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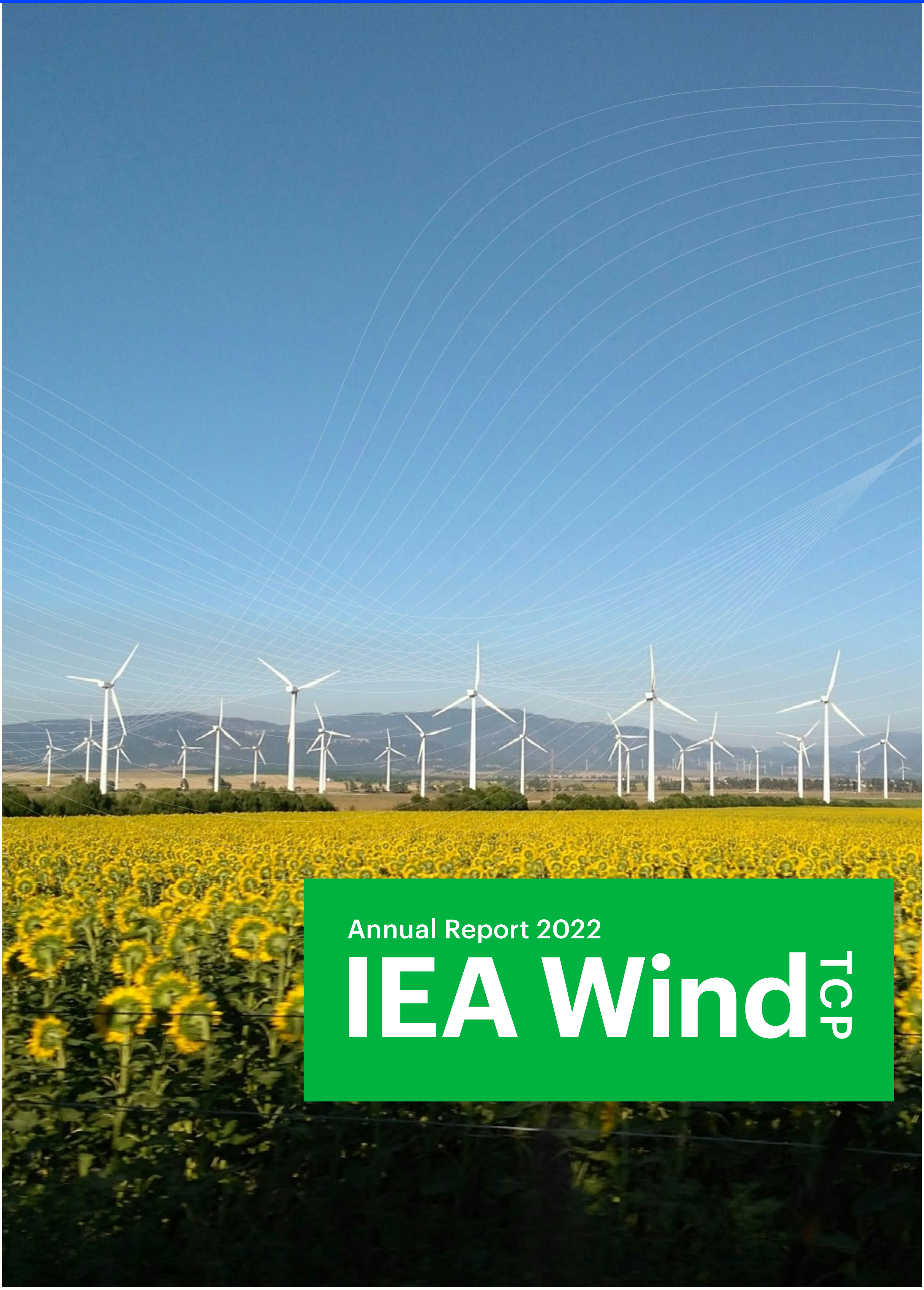
by iea



Annual Report 2022

IEA Wind TCP

Content

Photo: Rogier Ralph Floors / DTU Wind

2022 IEA Wind TCP *Overview*

The wind industry is nearing the 1 TW (1000 GW) landmark in cumulative installed capacity [1]. Demand for more wind-generated energy continues to surge as it helps to mitigate both environmental and energy crises. Therefore, the industry has recently experienced a shift in priorities from a focus on cost reduction to increasing the speed of deployment to meet new renewable energy goals. Although 2022 saw less growth than the previous two years, forecasts show substantial growth in yearly deployment numbers [2]. Despite this positive growth trend, the industry is challenged by the significant leap in deployment needed to reach the new targets set for 2030 and beyond.

Globally, 77.6 GW of new wind power capacity was connected to power grids in 2022, bringing the total installed wind capacity to 906 GW [1]. This brought the cumulative year-on-year growth rate to 9%. Furthermore, the offshore wind capacity reached a total of 57 GW by the end of the year [1]. Overall, the growth in installed new capacity in 2022 fell below the yearly additions of wind power of the last two years, which reached more than 90 GW of new capacity annually.

The environmental and energy crises were specifically highlighted in the global agenda in 2022, which has stimulated an accelerated ambition in targets for implementing renewable energy sources. Revised targets include a doubling of the wind power capacity from its current share by 2030 and a tenfold increase, specifically in offshore capacity.

Auctions for land-based and offshore capacity were complemented by the private sector announcing investment decisions for new subsidy-free wind power plants through PPAs (Power Purchase Agreements) and further supported by energy price increases. Wind energy furthermore contributed to keeping the electricity market prices low, benefiting society.

The pressure for cost reductions from competitive auctions for the whole value chain is proving challenging with increasing raw material prices and interest rates. However, the motivation to achieve the updated, more ambitious wind and renewable energy targets fosters urgency to increase deployment rates. Therefore, the industry currently sees an emerging trend in prioritising deployment urgency before cost reductions. Despite continued growth in wind markets, it is not projected to reach the level required to achieve the 2030 climate goals.

The near future for wind energy is bright yet challenging. Extensive growth in both deployment rate and technological advances is expected. However, this growth must be done sustainably. Continued growth strategies lie in establishing permitting procedures that simplify authorisation procedures while ensuring that public acceptance of wind energy remains supportive. Special attention will be paid to training and reskilling

Trend in prioritising deployment urgency before cost reductions is emerging.

RD&D investments are complemented by broader initiatives with an increasing focus on local job creation, competitiveness and protection of critical infrastructure.

to provide the skilled workforce needed for the increased deployment and operation of wind power plants.

Investments in wind energy RD&D are needed across the entire value chain from initial research to testing and demonstration and include multiple disciplines. Public energy RD&D reached nearly 44 billion USD (40 billion EUR) in China, constituting a new record in research investment. 80% of the budget was specifically devoted to clean energy topics. Often, RD&D investments are complemented by broader initiatives with an increasing focus on local job creation, competitiveness and protection of critical infrastructure.

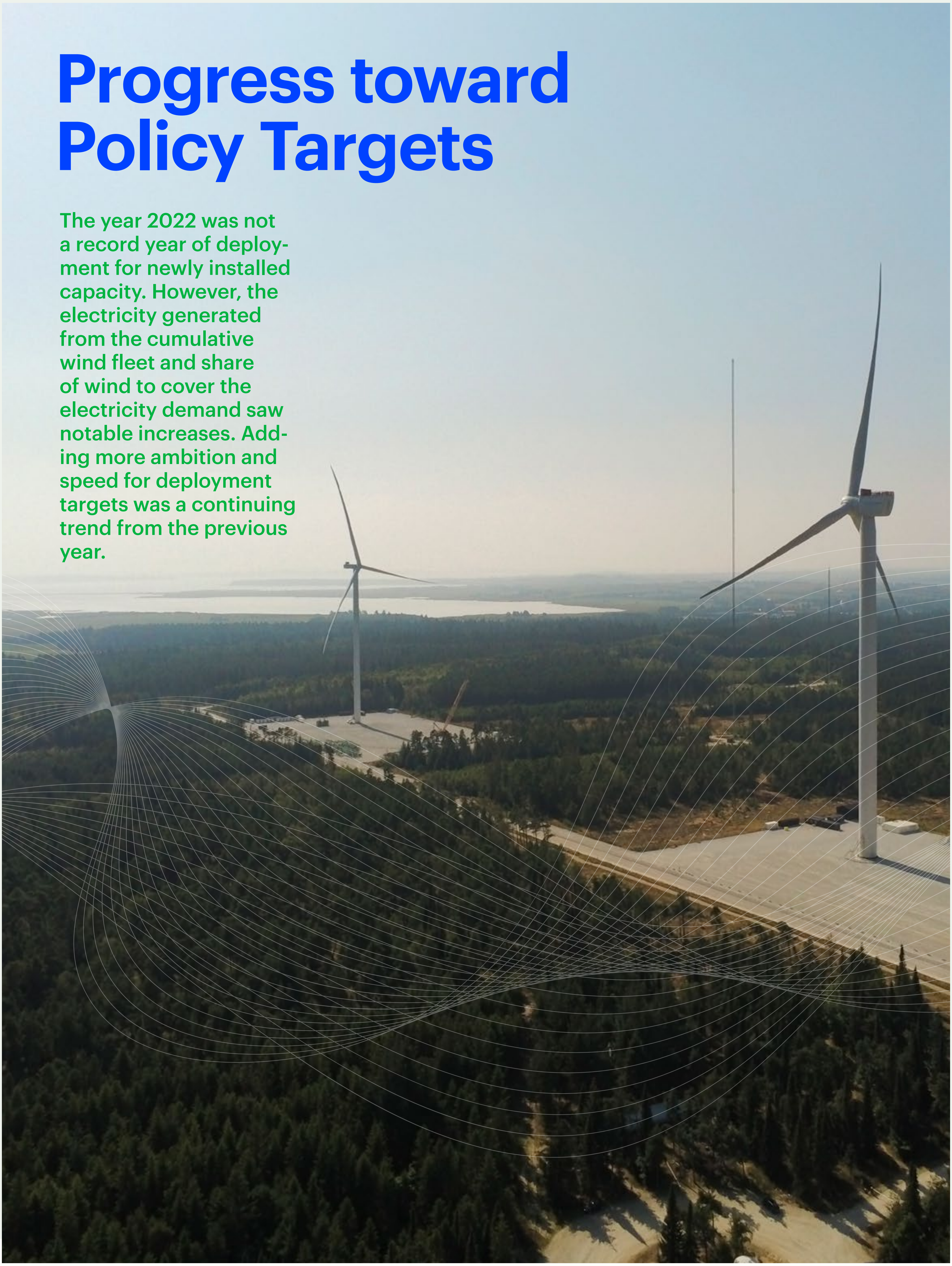
This summary of the *IEA Annual Report 2022* presents highlights and trends from 22 countries and the European Union and WindEurope for deployment and RD&D activities. Data for 2022 will be published towards the end of 2023, with graphics showing the evolution of trends from previous IEA Wind TCP documents (1995-2021).

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

Photo: Simon Rubin / DTU Wind

Progress toward Policy Targets

The year 2022 was not a record year of deployment for newly installed capacity. However, the electricity generated from the cumulative wind fleet and share of wind to cover the electricity demand saw notable increases. Adding more ambition and speed for deployment targets was a continuing trend from the previous year.



New Records in Many Countries – With a Need to Step Up Deployment

China continued to lead with the most significant proportion of deployment, although it did not reach the record of 50 GW of new installed capacity in previous years. Overall, China is close to reaching 400 GW of installed capacity (365 GW grid-connected).

Europe had another record year by adding 19 GW of new capacity, while the U.S. saw a drop in deployment, adding 8 GW.

Wind energy has proved its resilience by continuing its high rate of development throughout the COVID-19 pandemic on a global scale. It is furthermore projected to continue this growth trajectory in the following years. However, it is clear that more than the predicted increase is needed to reach the demand for clean power defined by the targets set for 2030 and 2050. For example, more than 30 GW/year must be installed throughout Europe, which is a significant increase from the initial 20 GW/year levels that were expected.

Highlights of Deployment from 2022:

- Europe had another record year of installations with 19 GW of new wind, which now exceeds 250 GW in total. The EU's newly installed capacity increased by 15%, with 16 GW of new capacity surpassing the 200 GW landmark.
- The UK's new record for offshore installations brought the annual added capacity to 3 GW.
- Finland saw a 74% increase in installed capacity, equivalent to 2.4 GW.
- France reached a new record of nearly 2 GW in new capacity added. The country has now surpassed 20 GW total installed capacity.
- Sweden had a second record year exceeding 2 GW in yearly installation.
- Canada's new record yielded 1 GW of new installed capacity.
- Increases in electricity production from wind energy created new records due to a high wind year in many regions, as well as the results of full-year generation from significant capacity additions of previous years. Additionally, the share of wind in the electricity mix jumped due to electricity demand reductions in 2022.
- Denmark achieved a new record of 53% of energy demand provided from wind energy (59% with wind and solar). Following this record, Ireland is in second place, providing 35%, with Portugal at 26% and the UK at 25%.
- Portugal reported a record instant share of wind of 110% for one hour and 76% throughout the day. Greece hit a record of 83% instant share of wind.
- The EU and UK achieved a record of 16% of their demand from wind power, which is equal to almost 490 TWh.
- Sweden surpassed 30 TWh to reach a 24% share of wind. Meanwhile, the Netherlands generated 20 TWh to reach an 18% share of wind. Greece surpassed 10 TWh to reach 20% share of wind.
- Significant increases in generation were recorded in the three countries surpassing a 10% share of wind: Finland (40%), Norway (25%) and the U.S. (15%). China increased generation by 15% to reach 756 TWh, close to 9% of demand by wind.

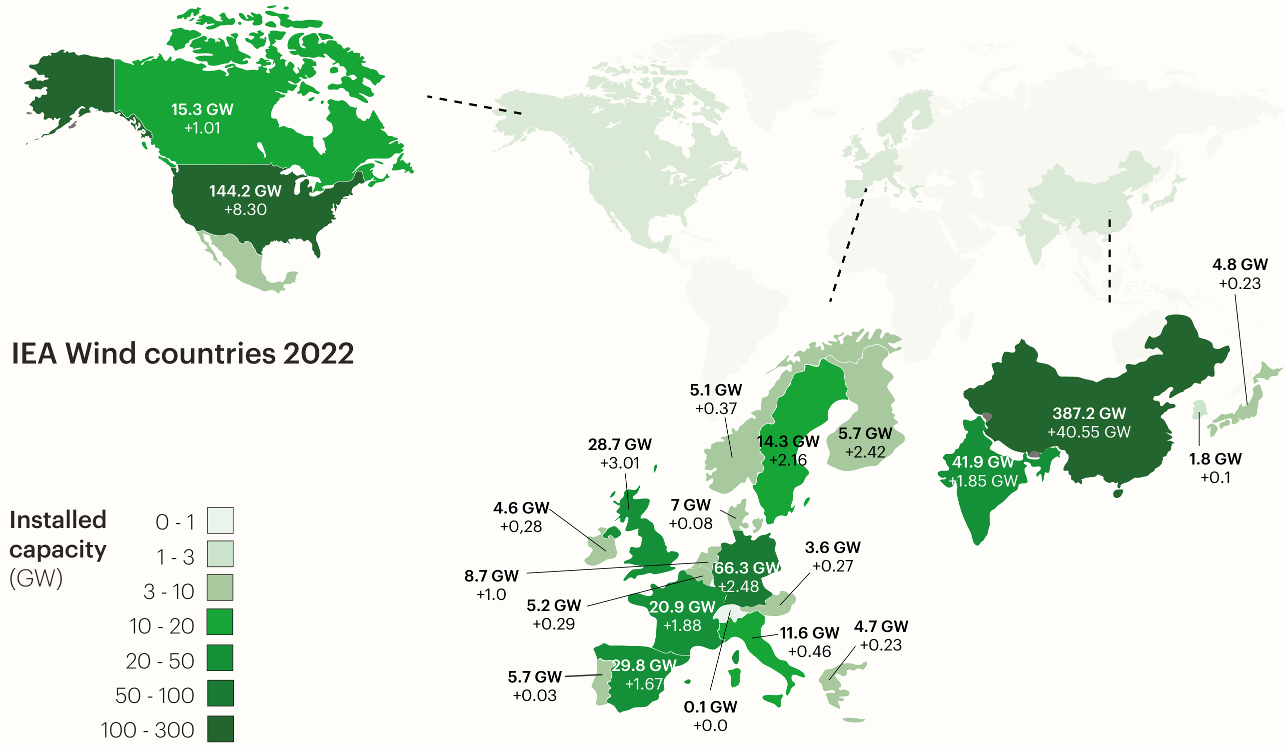


Figure 1. Total installed wind power capacity by the end of 2022 in IEA Wind TCP countries.

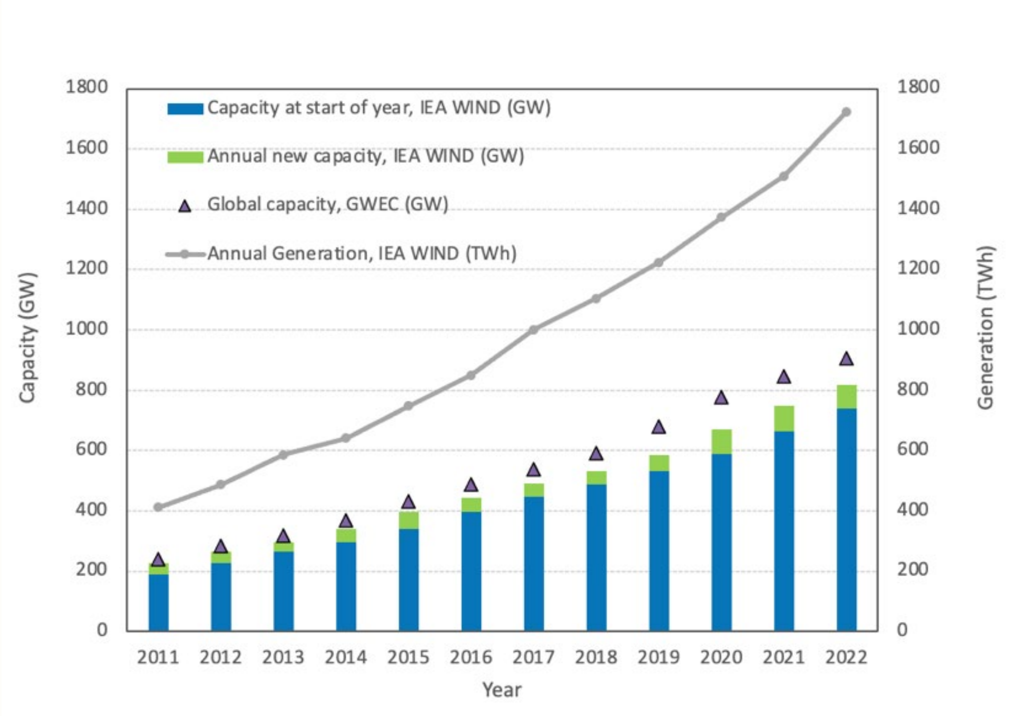


Figure 2. The trend of wind deployment for 2011-2022 in IEA Wind TCP countries and globally. *(Note, Mexico is included in IEA Wind TCP up until 2020).*

Offshore Wind Increasing Momentum Also for Floating Projects

The installation of offshore wind power increased by 9 GW globally, all of which was installed in IEA Wind member countries, where 5 GW was installed in China and 4 GW in Europe. Floating wind is seeing first projects and significant targets and share of the offshore areas designated by countries for future deployment.

Reported Offshore Projects Under Construction in 2023:

- In France, 2 projects are under construction and expected to be commissioned in 2023, as well as 3 projects projected for 2025.
- In the Netherlands, 1.5GW and 0.8GW are under construction and expected to be commissioned in 2023.
- The world's largest floating offshore wind farm Hywind Tampen, in Norway, delivered its first power in 2022, generating 88 MW.
- Germany currently has 86 MW under construction and another 5.6 GW approved by planning entities.
- In Korea, the 100 MW Hallim project is under construction. The project is expected to be commissioned in 2024.

Auctions and tenders for a pipeline of offshore projects were completed or announced in 2022:

- The UK has reported projects worth 20 GW in offshore capacity that have secured financing, with an additional development pipeline of 40 GW. Offshore wind ensured almost 7 GW of the fourth Contracts for Difference (CfD) scheme at a record-low price of £37/MWh (€43 /MWh; $46/MWh) (2012 prices). Option agreements in the ScotWind leasing round saw 20 projects totalling 27.6 GW awarded. Around 17 GW was for floating wind, equalling more than half of these projects.
- In the Netherlands, 1.4 GW permits were issued in 2022, and an additional 2x 2 GW are planned for 2023.
- Germany announced yearly auctions for both state-run pre-assessed and not pre-assessed areas.
- France is continuing its 1 GW per year offshore tenders (bottom fixed and floating).
- In Denmark, auctions are planned for 9 GW of offshore wind in 2023.
- In Finland, the first auction result for public areas offshore was announced in 2022 for the 1.3 GW Korsnäs wind power plant. After which, two tenders per year are planned in 2023 and 2024, plus one additional to reach a total of 6 GW. Finland's offshore wind project pipeline had a total of 13 GW at the end of 2022, and the first 1.3 GW had completed the environmental impact assessment.
- In the U.S., two milestone auctions of 11 leases for offshore wind areas were completed: Six allocated to New York and New Jersey and five allocated to offshore California, the first in the Pacific region. Current offshore wind projects in development are led by four states: New York with 4.2 GW, New Jersey with 3.8 GW, Massachusetts with 3.2 GW, and Virginia with 2.6 GW.
- In Norway, exclusive rights to the first four offshore projects will be given in 2023, ranging between 3 – 3.7 GW for three floating and one bottom-fixed offshore projects.
- Portugal is working towards an offshore target of 10 GW and an announcement of an auction or similar scheme in 2023. Additional offshore auctions in Spain and Greece are anticipated.

Offshore areas designated for future deployment:

- China has designated five offshore bases.
- A European cooperation was declared for the North and Baltic Sea offshore grids. Denmark, Belgium, Germany, and the Netherlands agreed to jointly develop 65 GW of offshore wind by 2030 and aim to implement a total of 150 GW by 2050 in their North Sea territories. Furthermore, eight Baltic Sea countries agreed to increase the offshore wind capacity sevenfold, from 2.8 GW to 19.6 GW by 2030.
- Plans for energy islands advanced in Denmark, Germany, Belgium, and the Netherlands. The aim is to create hubs that can facilitate

Highlights of Installed Offshore Wind Capacity in 2022:

- The UK set a record by adding 2.7 GW, bringing its total offshore wind capacity close to 14 GW. Additionally, the Hornsea 2 was fully commissioned, making it the world's largest operational offshore wind farm at 1.3 GW.
- France also set a record by adding 0.5 GW, inaugurating its first commercial-scale offshore wind power plant in Saint Nazaire.
- Both Italy and Japan commenced operation of their first offshore wind power plants: Italy with ten 3 MW units and Japan with fourteen 4.2 MW and twenty 4.2 MW fixed-bottom offshore power plants.

Photo: DTU Wind

more efficiency between energy from offshore wind and the energy systems in the region.

- In the U.S., ten states have set offshore wind procurement targets totalling more than 81 GW.
- In Korea, Electricity Business Licences for offshore wind are increasing. The aim is to develop more than 20 GW spread between 70 locations at the end of 2022. Only a few have already received permits.
- In Canada, the province of Nova Scotia announced a target to offer leases for 5 GW of offshore wind by 2030, and regional assessments of offshore wind in the provinces of Nova Scotia and Newfoundland Labrador were initiated.
- Many offshore wind projects in Italy, totalling more than 100 GW are at different authorisation stages. Additionally, the Maritime Spatial Plan will be published in 2023.
- In Spain, the Maritime Spatial Plan has been accomplished with a target of 3 GW in floating offshore projects.
- Swedish government agencies were commissioned to identify new areas for an additional 90 TWh of annual electricity production at sea, with results expected in spring 2023. A decision to remove offshore grid connection costs made by the previous government has been abandoned by the new government in 2022.

Wind Energy Plays a Critical Role in National Climate Targets

Carbon neutrality targets set in most countries are pushing electrification incentives of industry, transport, and building sectors, creating demand for additional renewable power capacity. Wind power is one of the primary means to achieve decarbonisation goals.

Russia's invasion of Ukraine created a powerful incentive for Europe to accelerate its shift away from imported fossil fuels and reduce its dependence on Russia. With growing concerns for security and strengthened commitments to climate neutrality on the global agenda, the events of 2022 have generated greater urgency to accelerate wind energy deployment. This has resulted in increasing targets for renewables, including wind power, aiming for significant progress by 2030.

- In the U.S., a new target to deploy 15 GW of floating offshore wind capacity by 2035 was announced, adding to the target of 30 GW in offshore wind capacity announced in 2021.
- In China, the 14th Five-Year Plan for the Development of Renewable Energy was formulated in June 2022, where new targets aim to double wind and solar energy generation, with more than 300 GW of wind power to be constructed in the five years.
- In Europe, a revision of the Renewable Energy Directive has led to a new renewable energy target of 42.5% in the EU by 2030, an increase compared to the previous 32%. It is furthermore supported by the GreenPowerEU plan. The EU targets have more than doubled from 204 GW today, to 510 GW in 2030. Regarding offshore wind capacity, its current level of 18 GW is aimed to become at least 60 GW by 2030.
- Germany is determined to reach its ambitious 160 GW land-based wind power target by 2035, as well as 30 GW in offshore wind power, which is more than triple the current wind capacity.
- In the Netherlands, an accelerated target of 28 GW for both on- and offshore wind was announced for 2030. Offshore wind is projected to grow from its current 2.5 GW to 21 GW in 2030, 50 GW in 2040 and 70 GW in 2050.
- In France, government law for acceleration of renewables was drafted (approved in 2023) and target of 40 GW land-based and 40 GW offshore wind power in 2050 was announced.

Photo: Simon Rubin / DTU Wind

- Norway's government announced its goal to allocate offshore areas for deploying 30 GW of wind power by 2040.
- In Denmark, dramatic offshore wind development was announced, which aims to install 36 GW by 2050. 9 GW in offshore capacity is planned to be auctioned by 2030 to quintuple domestic offshore wind capacity from its current 2.3 GW.
- The UK announced its goal to install 50 GW of offshore wind energy in its waters by 2030 instead of the initially proposed target of 40GW.

Repowering Expected to Increase

An increasing proportion of currently installed capacity will reach its end of life between 2022 and 2030. So far, the decommissioned capacity reported remains at a relatively low level. In Europe, 454 MW was decommissioned in 2022, enabling 591 MW repowering, mainly in Germany and Austria. In China, 604 turbines (930 MW) were decommissioned in 2022.

- In Portugal, an estimated 10 GW of additional capacity may be achieved by repowering existing wind power plant sites. New regulations to enable repowering of these sites are underway.
- In Denmark, decommissioning and repowering of the old wind turbine fleet is considered in the plans to substantially expand onshore wind.
- In Italy, repowering is included in the auctioning system.
- Spain is anticipating 10-15 GW of repowering in the next decade.

Performance Gains from Wind Technology Improvements

The trend favouring larger turbines continued in 2022. Capacity factors saw improvements and cost reductions from auctions have brought an increasing amount of subsidy-free wind projects through power purchase agreements.

Photo: Witold Robert Skrzypinski / DTU Wind

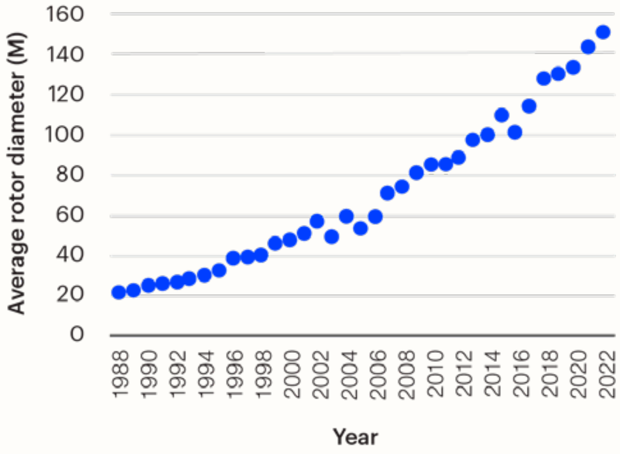


Figure 3. Rotor diameter trend.

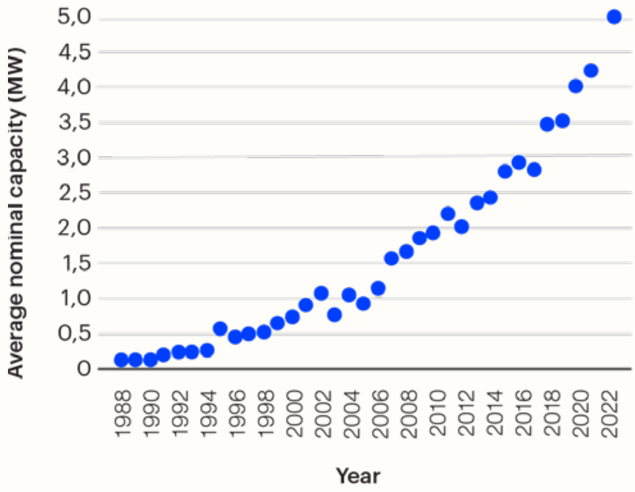


Figure 4. Nominal capacity trend.

Turbines and Wind Farms Continue to Increase in Size

The average power rating of new onshore turbines in Europe remained at the same level as the previous year: 4 MW for land-based and 8 MW for offshore turbines. However, this is anticipated to increase in 2023, as the average power rating of onshore turbines ordered in 2022 was 5.1 MW for land-based and 12.2 MW for offshore turbines. This is based on disclosed wind turbine orders.

In Finland, the Netherlands and Sweden, the average size of new land-based turbines in 2022 surpassed 5 MW. In Canada, Germany and the Netherlands, the average size surpassed 4.5 MW, and China reached 4.3 MW for new land-based capacity. In Italy, a turbine of 5.7 MW was erected, making it the world's largest onshore turbine.

A report detailing the trend in increased turbine sizes can be found in the country chapter for Sweden.See figure 3 (Rotor diameter trend) and figure 4 (Nominal capacity trend).

Also the size of both offshore and onland wind power plants is growing. In Canada, six of the seven land-based projects installed in 2022 had capacities of greater than 100 MW.

Improved Technical Performance Leads to Higher Capacity Factors

Technological advancements in taller turbines and longer blades drive the long-term trend of improved performance.

2022 was furthermore characterised by a higher wind resource than the previous year in Nordic countries, Germany, and the UK, while it was lower than average in France and Spain.

Increased capacity factors in 2022 for land-based wind turbines reached almost 35% in Norway, 33% in Finland, and 30% in Canada. High capacity factors for the offshore fleet were recorded in Denmark, measuring 43% and 41% in the UK.

Cost Reduction Trends Show Signs of Reversing Rue to Inflation

The cost reduction trend for wind energy was still reported from the UK offshore auctions in 2022 (See previous section). However, inflation and the cost of materials have impacted the cost of wind turbines, as well as costs for other energy technologies. The lowest costs reported in recent years may not be reached in the near future. However, future cost reductions are still anticipated [2] and remain targets in R&D, especially for floating offshore wind.

The success of cost reductions has also enabled corporate Power Purchase Agreements (PPAs) and opportunities to build wind power outside of subsidy schemes (so-called merchant markets), mainly prominent in Finland, Spain, and Sweden.

In Europe, wind energy secured 16.9 GW in 15 countries, surpassing the figure of 12.4 GW that was allocated in 2021. 9.5 GW was awarded to offshore wind in the UK, Germany, and the Netherlands, and 7.4 GW of onshore wind was awarded in the following 15 countries:

- Germany awarded 3.23 GW for onshore wind projects from a total available capacity of 4.57 GW through technology-specific auctions. The average capacity-weighted award value for onshore wind was €58.3/MWh ($63/MWh), just below the maximum permissible value of €58.8/MWh ($63.5/MWh).
- The UK awarded almost 1.5 GW for onshore wind, all in Scotland: 0.9 GW at £42.47/MWh (€49.8/MWh; $53.5/MWh), and 0.6 GW

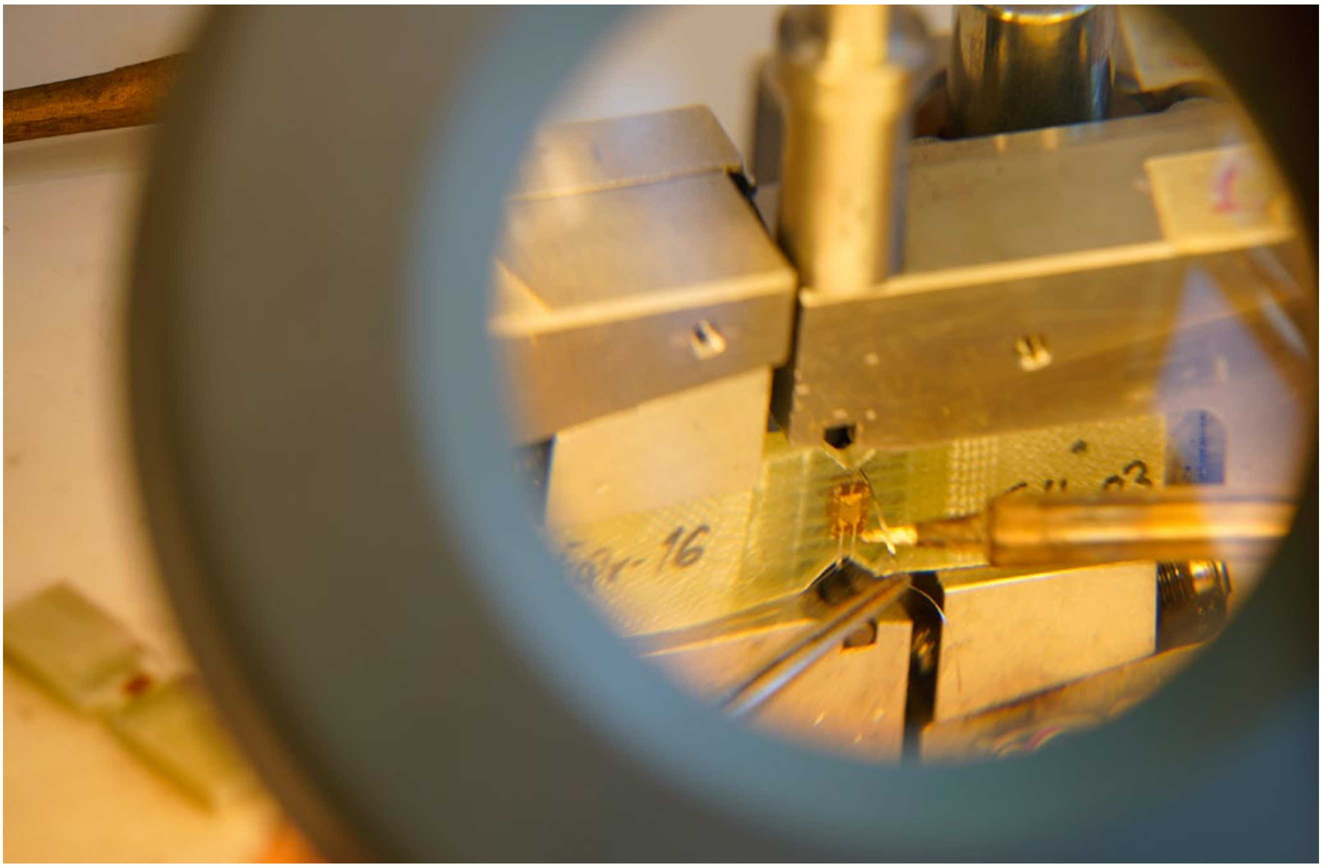


Photo: Simon Rubin / DTU Wind

for onshore remote island wind at £46.39/MWh (€54.4/MWh; $58.43/MWh).

- France's first rounds of auctions in 2022 secured 0.3 GW of onshore wind capacity at €67.5/MWh ($72.9/MWh) and less than 0.1 GW at €76/MWh ($82.1/MWh). The tenders were undersubscribed and, therefore, didn't reach the 1 GW that was expected.

- Ireland awarded 0.4 GW of onshore wind capacity via the second edition of its technology-neutral Renewable Electricity Support Scheme, with a weighted average price of all successful bids, also for solar PV as well as community projects, of €97.9/MWh ($105.8/MWh).

- In Italy, three joint tenders for onshore wind and PV resulted in 231 MW wind capacity awarded, constituting 28% of the total capacity awarded. In addition, 105 MW from small plants (Capacity < 1 MW) signed up in registers. A new decree defining the renewable incentive mechanism is expected to be published and implemented in 2023.

- Greece awarded 166 MW in onshore wind in its technology-neutral auction with an average price of €57.7/MWh ($62.3/MWh).

- In Spain, only 46 MW of wind was successful in auctions in 2022, of a possible 1.5 GW. The auctions were undersubscribed due to a meagre cap price, which didn't account for the impact of inflation on wind turbine costs.

Overcoming Policy and Deployment Barriers

Permitting and global supply chain issues have slowed the estimated growth in many countries. Policy actions can often help overcome or even remove these barriers. The main activities to remove barriers reported in 2022 include speeding up permitting procedures and increasing social acceptance.

Photo: DTU Wind

Photo: Alexander Rietz Vesterhauge / DTU Wind

Speeding up permitting by simplifying the authorisation procedures is required.

Seeking Ways to Improve Public Acceptance

Social acceptance continues to be a key constraint on the development of wind energy projects, and thus, increasing public acceptance will help member countries meet their renewable energy obligations. More on this subject is explained in IEA Wind TCP Task 28, which focuses on social acceptance of wind energy, and Task 34, through studies conducted on environmental impacts in several countries.

Wind energy generally has a strong public acceptance rate in the conducted surveys. For example, in 2022, according to an energy attitudes survey in Finland, 82% of Finns support increasing wind power. Additionally, wind energy receives high levels of public support in national energy attitude polls in Austria and Switzerland. However, public acceptance of onshore wind power has been an issue in Norway for several years. Furthermore, Korea reports low acceptance attitudes for land-based and fixed-bottom offshore wind power.

Opposition to any new wind power plant proposal is often found in local communities, even if the general public is supportive. Local communities appealing against the construction of wind energy facilities may take years to resolve. However, such legal cases could be avoided by involving these communities during the project planning stage and offering them the opportunity to participate in the investments. Evidence for this approach can be found in Finland, where the property tax from wind power plants for small municipalities has received positive publicity.

Mitigating Administrative Barriers

To achieve the new ambitious wind energy targets set for 2030, the EU and individual nations such as Austria, Belgium, Germany, Greece, Italy, Ireland, and Sweden are demanding measures to speed up permitting by simplifying the authorisation procedures. Mitigation possibilities reported include:

- **Renewables as an overriding public interest and fast-tracking:** The EU agreed to emergency measures in 2022, known as the REPowerEU Plan, where renewables are of overriding public interest. It allows Member States to fast-track renewables permitting while ensuring a good working balance with other societal interests such as biodiversity protection. The emergency measures will remain in place until the revised Renewable Energy Directive is transposed into national legislation. In Germany, the new summer package aiming for significant increases in renewables has launched the principle that the use of renewable energy is in the overriding public interest and serves public security.

- **Setting regional targets:** In Germany, the new "Wind Energy Area Requirement Act (WindBG)" aims to allocate defined areas of the German territory to onshore wind turbines by 2032, distributed over the Federal States in between 0.5% and 2.2%. Regional and local targets have also been reported as mitigation measures in Austria, Greece, the Netherlands, Sweden, and Switzerland.

- **A "one-stop-shop"** for simplifying and expediting licensing procedures has mitigated the complexity of permitting procedures in Belgium, France, and Sweden and is being adopted for offshore wind in the Netherlands. Furthermore, the authorities' involvement in overseeing permitting procedures has been a long-standing requirement in the Netherlands. However, it remains a tedious process. Overcoming barriers such as radars and grids, especially in densely populated areas, requires careful coordination with stakeholders to maintain the growth of renewable energy production onshore. Ambitious targets for offshore wind in energy and climate strategies are accompanied by streamlined

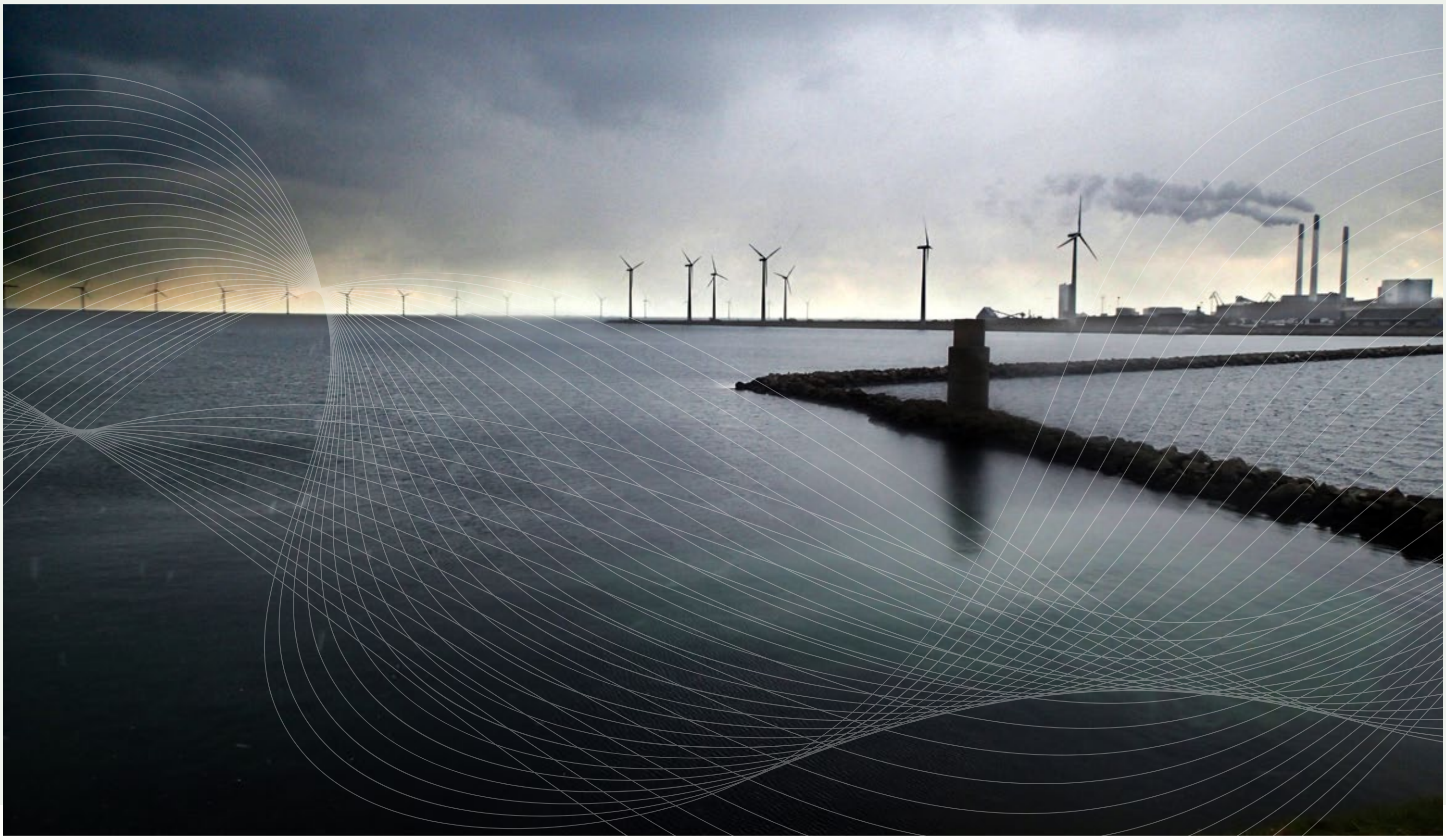


Photo: DTU Wind

processes and consenting time reduction for projects in the UK, Germany, Ireland, and Italy.

- **More funding for administration to speed up permitting**. In Finland, additional funding was allocated in 2022 for planning, licensing and studies guiding wind power construction in municipalities and regional councils. In Greece, the first phase of measures to reduce permitting from over seven years to two years included an additional workforce that facilitates information flow between authorities and systems to speed up the permitting process.

In Norway, the UK, and the provinces of Newfoundland and Labrador in Canada, previous stops for onshore wind have been revisited to re-open the process.

In Finland, radar surveillance interference has limited the country's Eastern part to very few wind power projects. A government report produced potential solutions using active and passive sensor systems, including airborne surveillance capability and a phased approach developing one area at a time.

Furthermore, spatial planning limitations and lack of eligible wind zones are reported from Austria, Belgium, Germany, Italy, and the Netherlands.

- Distance regulations, height limits near airports and turbine lighting are issues that have been reported as barriers to continued development. Updates to regulations have been reported to mitigate the issues and allow for larger turbine sizes to be deployed.

- 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. Additionally, new projects are starting to move to areas like the desert with less population. The first 97 GW batch will be put into operation in 2023, while construction has begun on the second batch of about 350 GW. A project list for the third batch will be released for implementation soon. Local wind power development for industrial parks, development zones, mining and rural areas is widely promoted.

- Italy adopted a new accelerated authorisation process for onshore and offshore wind plants in 2022. More policies, regulations, and adoption of processes are expected in 2023, which is a similar reform for ongoing licensing processes in Greece. In Portugal, new legislation is expected to define go-to areas and accelerate the permitting procedures for renewable energy projects.

Photo: Alexander Rietz Vesterhauge / DTU Wind

Supporting Investments and Competitiveness in Electricity Markets

Incentivising wind power investment has been a primary tool used to improve deployment. Government-backed revenue stabilisation mechanisms are still the preferred support scheme for the industry, but corporate renewable PPAs continue to play a growing role in financing wind energy projects.

Competitive auctions have proved to be efficient in lowering the cost of wind energy. However, the results are challenged by the increasing prices of commodities, too few sites developed due to long permitting, and have resulted in undersubscribed auctions, as seen in Italy, Germany, and Greece. These challenges made the respective bid price ceilings too low to cover the increased costs, making projects uneconomical. Auctions are considering implementing criteria other than solely price to reduce manufacturers' likelihood of operating at a loss due to high material prices and disturbed supply chains. These criteria could include risk assessments; minimising environmental issues; or support to grid. and have been discussed in Denmark, Germany, and the Netherlands. To tackle the impact of inflation, government support should be fully indexed to inflation to protect developers and the supply chain from significant increases in project costs.

In Europe, in 2022, investment decisions in new wind projects were strongly impacted by uncertainty in electricity market interventions, rising inflation rates, interest rates, and increased risk margins. National governments introduced emergency measures in good faith to protect consumers from high energy prices. However, these measures undermined generator revenues, and the discoordination between them led to a patchwork of different market interventions. This highlights that government action is still needed to ensure investors' confidence, especially during regulatory changes. Some positive government actions include the following:

- In the U.S., two new federal laws ushered in significant funding and support for U.S. wind energy, including production extensions and investment tax credits.
- In the UK, CfD rounds would now be held on an annual basis instead of every two years. Additionally, a new leasing round was announced, aimed at renewable energy that directly powers existing oil and gas assets and supports small-scale innovative offshore wind projects.
- In the EU, the Green Deal Industrial Plan was agreed on to enhance the competitiveness of Europe's net-zero industry and accelerate

the transition to climate neutrality, as well as ensuring sufficient access to identifying goals for net-zero industrial capacity and providing a regulatory framework suited for its quick deployment and ensuring sufficient access to critical materials, like rare earths, that are vital for manufacturing key technologies.

Building a unified market fit for investment in renewables is essential. Wind energy has proved to be a hedge against high prices in electricity markets. This became evident when electricity prices soared in 2021- 2022, and wind energy helped reduce price peaks. In Spain, wind generation during high market prices in 2022 increased the value of wind to electricity system, in 2021 this was estimated to be 4,757 million EUR (5,413 million USD).

Grid Integration and Adequacy of Transmission Infrastructure

The significant increase in wind capacity necessitates a corresponding optimisation of the grid, both onshore and offshore. Grid bottlenecks and ways to mitigate them are reported from:

- The U.S., where delayed approvals for grid interconnections have become a deployment barrier. At least 247 GW of wind capacity, nearly one-third of which is offshore wind, is awaiting interconnection at the end of 2021. The U.S. Department of Energy (DOE) has launched several programmes to mitigate the grid barrier, including the Interconnection Innovation e-Xchange, which aims to develop solutions for faster, simpler, and fairer interconnection of clean energy resources.
- The UK, where grid reinforcements are needed for the ambitious targets for wind, in addition to plans and ongoing work for Power to H2.
- Denmark, where grid and interconnectors were added to deal with additional wind, as well as a support scheme for renewable hydrogen.
- Finland, where the concentration of wind power projects on the Northern part of the West coast, is currently challenging the transmission system. The system operator is preparing for massive wind deployment on- and offshore in their transmission planning.
- Greece, where grid reinforcements are also proceeding for the islands, such as the Crete connection to the main grid, which had its first full year of operation in 2022.
- Portugal, where the grid connection barrier has been mitigated by defining measures to ease overplanting, repowering, and hybrid power plants, also hybridisation of existing wind power plants.

Increased electrification demand can help bring more local loads to the power system. However, it is a huge challenge to balance the growth of supply and demand in the transition process towards renewables. In the Netherlands, a coordinated supply and demand is being discussed which aims to collaborate with industry and the offshore energy landing programme, to avoid a situation where wind power will suppress prices to zero while waiting for the new demand to be built. In addition, industry and other sectors will have to make drastic changes to their type of energy consumption, for instance using electrical heating or heat pumps or switching to electrical mobility. Also, short- and longer-term storage need to be developed.

Wind energy has proved to be a hedge against high prices in electricity markets.

A signal of insufficient grid capacity and flexibility can be seen in the need to curtail wind energy:

- In China, a series of policies and regulations to reduce wind curtailment, in addition to large transmission upgrades, have been successful in reducing the curtailed energy to about 3% (25 TWh) in 2022, compared to more than 10 % (almost 42 TWh) in 2018.
- In Europe the curtailments in some countries show an increasing trend, as the shares of wind increase. However, in Italy, they have been reduced to 1.5% of wind energy generated, and Portugal still reports no curtailments even when about a quarter of demand is generated from wind energy. In Spain, the non-compensated (out-of-market operation) curtailment increased significantly in 2022. However, this still represents less than 1% of wind generation. Germany and the UK report 4-5% curtailments.

Allowing wind power plants to access markets for grid support, especially when part of the generation is curtailed, will help the balancing task of system operators, and provide revenue for wind power plants.

Impacts of Wind Energy Development

Securing energy supplies and meeting climate targets accelerate the continued development of wind energy worldwide and impact the economy, environment, and society. Geopolitical pressure and national priorities impact global supply chains, reshore critical components and create local jobs. The sector strives to lessen the carbon footprint of the technology and to commission it with the least impact on the environment as possible.

Photo: Simon Rubin / DTU Wind

Economic Impact and Jobs

Wind energy employment is set to shift dramatically as countries and companies accelerate their efforts to comply with the ambitious new climate goals. In the context of the global energy crisis and the war in Ukraine, governments and industry rethink their global supply chain and reshore critical components and materials [1].

The construction of new projects, including the manufacture of their components, is the largest driver of energy employment across the value chain. The sector requires higher-skilled workers than other industries and this share is even higher for jobs in research and development for new energy innovations, many of which are anticipated to increase rapidly towards 2030 [3]. The Global Wind Energy Council expects 1221 GW of new capacity to be added from 2023-2030 [1]. This will create jobs throughout the lifetime of the wind energy plants, from project planning to manufacturing to operations and, maintenance and decommissioning. Furthermore, it will encompass a variety of technical and professional skills. The emerging clean energy industries will require an even larger share of skilled employees, which will require new programmes of education, certification, and vocational training as well as targeted upskilling or reskilling training programmes for the existing workforce [4].

In a situation where China dominates the global supply chain for various components and materials, many countries and global industries intend to create a more regional balance between the supply and demand of wind energy technologies. This aims to foster local development and job creation and increase their ability to deliver on ambitious climate and security goals [3,4].

A recent U.S. study outlined the required workforce for the offshore wind energy industry. It offered guidance on actions to meet workforce demand, including detailed assessments of education resources and prioritising training for the sector's most immediate needs. Another U.S. multi-year study identified experience, geography, and hands-on training as critical factors in the gap between the available wind energy workforce and that needed to keep pace with industry growth.

Climate and Environmental Impacts

Due to the extensive planned expansion of offshore wind in Northern Europe, the necessity for strategic environmental screening of those areas is becoming increasingly crucial. For example, the Danish Energy Agency has commissioned a strategic environmental screening of offshore wind in Danish waters. The study will collect the necessary environmental data and map the areas potentially vulnerable to large-scale offshore wind, including the cumulative impacts of offshore wind energy, and support the long-term planning and decision-making of large-scale offshore wind in Denmark.

A recent scientific study found that the potential long-term impacts of offshore wind energy on biodiversity, specifically fish communities, remain uncertain [5]. However, ongoing research continues to gather novel data regarding offshore wind farms' effects on marine environments as well as knowledge of suitable management plans to mitigate conflicts between offshore wind farms and other ocean users.

France Energie Eolienne published a report about wind power and biodiversity in the context of France [6]. It showed that the "wind power industry is fully aware of its impacts on biodiversity" and that "wind companies are already applying their resources towards mitigating their impacts". In addition, several research projects focus on the impact of wind turbines, such as MIGRATLANE, MAPE, SEMMACAPE, ECOSYSM-EOF, ORNIT-EOF.

The German Nordex Group published two new LCAs for the Nordex N155 and N163 turbines, demonstrating the low environmental footprint of onshore wind turbines' energy generation, emitting only 5.5 and 2.7 grams of CO2-equivalent per kWh, respectively.

Value of Research, Development, and Demonstration

Along with market incentives, wind energy RD&D is a key driver in reducing GHG emissions, developing affordable, resilient energy systems and creating jobs and prosperity across the entire supply chain.

Photo: Yifu Wu / Unsplash

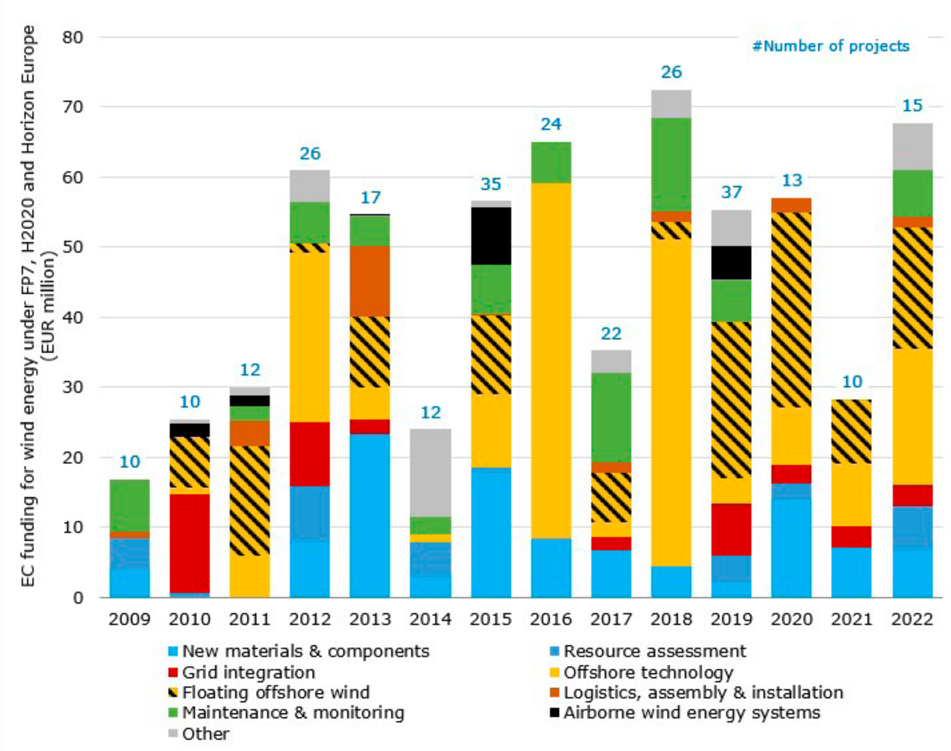


Figure 5. Development of R&I funding in 2009 – 2022 under the Horizon Europe funding programme and its predecessors, FP7 and H2020. With 29% of EC funding (19.5 million EUR (20.9 million USD)) granted to wind energy projects starting in 2022 focused on offshore wind technology research, followed by floating offshore (17.4%) and New materials and components (7%).

National RD&D Funding and Initiatives

In 2022, China accomplished a new record in public energy RD&D, which reached nearly 44 billion USD (40 billion EUR). 80% of which was devoted to clean energy topics [7]. Among IEA member countries, the U.S. invested the most in energy RD&D, followed by Japan, France, Germany, the UK and Canada. The data also includes the EU's energy RD&D budget under its Horizon 2020 programme and its Innovation Fund.

All major economies invest heavily in developing climate-neutral energy systems in which wind energy plays an important role. Most often, these investments combine market pull and technology push incentives with an increasing focus on local job creation, competitiveness, and protection of critical infrastructure:

- In the EU, the 20 billion EUR (21 billion USD) RePower package is expected to boost the European industry while achieving energy and climate goals. Efforts are also being made to reduce dependence on critical minerals and rare earth elements. For over two decades (2009-2022), the wind energy RD&D has been financed under Horizon Europe and its predecessors FP7 and H2020. The figure illustrates the priorities of these investments with projects on offshore wind (186 million EUR; 201 million USD), floating offshore wind (132 million EUR; 142 million USD) and new materials components (105 million EUR; 113 million USD). See figure above.
- In 2020, Japan published its First Vision for Offshore Wind Power Industry, and its designated seabed areas have been identified. The Ministry of Economy, Trade and Innovation (METI) supports this vision through the Green Innovation Fund over a period of ten years with a first phase investment of 282 million USD (261 million EUR) and a second phase with 694 million USD (642 million EUR). The overall goal is to lower the costs of offshore wind, covering next-generation wind turbine technologies, Manufacturing and installation of floating foundations, wind power operation maintenance and demonstration of floating offshore wind.
- The UK has a portfolio of RD&D programmes to accelerate offshore wind energy and hydrogen. Its programmes include the Department for Business, Energy, and Infrastructure Floating Offshore Wind Demonstration Programme (31.6 million GBP; 36.8 million EUR; 40 million USD) and matched by the industry), The Net Zero Hydrogen Fund (worth up to 240 million GBP; 280 million EUR; 302 million USD) and other initiatives. The Offshore Wind Sector Deal from 2020 brings together government and industry to develop supply chain growth, system integration, skills, and future workforce.
- The U.S. Infrastructure Investment and Jobs Act (IIJA) of late 2021 provides more than 100 million USD (92 million EUR) to wind energy

Photo: Alexander Rietz Vesterhauge / DTU Wind

projects covering onshore, offshore, and distributed wind energy systems, advanced manufacturing, grid integration and wind system recycling. This is complemented by the Inflation Reduction Act, which provides a variety of tax and investment credits for renewable energy. These provide, for example, bonus tax credits for wind energy projects developed in communities that historically have been economically dependent on fossil fuels and manufacturing investment tax credits for domestic clean energy technologies and components.

- The 14th Chinese Five-Year Plan (2021-2025) focuses on developing offshore wind turbines, including 10 and 15 MW floating wind turbines and 20 MW offshore wind turbines.

Research Initiatives and Results

Member countries highlight key topics driving ongoing and future RD&D activities, many of which are designated as national priorities. The highlights of national and cooperative projects below show the variety in RD&D activities. These are grouped according to the four IEA Wind strategic areas:

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

Resource, Site Characterisation and External Conditions

- **The Finnish project TUTTE** (Wind power production and efficiency) focused on wind farm efficiency, wakes, and contribution of surrounding terrain and atmospheric icing in Finland. The dataset showed that a given wind turbine would be operating with clean inflow between 31–65% of the time, 20–26% of the time affected by a single wake, and the rest of the time affected by two or more wakes. Most icing seemed to occur at temperatures close to 0°C and wind speeds below 7 m/s.

- **The Swiss EPFL MaxWep project** explores the potential of wind resources in complex terrain during wintertime in Switzerland. A wind resource assessment method is

Figure 6. The Dutch MuteSkin.

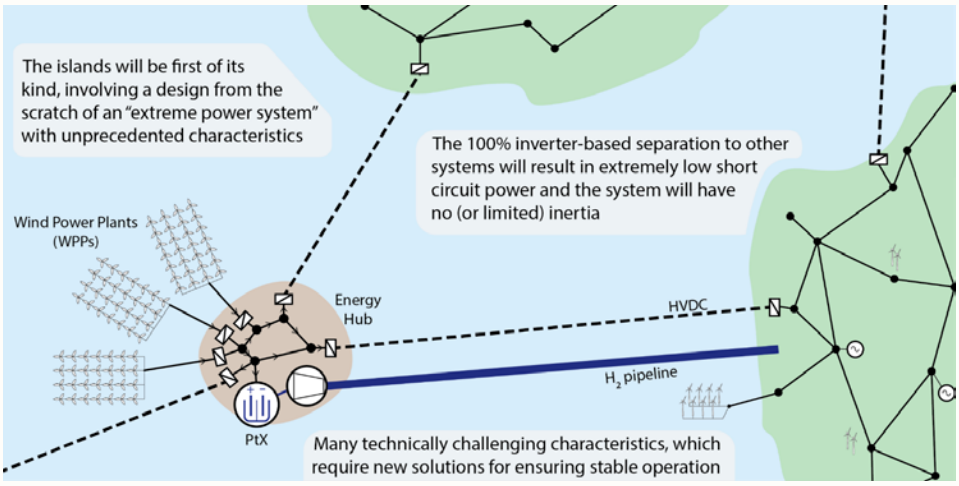


Figure 7. Offshore Energy Hubs.

developed based on short-term wind profile measurements with a wind lidar, long-duration meteorological station measurements, which are connected via machine learning to a specific site. Driving a high-resolution numerical weather model (WRF) with the COSMO model as an input, a map of the spatial pattern of the local wind speed potential for short episodes of predominating weather patterns was created.

- **The American WAKE experimeNt** (AWAKEN), launched in 2022, is an immense effort to capture precise data on how winds shift as they travel from one wind turbine to another or from one wind plant to another. The data is expected to help facilities produce more energy from the same winds, increase profits, and eventually reduce consumer electricity prices.

Advanced Technology – Components

- **The Chinese low-noise wind turbine technology** was developed by Yangzhou University, NUAA, Gold Wind, MYwind, Chinawindey, Shanghai Electric and CGC. The project also improved the wind turbine aerodynamic noise source model, developed the PE noise propagation models in complex terrain and researched coupling methods of PE models and CFD in complex terrain.

- **The Dutch MuteSkin** is a new type of blade extension to further reduce wind turbine noise. The MuteSkin blade extension can achieve 6 dB in noise reduction compared to the current 3 dB. The blade add-ons have anisotropic permeability that reduces turbulent-boundary-layer trailing-edge noise. This extra noise reduction opens the possibility of installing wind turbines closer to housing areas. See figure 6 above.

- **The German AgileDataDev** developed system engineering guidelines for optimising the product development process in the [wind turbine] industry by integrating agile methods and data-based assistance. Achieved benefits include the increase in effectiveness by specifically addressing requirements, the improvement of efficiency by reduction of unintended iteration steps, the provision of data-based decision support, and the decrease of time-to-market and improvement of market-fit of products.

- **The UK Joule Challenge Phase 2** is working towards proving that composite materials can deliver significant performance and light-weighting opportunities essential to addressing the technical challenge of developing the next-generation wind turbine platform beyond 20 MW.

Advanced Technology – Offshore Wind

- **The Danish Offshore Energy Hubs** (OEH) develops technical solutions addressing several aspects of Energy Islands: a) Tools and control solutions for stable and resilient hub operation, b) cost-efficient design of wind power plants (WPPs), and c) hub-optimised offshore Power-to-X (PtX). The value creation of the OEH-solutions is both direct and indirect. The developed solutions can potentially reduce capital costs by 20 billion DKK (3 billion USD; 3 billion EUR) for an energy island of only 10 GW. Most importantly, it will enable a future-proof expansion of energy islands. See figure 7 above.

- **The EU NEXTFLOAT** project will demonstrate a competitive, sustainable, and integrated floating offshore wind solution optimised for deep waters and accelerate the industrial-scale deployment of floating offshore wind. The integrated solution relies on X1 Wind's floating offshore wind technology,

Photo: Simon Rubin / DTU Wind

which is a lighter floater design with a reduced steel requirement, as well as a more efficient and compact mooring system that can minimise the impact on the seabed.

- **The Norwegian NorthWind** Centre for Offshore Wind is managed by SINTEF and has 20 industrial and five academic partners. This 35 million EUR (38 million USD) centre was created in 2020 and will run for eight years. The overall aim of NorthWind is to bring forward outstanding research and innovation to reduce the cost of wind power and facilitate its sustainable development, which will grow exports and create new jobs.

- **The Italian R&D support program RdS** started a new three-year term, including wind-related research activities with a total budget of around 5 million EUR (5.4 million USD). As part of this, the National Research Council (CNR) is testing at the MaRELab sea test-site, the Hexafloat (Saipem patent) floating offshore wind turbine prototype, with different mooring configurations and materials, including synthetic chains. It has a scale factor of 1:6.8 concerning a 5 MW machine and hosts a 10 kW TN535 turbine.

Energy Systems with High Amounts of Wind

- **The American Interconnection Innovation e-Xchange** (i2X) enables a simpler, faster, and fairer interconnection of clean energy resources while enhancing the reliability, resiliency, and security of the electric grid. The programme is led by the U.S. DOE's Solar Energy Technologies Office and Wind Energy Technologies Office with the support of several national laboratories, including the Pacific Northwest National Laboratory, National Renewable Energy Laboratory, and Lawrence Berkeley National Laboratory. The i2X facilitates collaboration by conducting stakeholder engagement, data collection and analysis, strategic roadmap development and technical assistance.

- **The Canadian Electricity Transformation Hub** was launched by The Canadian Renewable Energy Association (CanREA) with funding from Natural Resources Canada. The Hub is intended to be a knowledge-transfer tool to support electricity utilities and system operators in accelerating their decarbonisation efforts, facilitating the integration of more significant amounts of wind energy, solar energy and energy storage needed to support electrification and Canada's net-zero GHG-emission targets.

- **The Norwegian SeaConnect** project focuses on high-voltage subsea connections for resilient renewable offshore grids. It will develop new materials and designs for the subsea components with the highest risk of failure in offshore power grids. It also aims at increasing the breakdown voltage and service life for subsea cable terminations and connectors.

Figure 8. US Carbon Rivers.

Social, Environmental and Economic Impact

- **The Dutch BeWild project** (Biodiversity Enhanced Wind Farm development, Integrated monitoring & inspection and Localised Design) aims to measure biodiversity at offshore wind farms. It focuses on developing innovative methodologies and technologies for remotely collecting environmental DNA (eDNA) samples in the North Sea. The project will develop remote marine eDNA collection, analysis, and interpretation capabilities as part of its remote inspection solutions. It will also integrate the eDNA sampling into its uncrewed surface vessels and remotely operated vehicles.

- **The Spanish Oceanic Platform of the Canary Islands** (PLOCAN) is a non-profit consortium located in Gran Canaria dedicated to science and technology in the marine and maritime sector in the region. Its mission is the cost-effective combination of services such as observatories, test beds, underwater vehicle support, information technology, training and innovation hub. Furthermore, the assessment of the acoustic impact of wind and tidal farms on marine life and the impact of sound on marine ecosystems from offshore wind generation.

- **The Swedish research programme VINDAL** launched three new projects on the environmental and social impact of wind energy. These included wind power and experience values in nature areas, wind power and unforeseen impacts on species and their habitats, and wind power, bats and birds in forest environments.

- **The U.S. project with the company Carbon Rivers** has achieved 99.9% recycled glass fibre purity from different end-of-life waste streams like wind turbine blades. The high-purity material creates the potential for remelting, allowing recycled glass fibre to be incorporated into virgin fibreglass, thereby closing the material loop and creating a circular economy. See figure 8 above.

Test Facilities and Demonstration Projects

- **The Wind Energy Institute of Canada** (WEICan), in collaboration with Nova Scotia Power Inc. and Enercon completed a study on the provision of ancillary services including power-frequency responses and automatic generation control (AGC) from IEC Type 4 turbines. Empirical data gathered at the 50.6 MW Nuttby Mountain wind farm in Nova Scotia was used to inform the analysis.

- In China, a 6.2 MW floating wind turbine was installed in sea water at 65 m depth in July 2022. In March 2023, the **China National Offshore Oil Corporation** (CNOOC) commissioned a 7.5 MW floating wind turbine in the sea water at a depth of 126 m, 136 km off the coast of Hainan Province.

- At **Østerild Test Center** in Denmark, the VESTAS V236-15.0 MW prototype wind turbine produced its first kWh power in December 2022.

- The **Norwegian Hywind Tampen** floating offshore wind farm was partially completed and delivered its first power in 2022. The 88 MW wind farm will supply five offshore oil platforms with approximately 35% of their annual electricity demand.

- **The French Open-C foundation** was founded in 2022 and is now coordinating all French test facilities:
  - The SEMREV test site on the Atlantic Coast, managed by Ecole Centrale de Nantes, involves a large number of academic and industrial partners.
  - The Mistral floating wind test site on the Mediterranean coast, developed by Valeco/EnBW, in cooperation with France Energies Marines.
  - The Saint-Anne du Portzic test site located near Brest dedicated to floating wind turbines (Eolink, Windquest) and wave energy systems (PH4S, Dikwe).
  - Other sites are Paimpol-Bréhat (Brittany) and Seeneoh (located on the Garonne downstream from Bordeaux) for the wave, currents, and tidal energy.

- In Aberdeen, ETZ Ltd and ORE Catapult will co-invest and collaborate in a 9 million GBP (10 million EUR; 11 million USD) National Floating Wind Innovation Centre, dedicated to accelerating the commercialisation of floating offshore wind throughout the UK. The initial focus of the centre will be digital simulation and modelling, moving to the testing and validation of the key components of floating structures.

A list of test and demonstration facilities in the IEA Wind TCP countries will be available as a Table in the data statistics.

Collaborative RD&D

Countries collaborate intensively in the IEA Wind Tasks, all of which play a part in the strategic priority areas:

Resource, Site Characterisation, and External Conditions	
Task 31	Benchmarking Wind Farm Flow Models (WAKEBENCH)
Task 44	Wind Farm Flow Control
Task 49	Integrated DEsign on Floating Wind Arrays (IDEA)
Task 51	Forecasting for the Weather-Driven Energy Systems
Task 52	Large-Scale Deployment of Wind Lidar
Task 53	Cold Climate Wind Power
Advanced Technology	
Task 30	Offshore Code Comparison Collaboration, Continued with Correlation and unCertainty (OC6)
Task 40	Downwind Turbine Technology
Task 43	Wind Energy Digitalisation
Task 46	Erosion of Wind Turbine Blades
Task 47	TURBulent INflow Innovative Aerodynamics (TURBINIA)
Task 48	Airborne Wind Energy (AWE)
Energy Systems with High Amounts of Wind Energy	
Task 25	Design and Operation of Power Systems with Large Amounts of Wind Power
Task 37	Systems Engineering
Task 41	Enabling Wind to Contribute to a Distributed Energy Future
Task 50	Hybrid Power Plants
Social, Environmental, and Economic Impact	
Task 28	Social Science of Wind Energy Acceptance (SoSWEA)
Task 34	Working Together to Resolve the Environmental Effects of Wind Energy (WREN)
Task 39	Quiet Wind Turbine Technology
Task 42	Wind Turbine Lifetime Extension
Task 45	Recycling of Wind Turbine Blades
Task 53	Wind Energy Economics
Communication, Education, and Engagement	
Task 11	Strategy, Collaboration & Outreach on Urgent Topics of Wind Energy Research (Wind SCOUT)

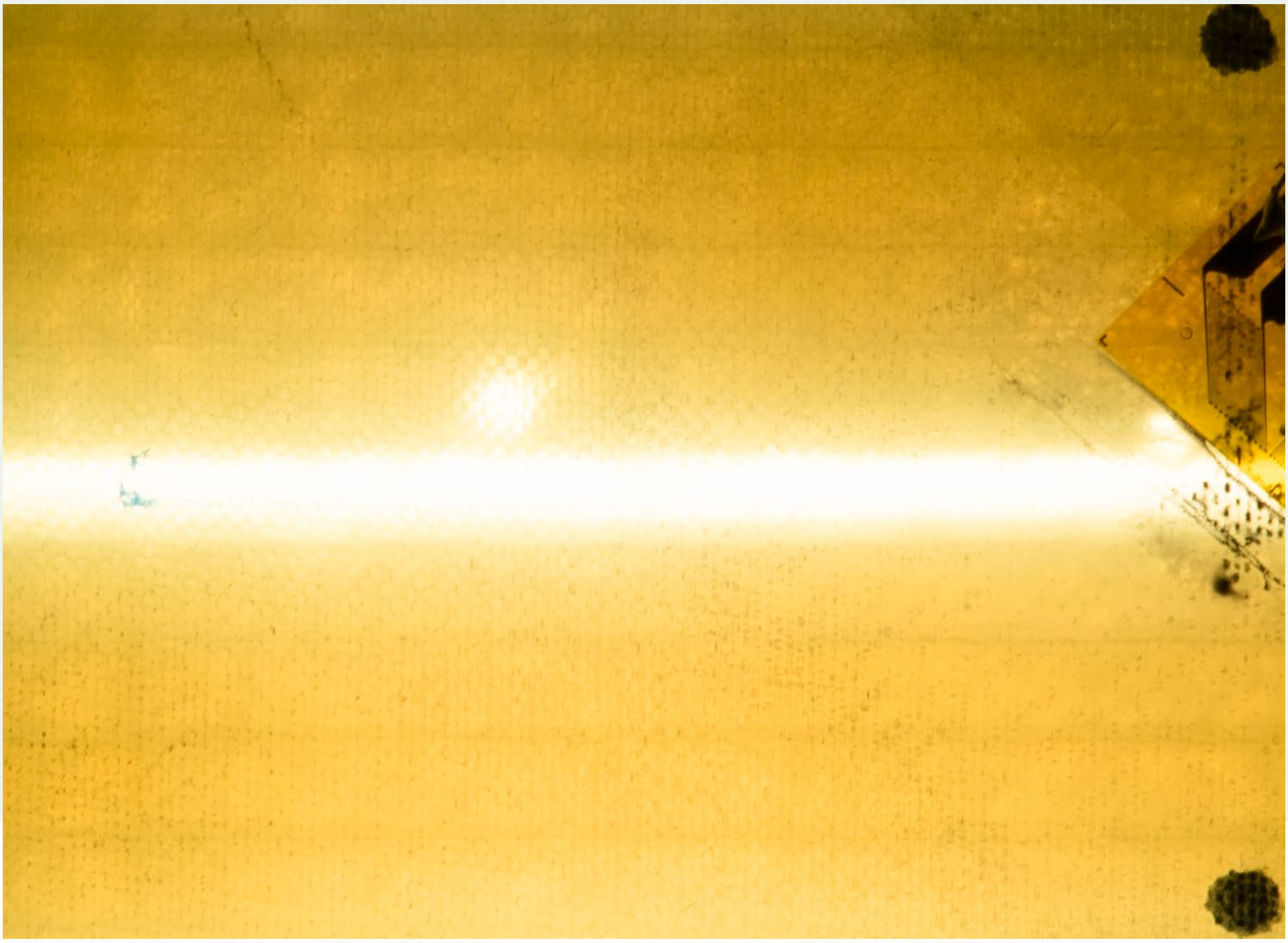


Photo: Christen Malte Markussen / DTU Wind

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Technology Collaboration Programme
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