up to a scale of 8MW, and they now all have to go through a similar learning process on these new measurement techniques. Sharing experiences is then a very fruitful way to steepen the learning curves.

Moreover, a sound scientific approach requires a cross fertilization between measurements and theory where experiments feed theory and vice versa. Therefore, the new (and existing) aerodynamic measures are analysed and simulated by a large group of research institutes and industries.

In parallel, simulations are carried out on a 15 MW Reference Wind Turbine as designed in IEA Task 37.

In 2021, the Task has started with designing experiments and the organisation of workshops around on several subjects which are relevant for detailed aerodynamic measurements. First data are collected already. Moreover, several calculational cases have been defined and started.

Task 48 Summary

Kristian Petrick, Airborne Wind Europe (AWE), Belgium
Sean Kerrigan, Airborne Wind Europe (AWE), Belgium

Airborne Wind Energy

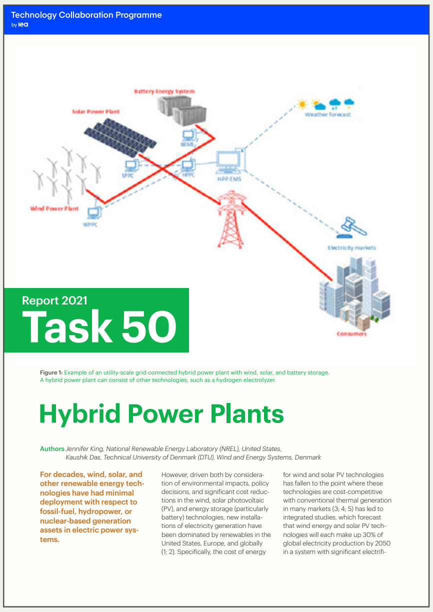
The new Task 48 on Airborne Wind Energy (AWE) deals with the harvesting of wind energy through automatic tethered flying devices such as kites or unmanned aircraft.

AWE systems give access to stronger and more stable high-altitude wind resources, including in remote areas and floating offshore, and thus play an important part in the future energy mix. AWE also reduces material consumption which leads – in combination with a higher capacity factor – to potentially very low LCOEs and lower carbon and environmental impacts. So far, individual AWE units of a few hundred kW have been proven, and the first systems are commercially available. The AWE Task will expand the scope to utility-scale AWE farms, paving the way to make AWE a significant part of the future energy system.

The objective of the Task on AWE is to tackle various of the specific challenges on a global level, also by addressing and including stakeholders who are not primarily AWE developers, i.e., policy makers, authorities (like EASA and National Aviation Authorities), regulators, and other wind energy and technology experts.

The Task was kicked-off in October 2021 with more than 100 participants from 15 countries and over 60 institutions. The Task is supported by 9 countries (BE, CH, DE, DK, ES, IE, NL, UK, US), and it consists of five Work Packages: i) Resource potential and markets; ii) reference models, tools, and metrics; iii) safety and regulation; iv) Social Acceptance; v) AWES Architectures. The first results are expected in the course of 2022.

Read Task 49



Read Task 50

Task 49 Summary

Matt Shields, National Renewable Energy Laboratory (NREL), United States
Pauline Bozonnet, IFP Energies nouvelles (IFPEN), France
Cian Desmond, Gavin & Doherty Geosolutions (GDG), Ireland

Integrated DEsign of floating wind Arrays (IDEA)

IEA Wind Task 49 on the Integrated DEsign of floating wind Arrays (IDEA) kicked off in December 2021. The overall goal of the Task is to accelerate the global development of commercial-scale floating wind projects by providing resources to the research and planning communities. Expanding the industry beyond the current demonstration-scale projects will require addressing unique challenges associated with having dozens of co-located floating platforms in a confined ocean space, such as designing reliable and effective stationkeeping systems, optimising array layouts, and considering the needs of other ocean users. Considering holistic design principles from the earliest stages of the industry will streamline the growth of cost-effective, globally deployed floating wind projects.

The primary challenge with developing commercial-scale floating wind designs is a lack of widely accepted methodologies, data, and resolutions to outstanding planning questions. The IDEA project brings together floating wind experts from around the world to consolidate their perspectives and experience. The Task will provide baseline tools and data for the research community, including reference site conditions, reference array designs and toolsets, an array-level risk assessment framework, and a register of major research and planning questions faced by the industry. Combining these resources into a unified repository will help provide a standardised foundation for future innovation, development, and industrialisation of floating wind projects worldwide.

Task 50 Summary

Jennifer King, National Renewable Energy Laboratory (NREL), United States
Kaushik Das, Technical University of Denmark (DTU), Wind and Energy Systems, Denmark

Hybrid Power Plants

For decades, wind, solar, and other renewable energy technologies have had minimal deployment with respect to fossil-fuel, hydropower, or nuclear-based generation assets in electric power systems. However, driven both by consideration of environmental impacts, policy decisions, and significant cost reductions in the wind, solar photovoltaic (PV), and energy storage (particularly battery) technologies, new installations of electricity generation have been dominated by renewables in the United States, Europe, and globally (1; 2). Specifically, the cost of energy for wind and solar PV technologies has fallen to the point where these technologies are cost-competitive with conventional thermal generation in many markets (3; 4; 5) has led to integrated studies, which forecast that wind energy and solar PV technologies will each make up 30% of global electricity production by 2050 in a system with significant electrification of the global energy system (5). NREL's 2018 Standard Scenarios also indicate significant growth in renewable penetration of the electric sector by 2050. As we look toward the future grid dominated by renewable energy, a paradigm shift is underway where the traditional model of energy-based revenue streams for wind and solar PV using power purchase agreements or feed-in tariffs is changing (6). With renewable energy growing to 10%-20% or more of overall electricity generation (6; 7; 8; 9), design objectives are shifting from producing energy at the lowest levelized cost and using the levelized cost of energy calculator (LCOE) to also include other design objectives (which varies from market to market) that maximise profitability from revenue streams associated with time-varying energy pricing, ancillary service, and capacity markets.

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