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IEA Wind TCP Annual Report 2023

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Annual Report 2023

IEA Wind TCP

Content

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2023 IEA Wind TCP *Overview*

The year 2023 marked the passing of the 1 TW (1,000 GW) landmark in cumulative installed wind power capacity [1] after a record year where more than 100 GW of new capacity was installed. Demand for more wind-generated energy continues to surge as new goals for renewable energy are being set for 2030 and beyond. Increasing the speed of deployment has become an urgent matter as a significant leap is still needed to meet net zero carbon targets.

Globally, 115 GW of new wind power capacity was connected to power grids in 2023, bringing the total installed wind capacity to 1,021 GW [1]. This brought the cumulative year-on-year growth rate to 13%. The offshore wind capacity surpassed 70 GW by the end of the year.

The environmental and energy crises continued to prevail in the global agenda in 2023, which has stimulated an accelerated ambition in targets for implementing renewable energy sources. Electrification of industry, transport and building sectors is needed to reach the net zero carbon economy. This will create a 50-100% increase in demand for renewable power 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). During a period of high energy prices in past years, wind energy has proven its role as a hedge against high electricity prices for consumers during windy days.

The pressure to reduce costs throughout the whole value chain from competitive auctions is still challenging because of inflation and increasing interest rates. Auction mechanisms are beginning to mitigate this challenge by indexed strike prices and adding new criteria, on top of the cost. Another emerging barrier is in grid connection – reinforcing the transmission infrastructure is moving too slowly in many countries.

The near future for wind energy is bright, with extensive growth in both deployment rate and technological advances. The challenges lie in how this growth will be done sustainably. While permitting procedures that simplify authorisation procedures are moving ahead, special attention is needed regarding the social acceptance of wind energy. Financial sustainability remains a challenge with inflation increasing costs and challenges for the supply chain.

> **Record year adding more than 100 GW to reach 1 TW (1,000 GW)**

Investments in wind energy RD&D are needed across the entire value chain from initial research to testing and demonstration and include multiple disciplines. The IEA Wind TCP countries reported a total of EUR 532.1 million (USD 570.9 million) in 2023, of which the European Commission invested the most with EUR 169.1 million (USD 181.4 million) followed by the U.S. (EUR 123 million; USD 132 million), Germany (EUR 65.2 million; USD 70 million) and Korea (EUR 41.6 million; USD 44.6 million). 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 Wind TCP Annual Report 2023 presents highlights and trends, reported by 21 member countries, as well as the European Union, WindEurope and Chinese Wind Energy Association for deployment and RD&D activities. Data for 2023 will be published towards the end of 2023, with graphics showing the evolution of trends from previous IEA Wind TCP documents (1995-2022).

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

Photo: Praneeth Peiris / Unsplash

Progress toward Policy Targets

The year 2023 was a record year of deployment for newly installed capacity. 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.

Photo: Zac Ong / Unsplash

New Records in Wind Deployment

The record year of 2023 was mainly achieved through high deployment in China, as in previous years.

Highlights of Deployment from 2023:

- China continued to lead global deployment, making a new record of 76 GW grid connected capacity in 2023 (79 GW built), and passing the 400 GW landmark to reach 441 GW grid-connected capacity.
- The U.S. exceeded the 150 GW landmark.
- The U.K. surpassed 30 GW with 1.4 GW newly added capacity.
- France added a new record of 2.6 GW new capacity to reach 23.5 GW.
- The Netherlands added 2 GW, surpassing 10 GW landmark.
- Canada's new record yielded 1.7 GW of new installed capacity to reach 17 GW.
- Japan added a new record of 0.6 GW capacity and surpassed 5 GW of total capacity.
- Cumulative capacity was growing with 2-digit numbers in Finland (22%), China (16%) Sweden (14%), Greece (12%), Canada (11%), and France, the Netherlands and Japan at 10%.

Increases in electricity production from wind energy created new records due to added capacity and a good wind year in many regions. Additionally, the share of wind in the electricity mix surged in some countries due to lower-than-average demand in 2023. In IEA Wind countries, the total wind generation surpassed 10% of the total electricity demand. Now nine countries, all in Europe, provide more than 20% share of electricity with wind. In the U.S., wind energy was the largest source of electricity in Iowa, Kansas, South Dakota, and Oklahoma, and it delivered more than 20% of the electricity in another eight states.

Ten European countries, and 12 states in the US, generate more than 20% of their electricity needs by wind energy

Highlights of wind generation as national records:

- Denmark had a record again as 54% of energy demand was from wind energy. Ireland is in second place, providing 36%, with the U.K. at 28%, Germany at 27%, Portugal, Sweden and Spain at 25%.
- The Netherlands, Belgium and Greece surpassed 20% share of wind, the Netherlands with a leap to 24%.
- France surpassed 50 TWh and 10% share of wind.
- China's record high wind generation (886 TWh) was nearly 17% higher than the previous year and close to 10% of demand.
- The EU increased wind generation by 54 TWh reaching 466 TWh and a leap in share of wind from 16% to 19% of demand.
- Portugal reported a record in the 15-minutes instantaneous share of wind power of demand: 108%, and a new record for daily contribution by wind of 76% of demand. Greece hit a record of 86% instant share of wind.

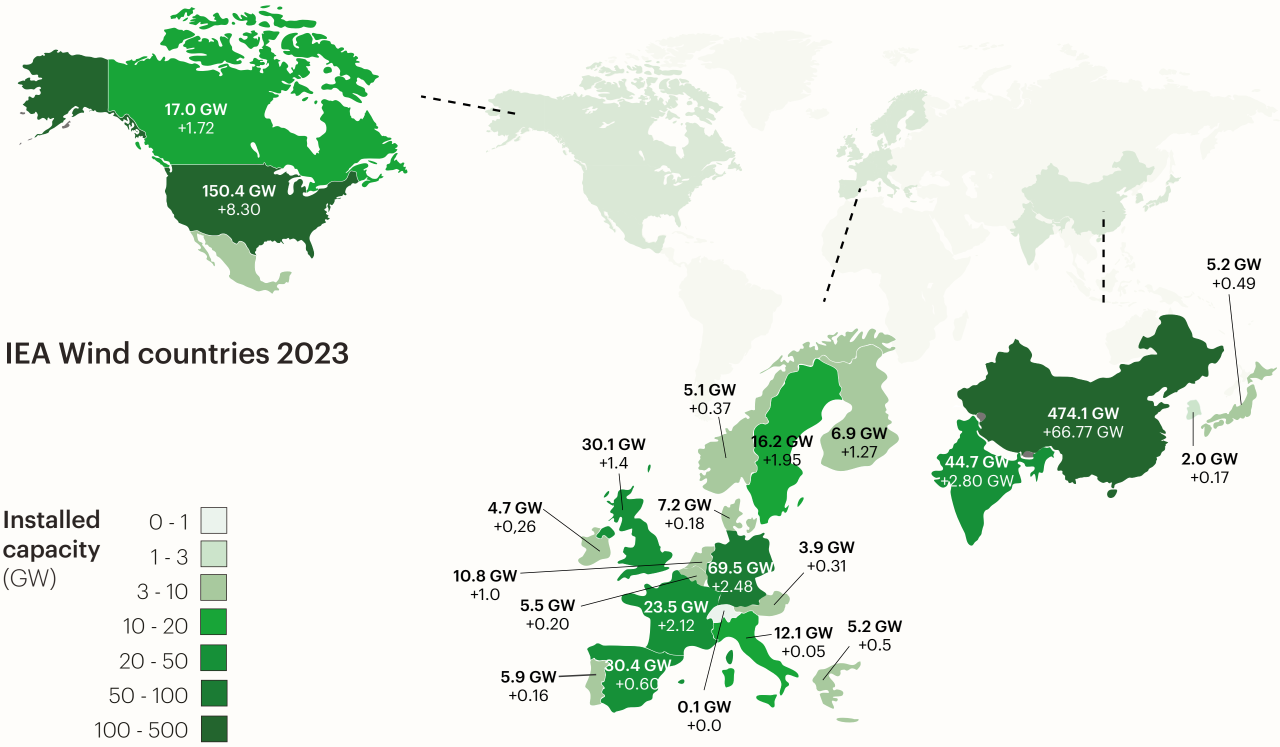


Figure 1. Total installed wind power capacity by the end of 2023 in IEA Wind TCP countries.

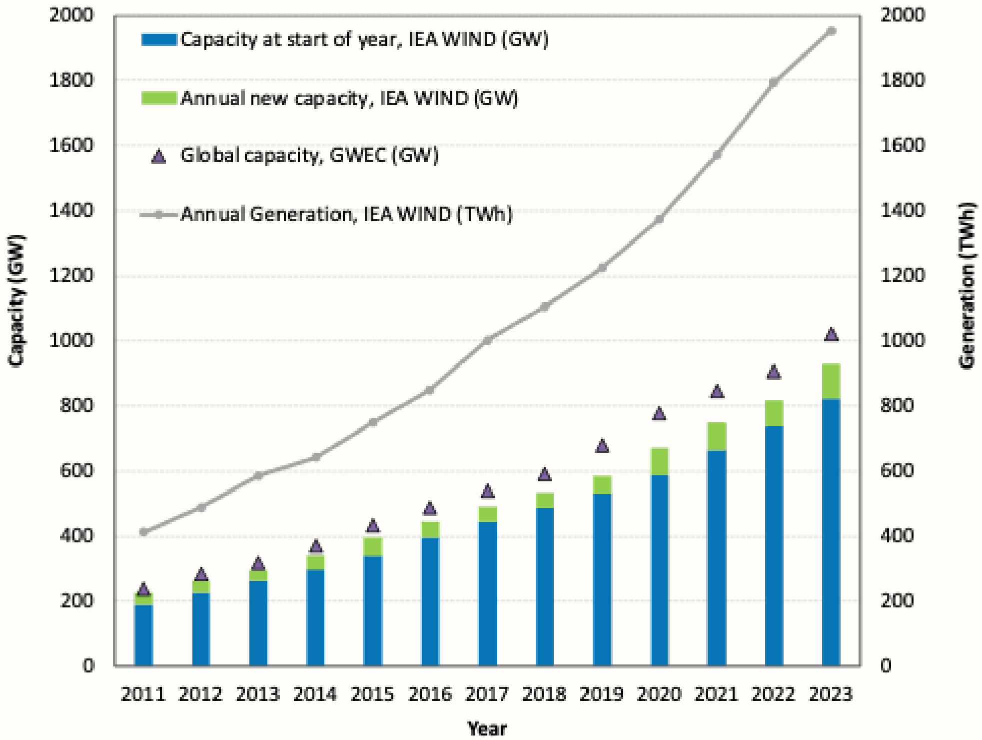


Figure 2. The trend of wind deployment for 2011-2023 in IEA Wind TCP countries and globally. *(Note, Mexico is included in IEA Wind TCP up until 2020).*

Photo: Groveb / Istock

Wind Energy Plays a Critical Role in National Climate Targets

Concerns for security and strengthened commitments to climate neutrality were high on the global agenda in 2023. Net zero carbon targets set in most countries are pushing electrification of industry, transport, and building sectors, creating demand for additional renewable power capacity. For example, Denmark anticipates a 50% increase in electricity demand by 2030 and Sweden announced a need to double the fossil-free electricity production to 300 TWh by 2045, mainly driven by the electrification of the transport and industry sectors. The Netherlands foresees an additional demand of 70 GW to electrify industry by 2050.

Wind power is one of the primary means to achieve decarbonisation goals. Increasing targets for renewables in general, and wind power specifically, are continued to be seen for year 2050, including significant progress by 2030:

- The Renewable Energy Directive in 2023 enshrined in EU law a target of at least 42.5% renewable energy of final energy demand by 2030.
- In new National Energy and Climate Plans of EU Member States, several countries, like France, Germany, Ireland, Italy and Portugal, increased their 2030 wind energy targets. A preliminary analysis shows that EU Member States have ambitions to collectively install at least 437 GW of wind energy by 2030.
- China is building on its 14th Five-Year Plan for the Development of Renewable Energy published in 2022, with the aim to double wind and solar energy generation, with more than 300 GW of wind power to be constructed in the five years from 2021 to 2025.
- In Canada, new planning targets as well as wind power procurement schemes were announced in three provinces.

Offshore Wind Increasing Momentum

The installation of offshore wind power increased by more than 12 GW globally, all of which was installed in IEA Wind TCP member countries, about half in China and half in Europe (mainly in the U.K., the Netherlands, France and Germany). Total offshore capacity surpassed 70 GW. A significant share of demand is already coming from offshore wind in Denmark (26%), Belgium (10%), Germany (5%) and the U.K. (new quarterly generation record at 21% of total electricity generation).

For floating offshore, France added 3 floating turbines in its first demonstration wind farm. Norway's (not gridconnected) Hywind Tampen, the world's largest floating offshore wind farm at 88 MW and installed turbine capacity of 94.6 MW, was fully commissioned.

Offshore projects under construction were reported from China, the U.S., the U.K., France, and Korea.

In France, the first large floating offshore project (250 MW) is due to start construction in 2025. Japan reported the start of a commercial operation of offshore wind power, with wind power plants coming online in 2022 and 2023.

A pipeline of yearly auctions is reported from France, the Netherlands, the U.K. and Germany. Ireland had its first offshore auction in 2023 with 3 GW, 12 TWh, and an average price 86 €/MWh (USD 92.3/MWh). The United States has a strong offshore project pipeline of 23 GW. Norway will have their first auction in 2024 for one fixed-bottom offshore wind project of 1.5 GW. In 2025, three to four floating offshore wind sites will be allocated representing 1.5 – 3 GW. Areas for a total of 30 GW of offshore deployment will be allocated gradually up until 2040.

In Finland, auctions for two sites in territorial waters started in 2023. Roughly 440 TWh of offshore wind power is under development in Swedish waters, of which roughly 190 TWh are applying for permits. In Italy, more than 90 GW of offshore wind capacity (most with floating technology) have applied for grid connection permits.

The combination of hydrogen production and offshore wind is seen in targets (North Sea energy hubs; Ireland), roadmaps (Canada) and in demonstrations (the Netherlands). Denmark finalised its first Power-to-X tender, awarding State Aid to six projects, totalling 280+ MW of electrolysis capacity. In Sweden, the focus for wind power is expected to turn to offshore and joint-production with hydrogen. Much of the deployment will be in the Baltic Sea, with short distance to shore, limited wave height and low salinity.

Bornholm Energy Island project in the Baltic Sea is proceeding as German and Danish Governments signed a legally binding agreement to develop it, deploying at least 3 GW of offshore wind. Transmission system operators 50Hertz and Energinet will work together to set up an electricity hub and install 525 kV DC submarine and land cables, providing offshore wind power to both countries. Procurement of HVDC cables is currently ongoing in the two countries. The Danish government has decided to postpone its decision to invite tenders for the North Sea Energy Island as an artificial island.

The first phase of development for a floating offshore wind project in the Celtic Sea in the U.K. was announced in 2023: Offshore Wind Leasing Round 5 of 4.5 GW. In Italy, more than 90 GW of offshore wind capacity (134 wind farms, most with floating technology) have applied for grid connection permits.

There are significant targets for offshore wind in several locations, also for floating offshore.

Highlights for offshore wind capacity targets:

EU targets aim for close to 70 GW of new offshore wind capacity by 2030, on top of nearly 20 GW in 2023

- Germany from 8 to 30 GW by 2030 and 50 GW by 2035.
- The Netherlands from 4 to 21 GW by 2032.
- France from 1.5 to 18 GW by 2035.
- Denmark from 2.5 to 11.5 GW
- Belgium from 2 to 8 GW.
- Ireland 7 GW (of which 2 GW for hydrogen).
- Spain 3 GW (floating).
- Greece 1.9-2.3 GW (80% floating)
- Italy 2.1 GW (mainly floating)
- Portugal 0.3 GW (floating).

U.K. from 15 to 50 GW by 2030, of which 5 GW floating.

U.S. 30 GW by 2030.

Korea 12 GW by 2030.

China from 37 GW to 115 GW by 2030.

In Canada, Nova Scotia, will release 5 GW of offshore wind energy leases by 2030.

In addition, work is ongoing to designate offshore areas for future deployment:

- In Canada, Regional Assessments for Offshore Wind Development are underway in two provinces: Newfoundland and Labrador, and Nova Scotia where the first call for bids will be opening in 2025.
- The development of offshore wind power plants is a key component of the Korean Green New Deal, and a total of 27 GW offshore wind projects have received Electricity Business License EBL by end of 2023.
- In Belgium, the second offshore zone is starting its development phase (first turbines operational in 2027).
- In Greece, the first batch of 600 MW pilot projects (up to 250 MW each) at preselected areas are planned to start under a feed-in tariff scheme (first permits for field studies have been granted to developers).
- In Sweden, the new marine spatial planning areas for energy extractions enables 90 TWh of annual electricity production at the North Sea, the Baltic Sea and the Gulf of Bothnia.
- In Portugal and Italy, Maritime Spatial Planning is ongoing including offshore areas.
- The Spanish Maritime Spatial Plan (MSP) was adopted in five marine demarcations.

Repowering Expected to Increase

An increasing proportion of currently installed capacity will reach its end of life in the next decade. So far, the decommissioned capacity reported remains at a relatively low level. In the EU, 720 MW of old land-based wind capacity was decommissioned (450 MW in 2022). In China, 1,260 MW were decommissioned (930 MW in 2022).

Portugal, Italy and Denmark are building their targets to expand land-based wind capacity on repowering existing wind power plant sites. Spain is anticipating 10-15 GW of repowering in the next decade.

Photo: Jason Mavrommatis / Unsplash

Technology development and performance

The trend towards larger turbines is still continuing, with new records reported from 2023. Capacity factors of recently built wind power plants are considerably higher than before, and cost reductions have brought an increasing amount of subsidy-free, merchant wind power through power purchase agreements.

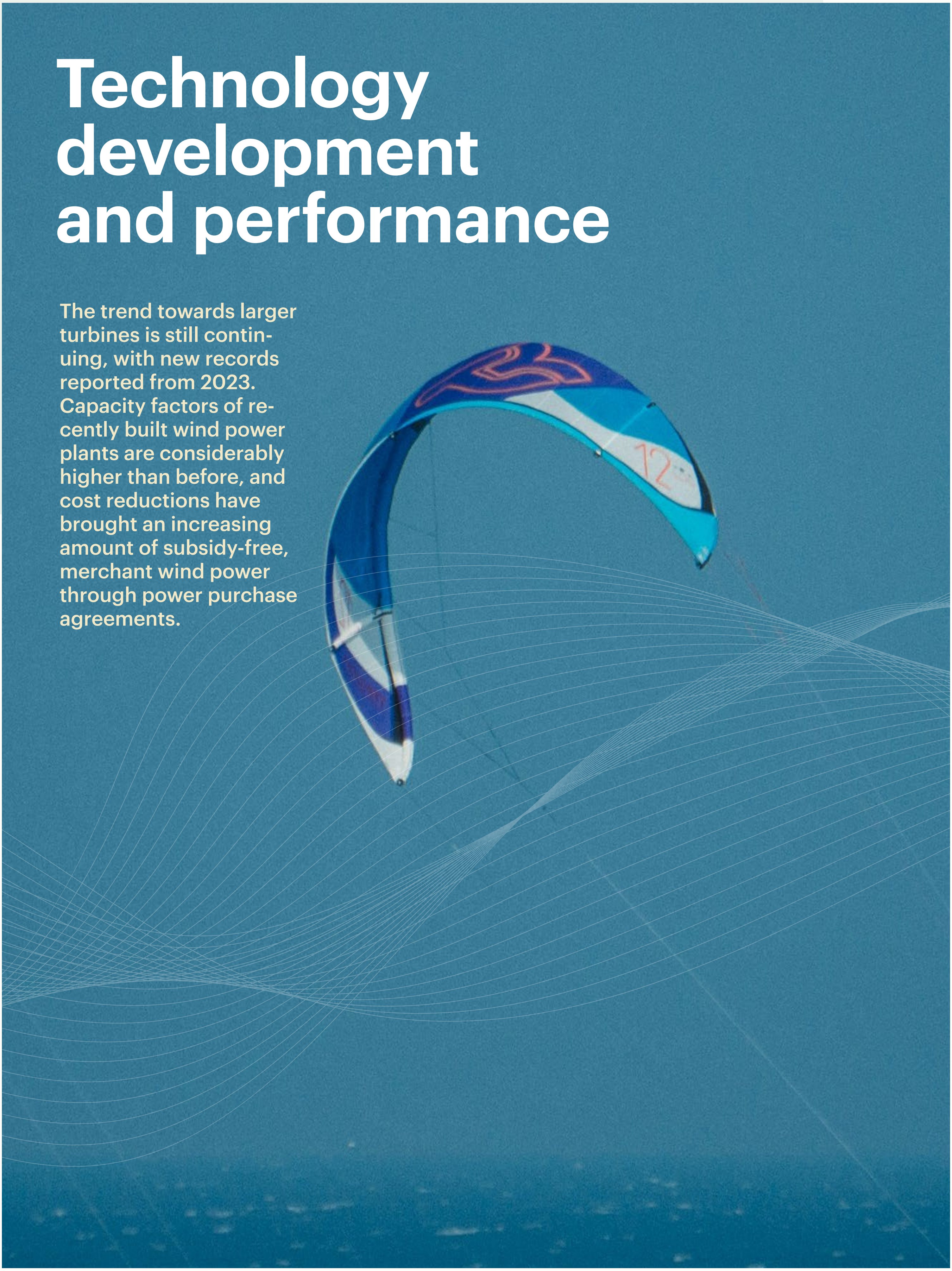


Photo: Matt Seymour / Unsplash

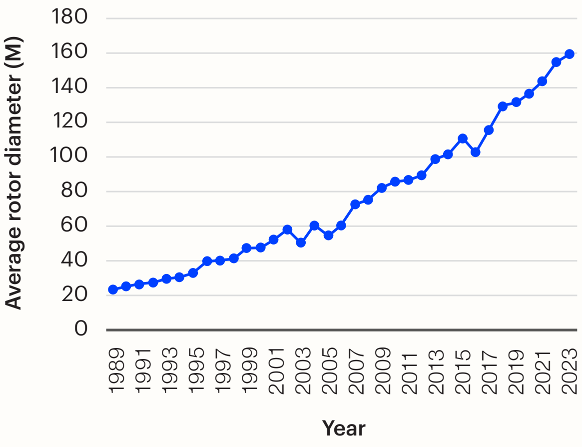


Figure 3. Rotor diameter trend.

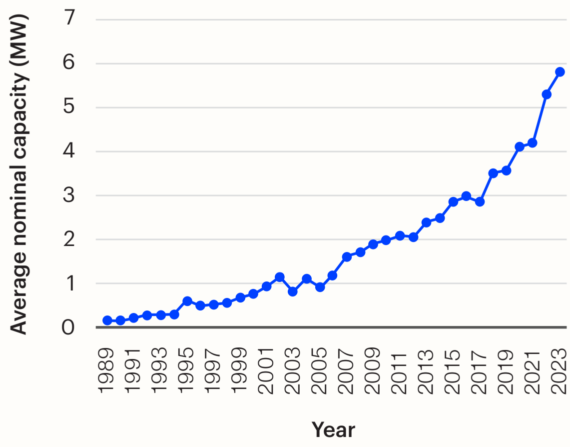


Figure 4. Nominal capacity trend.

Turbines Continue to Increase in Size

The average power rating of new onshore turbines in Europe hit new records: 4.5 MW, up from 4.1 MW in 2022, and for offshore turbines 9.7 MW, up from 8 MW in 2022. The average power rating of turbines ordered in 2023 was 5.5 MW for onshore and 14.9 MW for offshore. In Germany, a 15 MW turbine is to be commissioned for the first time in 2025.

In Finland, new onshore wind turbines are large: average rated capacity of 6 MW, hub height of over 150 meters and rotor diameter of over 160 meters. Sweden also reported a record-large average turbine size of 5.8 MW.

In Ireland, the Drumlins Wind Farm 158 m rotor GE 6.1 MW wind turbines, created a new record and is also the first example of segmented blade technology being used at a wind farm consisting of a 65-metre-long main blade section and 14-metre-long tip section.

In the U.K., the average rating of new installed offshore turbines reached a new record of 10.1 MW, while Dogger Bank A project had 13 MW turbines. In China, the largest turbines built in 2023 were 10 MW and 16 MW for land-based and offshore turbines, respectively.

Detailed trends in increased turbine sizes can be found in the country chapters for Canada and Sweden *(See figure 3 (Rotor diameter trend) and figure 4 (Nominal capacity trend))* [7].

Improved Technical Performance Leads to Higher Capacity Factors

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

2023 was characterised by a lower wind resource than the previous year in Northern Europe, while it was close to average in Portugal and Spain and higher than average in France and Germany.

Capacity factors for the entire wind fleet in the EU were 25% on average. Capacity factors for onshore were 24% (up from 23% in 2022), while offshore was 34% (down from 35%). The capacity factors of new installations are significantly higher than the fleets that include very old installations.

The highest average capacity factors were reported from the U.S.: 35% for land-based and 44% for offshore wind. Norway reported 32% (down from almost 35% in 2022) and Finland 29% (down from 33% in 2022). In the U.K., average load factors for offshore wind were 40% (down from 41% in 2022).

Cost reductions still a target despite profitability challenges

Inflation and the cost of materials have impacted the costs of all energy technologies, including wind turbines. Profit margins across the entire supply chain are unsustainable. The lowest costs reported in recent years may not be reached in the near future.

However, future cost reductions are still anticipated and remain targets in RD&D, especially for floating offshore wind.

The success of cost reductions has 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 2023, the Spanish government deemed wind energy auctions unnecessary as the price range established by the government in the auctions was lower than those of the electricity market, so the promoters preferred to go directly to the market (merchant, PPAs). In Finland, the market value of wind power in 2023 was 40 €/MWh (USD 42.9/MWh). This was only 72% of the average spot price in Finland, but still relatively high as the average spot price stayed at a higher level in 2023.

Matters affecting growth and actions to over-come deploy-ment barriers

The main barriers slowing down wind deployment are related to long permitting procedures linked with challenges in social acceptance of wind energy. In 2023, positive news of policy actions easing permitting bottlenecks was received. However, grid bottlenecks are emerging as a new key barrier. Other challenges are related to uncertainties in future regulations and recent cost issues that delay investment decisions.

Photo: Flavio / Unsplash

Streamlining Permitting Processes

Photo: Martin Castro / Unsplash

A pipeline of consented projects is needed to keep the deployment levels high. For example, in Ireland, the slow pace of deployment of renewable energy projects was brought to national attention, as it was revealed that only four decisions were made on wind power plant planning applications by the Irish planning board in 2023, all requiring judicial reviews.

To achieve ambitious wind energy targets set for 2030, the EU is demanding measures from member countries to speed up permitting by simplifying the authorisation procedures. Examples of mitigation actions reported include:

- **Renewables as an overarching public interest and fast-tracking:** In the EU, the Renewable Energy Directive in 2023 makes the temporary rules set in 2022 permanent: shorter deadlines for permitting, digitalisation of procedures, and the principle that the use of renewable energy is in the overall best interest of the public and serves public security. The Wind Power Action Plan from 2023 includes implementable actions regarding permitting. In Denmark, the government will identify areas with energy potential and eliminate regulatory hurdles to fast-track renewable projects to streamline processes and get local communities involved. Licensing revision in Greece has recently been implemented, acceleration of environmental permitting legislation was revised in Portugal, and streamlining permitting procedures is in process in Austria.

- **Setting regional targets:** A new law in France makes territorial planning for renewable energies a priority, giving municipalities the right to define, after public debate, acceleration zones where they primarily wish to see implemented renewable energy projects. The Netherlands is now divided into 30 regions where provinces, water boards, municipalities and organisations jointly draw up a Regional Energy Strategy (RES), choosing the portfolio of solar, wind and other sustainable energy for electricity and heat generation. In Spain, the government introduced a tool for a territorial model that groups together the main environmental factors, the result of which is a zoning of the environmental sensitivity of the territory. The Renewable Electricity Spatial Planning Framework was introduced in Ireland for onshore renewable electricity. Regional and local targets are reported in Austria, Germany, Sweden and Switzerland.

- **A "one-stop-shop"** for simplifying licensing procedures has mitigated the complexity of permitting procedures in Belgium, France, and Sweden and is being adopted for offshore wind in the Netherlands and floating offshore in Italy. In 2023, SEAI was appointed as a single point of contact in Ireland.

- **Reducing delays caused by appeals:** In Switzerland, combined procedures for land use planning and building permitting, as well as reducing the number of courts involved in the last step of wind energy authorisations, allows six wind energy projects to be built in 2025-2026, three years before originally planned. Finland is targeting a process where overlapping appeals are eliminated.

Spatial planning limitations (e.g., military, aeronautical, or traffic-related restrictions) can become barriers, especially in densely populated areas. In Belgium, reducing the thresholds (distances to radars, height restrictions, surface area and location of exclusion zones, etc.) that exist for the rollout of renewable energy would bring a potential increase of 1.5 GW of renewable energy. In Finland, potential solutions to interference with radar surveillance proposed in a 2023 report include a combination of active and passive sensor systems, including airborne surveillance capability; and a phased approach developing one area at a time.

Photo: Jennifer Griffin / Unsplash

Actions to improve social acceptance include involving local communities in planning as well as compensation plans.

The U.S. DOE launched the Renewable Energy Siting through Technical Engagement and Planning program, which will provide funding to support capacity building for large-scale renewable energy and energy storage development at the state and local level.

In countries starting their offshore wind deployment, governments need to address the permitting procedures. In Ireland, the National Industrial Strategy for Offshore Wind complements a suite of government policies through the Offshore Wind Delivery Taskforce. Finland and Sweden have started clarifying permit procedures of wind power in their exclusive economic zone (EEZ).

Preparing for offshore installations, including port infrastructure, needs to be addressed. For example, in Italy, the Ministry of Environment and Energy Security will ask for expression of interest to identify at least two ports for offshore wind farm installation. In Canada, World Energy GH2 bought Stephenville port in western Newfoundland in 2023 to create a future shipping hub of green hydrogen and ammonia. This is planned to be generated via a minimum of 328 wind turbines to be built in 2025 on the Port au Port Peninsula and in the Codroy Valley.

Seeking Ways to Improve Social Acceptance and Environmental Impacts

Issues concerning the social acceptance of wind energy may lead to future limitations in local support and barriers to siting. Social acceptance of onshore wind power in Norway has been an issue for several years and has stopped the deployment of onshore wind. To mitigate this, the licensing scheme was reworked towards a parallel licensing process that includes the Planning and Building Act and the Energy Act. The change effectively gives the municipalities veto power and the new licensing process was opened for new project applications in 2022.

There are cases where local communities' appeals against the construction of wind energy facilities are taking years to resolve. Such legal cases could potentially be avoided by involving the local communities more closely in the project planning stage and by offering them the opportunity to take part in investments through cooperatives. Examples reported include:

- In Denmark, residents near projects are offered a greater share in profits.
- In the Netherlands, local communities will be incentivised to participate for 50% of ownership in new wind projects in order to increase participation and support.
- In Finland, Social acceptance is generally high and local municipalities with larger amounts of wind power get considerable economic benefits from property tax contributions. Revamping the compensation mechanism to also include landowners along transmission lines is in process. Additionally, the requirements for environmental impact assessment and new requirements related to end-of-life activities such as dismantling the turbines will be clarified.
- In Greece, 3% of electricity sales from all wind farms return to the local communities as extra funding to local administration bodies and direct subsidies to the electricity bills of consumers in the communities hosting wind farms. In 2020-2021, a total of EUR 54 million (USD 57.9 million) was distributed to local communities through this mechanism.
- Germany plans to fund costs for the planning and permitting phase for onshore wind farms to be erected by local communities according to the Renewable Energy Act (EEG 2023).

Examples of investigations into effects on people, flora and fauna, and best practices reported include:

Photo: Berit K / Istock

- The effects of wind turbine noise on the health of people living nearby wind power plants have been investigated in the Netherlands. No significant relation has been found between health complaints reported by the general practitioner and sound levels.

- The red obstacle lighting on wind turbines during the night is experienced as a nuisance for people living in those areas. One of the solutions investigated in the Netherlands is approach detection, which switches the light on when an aircraft is near a wind turbine.

- The Austrian company, IG Windkraft, published a study on the impact of wind energy on birds and wildlife. Attention is also brought to bats at project sites where surveys were made on their behaviour prior to construction and during the first year of operation.

- An investigation has started in the Netherlands to see if bird collisions can be avoided by painting wind turbine blades black.

- In Finland, Suomen Hyötytuuli actively monitors birdlife at Tahkoluoto offshore wind farm using a bird radar.

- Best practices to consider reindeer husbandry during different phases of the life cycle of a wind power project was published by the wind power sector in Finland.

- A study commissioned by the French Biodiversity Observatory identified a number of actions (economic, technic-legal and socio-cognitive) to better integrate biodiversity into renewable energy projects.

- Ecological requirements are increasingly implemented in the Dutch offshore wind tenders. Research assignments are given to study the ecological effects of offshore wind, as well as ways to mitigate adverse effects and even nature-enhancing measures.

- In Korea, Ministries (of Environment; Trade, Industry and Energy; Oceans and Fisheries) jointly issued a "Plan for Offshore Wind Power Generation in Collaboration with Local Residents and the Fishing Industry". This presents measures to encourage the speedy development of large-scale offshore wind farms. Trickle-down benefits to local stakeholders are set out in the collaboration plan.

- In China, large-scale development has moved to desert areas to help improve the ecological environment. Developing wind power in combination with local cultural and environmental requirements and restoration of greenery with soil and water conservation are the main principles to maintain the ecological environment.

Changes to Auctions to Account for Cost Issues

Costs to realise wind farms are increasing because of long lead times, higher financing costs, increased prices for raw materials and transport costs. In Norway, this is further exacerbated by new taxation, like ground rent tax that can affect investor confidence. In Austria, some of the calls for projects in 2023 received no applications at all due to the increased interest rate, price increases and regulatory issues, among others.

For offshore wind, supply chain and cost struggles contributed to the cancellation of several projects and power purchase agreements in the U.S. In the U.K., one offshore project awarded a Contract for Difference (CfD) at a record low strike price of 42.13€/MWh (45,21 $/MWh) was dropped due to spiralling supply chain costs and increasing interest rates. RWE bought the project to be combined with other projects which will reach 4.5 GW when complete.

Some countries have already implemented changes in auctions to mitigate the supply chain issues. Initiatives such as increasing auction bidding ceilings and indexing strike prices to inflation to counter rising project costs are helping to get investments up again.

Investment in new EU wind power plants was a record EUR 30 billion (USD 32.2 billion). For the first time, the Danish state will be co-owners of offshore wind projects with a state ownership share of 20% of the tenders for 6 GW of wind projects.

There are regular auctions for land-based wind power in Germany, Greece, France, Ireland and the U.K. Recent outcomes reported include:

- In Germany, all four onshore wind tenders held were under-subscribed (awards of 6.4 GW of a total tender volume of 9.8 GW). However, this was double compared to 2022. The average award value across all 2023 auctions was 73.3 €/MWh (78.7 $/MWh), just below the maximum value of 73.5 €/MWh (78.9 $/MWh) that has been used in 2022 due to cost increases.
- In France, 54 new projects were selected at the end of November as a result of a call for tenders, for a total power capacity of 931 MW. The average price of the winning projects was 86.9 €/MWh (93.2 $/MWh). This was the second fully subscribed call for tenders of the year 2023. Further, a first call for tenders which made it possible to select 73 projects for a total power capacity of 1,182.36 MW and an average price of 84.76 €/MWh (USD 90.9/MWh). France's first rounds of auctions in 2022 resulted in lower prices but were undersubscribed (0.3 GW of onshore wind capacity at 67.5 €/MWh (72.4 $/MWh) and less than 0.1 GW at 76.4 €/MWh (82 $/MWh)).
- In Greece, the auction system, CfD, for wind and solar power plants had a gap year in 2023. In 2022, the mean price offered by wind farms was 57.7 €/MWh (61.9 $/MWh).
- In the UK, the results of Contracts for Difference (CfD) Allocation Round 5 were announced which delivered 1.5 GW of onshore wind capacity by 24 projects, more than double awarded in Allocation Round 4.
- In Ireland, RESS 3 auction resulted in 3 successful onshore wind projects, 414 MW, 1,270 GWh, with average strike price (for both wind and solar) of 100.47 €/MWh (72.4 $/MWh).
- In Spain, the inclusion of non-economic criteria in the auctions of the Renewable Energy Economic Regime was approved. In addition to the award criterion of the energy remuneration price, other non-economic criteria may be included up to a maximum of 30% of the weighting, such as the contribution to resilience, environmental sustainability, innovation, the socio-economic impact of the project or other aspects that improve the integration of renewables into the power system.

The UK Government responded to the first-ever CfD auction of no offshore wind bids through the publication of updated parameters for Allocation Round 6, which will run in 2024. These include an increase in the administrative strike price of 66% to 82.34 €/MWh (89.42 $/MWh) for fixed-bottom offshore wind and 198.53 €/MWh (213,02 $/MWh) (2012 terms) for floating offshore wind, in addition to allocating a separate funding pot for fixed-bottom offshore wind.

In Germany, offshore auctions for both pre-assessed and non-pre-assessed areas for tenders have additional criteria other than cost.

In the Netherlands, the offshore tenders are zero-subsidy auctions that include criteria like ecology, grid criteria, combinations of storage and solar. Several innovations are to be deployed from tenders so far: intelligent turbines for quick response to changing circumstances, wake-steering to reduce wake losses, combination of floating solar and wind, battery and hydrogen storage. In year 2023, tender (1.4 GW) ecological innovations and measures were to be implemented, such as: location-specific curtailment for migratory birds and bats by using radars, deterrence of bats, habitat recovery at the sea bottom, monitoring and research of harbour porpoises, creating corridors for birds and bats.

Action Needed to Mitigate Transmission Infrastructure Bottlenecks

Without prompt action, grids are going to become a major bottleneck if they are not already. Many countries struggle to build out the grid needed to integrate new wind capacity. A related issue is to filter out speculative grid connection requests.

Governments must urgently accelerate the grid expansion via anticipatory investments, optimising the use of the existing grid and proactively managing grid connection queues:

- In Austria, a law is currently under discussion to improve flexible grid connection and optimise energy storage and grid expansion.

- In Denmark, adding more grid and interconnectors remains one of the key pillars to manage grid integration of additional wind.
- In Finland, the concentration of wind power projects on the Northern part of the West coast is currently causing delays to grid connection of projects. However, the system operator is preparing for massive wind deployment on- and offshore in their transmission planning.
- In Greece, significant grid reinforcing works are either in progress or planned for the near future, aiming to interconnect to the mainland all major islands of the Greek archipelagos, which currently operate as isolated, diesel-powered grids. The first interconnection line for Crete (400 MVA) has been fully operational since 2021, while the second line (1 GW) is under construction and expected to be fully operational by 2025. When the second line is in operation, it will allow 2 GW of additional renewable energy capacity to be added to the system, in addition to significant savings in electricity cost, increasing security and improving the quality of electricity provided to the island. Targeted grid strengthening projects are in progress on the Greek mainland as well.
- In Spain, regulating access permits and connection, also for the orderly boost of electricity demand is planned to improve grid access and connection.
- In Europe, the Commission adopted EU Action Plan for Grids defining 14 actions to make EU's electricity grids stronger, more interconnected, more digitalised and cyber-resilient.
- The U.S. DOE published a draft roadmap in 2023 to tackle interconnection bottlenecks, aiming at a comprehensive set of reforms for the interconnection process. Considerable funding is directed to grid modernisation, for long distance transmission for offshore wind by HVDC as well as projects facilitating grid connection of renewables.
- In China, high deployment figures put the power grid under enormous strain, and multiple measures are being taken to ensure grid integration of wind power and improve the consumption of renewable energy.

For offshore wind, Belgium is proposing to set up a fast-track task force together with North Sea neighbouring countries for the accelerated development of an offshore wind network. The North Sea energy system development program will ensure that new techniques and a policy framework are available in time in the Netherlands.

Curtailing and active power management of wind generation

Most countries still report low curtailment levels in 2023:

- China has been able to bring its high curtailment levels down in recent years. The positive trend is continuing in 2023 with an average wind curtailment rate of 2.7%.
- Portugal still manages the 25% average share of wind energy without curtailments.
- In Greece, the occurrence of power curtailment was 1.2% of total non-dispatchable renewable production but is expected to increase in the near future.
- In Denmark, curtailments are back to very low levels after a new countertrade model was applied in the market settlement with Germany.
- In Spain, the curtailment levels have increased in recent years, reaching 1.1 TWh in 2023. This is 58% higher than 2022, but still less than 2% of the total wind energy produced.
- In Canada, significant congestion in certain parts of the Alberta grid, in particular, has brought an unprecedented number and severity of curtailments, about 5% in the last quarter of 2023.

In Ireland, the dispatch-down (curtailment and constraint of wind energy output) has been increasing with the high share of wind in the small island system. The dispatch-down energy from wind resources was 1.1 TWh in 2023 (8.9% of the total available wind energy) - a figure still below the peak dispatch-down of 11.4% in 2020.

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. Spain reported again in 2023 significant increases in wind power plants' participation in Replacement Reserves (RR), Technical Restrictions (TR) and Tertiary Regulation (mFRR). In Finland, the system operator published a guide for the participation of weather-dependent energy production in automatic reserves. It specifies requirements for baseline power, calculation of available active power, and the maintained reserve.

Impacts of Wind Energy Development

The impressive development of wind energy worldwide has an impact on the economy, environment, and society worldwide. 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 and people as possible.

Photo: Caleb Minear / Unsplash

Economic Impact and Jobs

Wind energy employs people across all professions and levels throughout the lifetime of the wind energy plants, from project planning to manufacturing to operations, as well as maintenance and decommissioning. Furthermore, it encompasses 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 [2].

Wind energy employment is set to shift dramatically as countries and companies accelerate their efforts to comply with the ambitious new climate goals and to make sure that the energy transition benefits local job creation and competencies. The global wind industry workforce has grown to 1.4 million people. Wind employment was concentrated in a relatively small number of countries. China alone accounted for 48% of the global total, followed by Asia (representing 55%), Europe (representing 29%), the Americas (representing 16%) and Africa and Oceania (representing 0.7%) [3].

According to Global Wind Workforce Outlook 2023-2027, nearly 600,000 skilled workers will be required to construct, install, operate and maintain the global wind fleet by 2027 alone [3]. 87-90% of these are needed within onshore wind and 10-13% within offshore wind to deliver on the projected wind capacity growth.

In a situation where some countries dominate the global supply chain for various components and materials, many other countries and global industries intend to create a better 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 [4].

In 2023, wind power was a key element to limit the price of electricity in Spain. According to the AEE figures, Spanish consumers saved more than EUR 6.32 billion (USD 6.8 billion) on their electricity bills. The reducing effect of wind power in the accumulated of 2023 was 20.41 €/MWh (21.90 $/MWh). In other words, without wind energy generation, the average price of electricity in 2023 would have increased by 19%. The gross savings from wind power in 2023 were lower than in 2022, mainly because the price per MWh in 2023 was 48% lower than in the previous year.

Climate and Environmental Impacts

Environmental impact assessment of wind energy projects is an integrated part of planning of wind energy projects in countries around the world. International organisations such as the International Union for Conservation of the Nature (IUCN) and the World Bank have published guidelines for how to develop best practices:

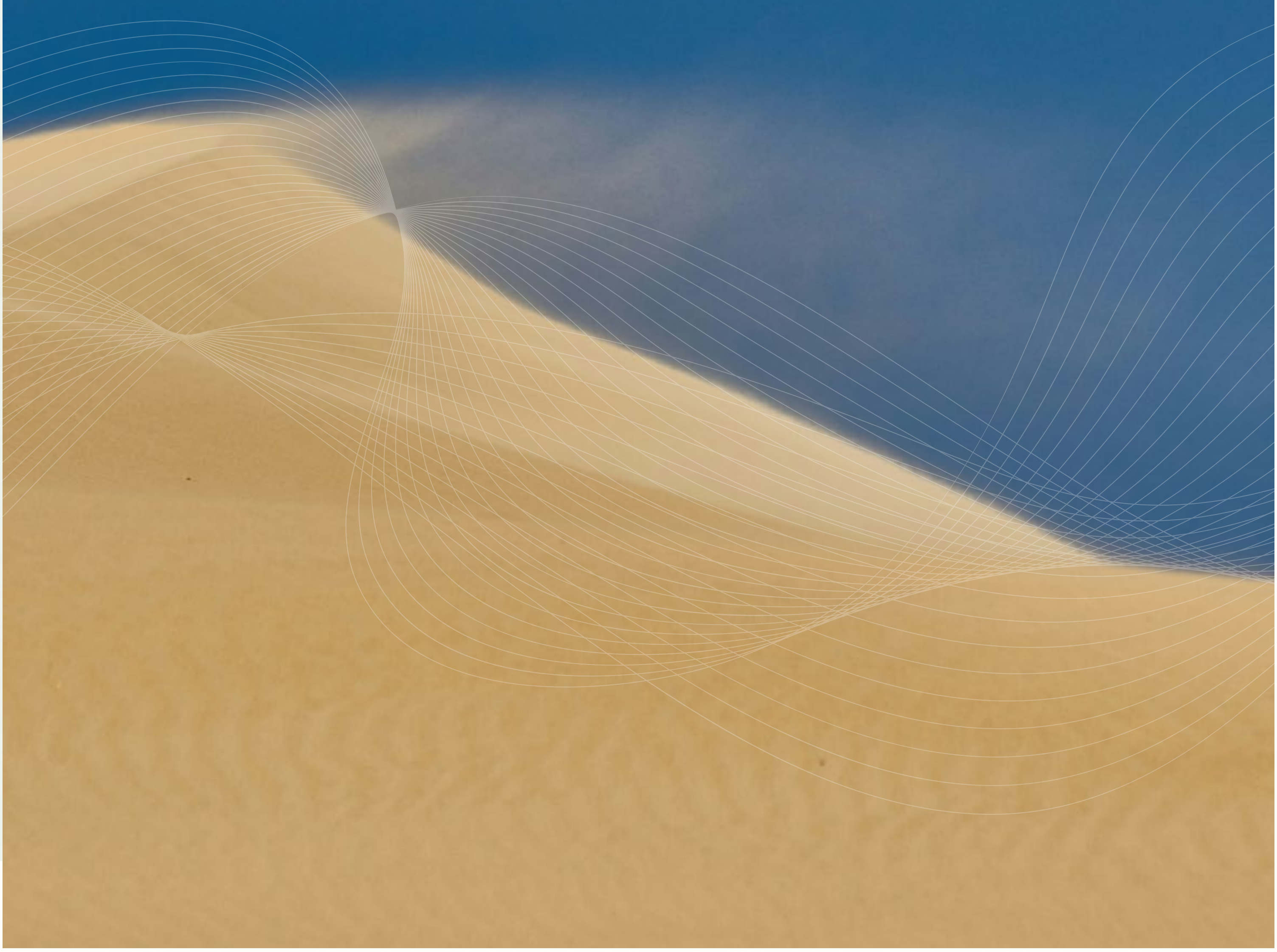
- IUCN published Industry guidance for early screening of diversity risk – onshore wind [5]
- The World Bank Group published the Integrated environmental and social sensitivity mapping – guidance for early offshore wind spatial planning [6]. It is designed to support government planners in emerging economies countries to identify potential areas for offshore wind with the lowest environmental and social sensitivity. Its process-oriented approach of four consecutive steps – desk research, stakeholder engagement, filling the data gaps and sensitivity mapping to inform early-stage offshore wind spatial planning – is based on key principles such as a mitigation hierarchy, precautionary approach, gender-based approach, knowledge co-creation and participatory approach.

Through electrification, wind power will increasingly replace fossil fuels also in heating, transport and industry. This has impact on CO_2 emissions and several countries report on that:

- EU highlights that wind energy in 2023 helped avoid 202,145 tonnes of CO_2 emissions with an estimated value of EUR 16.9 billion (USD 18.1 billion) based on the average yearly price of EU emission allowances. Wind energy also helped avoid 654 tonnes of NO_x and 3.8 tonnes of SO_2 emissions.
- Germany reports that the generation of around 142 TWh of wind energy led to a reduction of almost 108 million tons of CO_2-equivalent GHG.

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.



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National RD&D Funding and Initiatives

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 robust supply chains:

- The revised European Strategic Energy Technology Plan (SET Plan) is aligned with important EU policy initiatives such as RepowerEurope, the Wind Power Action Plan, the Raw Materials Act and the EU Action Plan for Grids. For more than two decades (2009-2023), the EU's wind energy RD&D has been financed under Horizon Europe and its predecessors FP7 and H2020. In 2023, a record budget for new projects was granted, particularly for floating offshore wind, grid integration and new materials and components.

- Following negotiation in 2023, the U.K. has become an associated country to EU's Horizon Europe research and innovation programmes, which will deepen the relationship with the U.K. research and innovation programmes. These include, among others, the Floating Offshore Wind Manufacturing Investment Scheme.

- U.S. incentives continued to support wind energy research and development. The U.S. Inflation Reduction Act of 2022 extended production and investment tax credits for, among others, wind energy projects, tying increased credits to the provision of high-quality jobs. Through the Infrastructure Investment and Jobs Act of 2021, the DOE supported deployment challenges, in offshore, onshore and distributed wind energy while its innovation prizes focused on floating offshore wind and turbine materials recycling.

- The third year of the 14th Chinese Five-Year Plan (2021-2025) continued to deliver on the research and manufacturing of super large wind turbines and its main components, including 15 MW onshore wind turbines, 16 MW floating wind turbines and 22 MW offshore wind turbines.

The IEA Wind TCP countries reported a total of EUR 532.1 million (USD 570.9) in R&D funding means in 2023, of which the EU invested the most with EUR 169.1 million (USD 181.4 million) followed by the U.S. (EUR 123 million; USD 132 million), Germany (EUR 65.2 million; USD 70 million) and Korea (EUR 41.6 million; USD 44.6 million).

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 five IEA Wind strategic areas:

1. The Atmosphere
2. The Turbine
3. The Plant and Grid
4. Environmental Co-design
5. Social Science

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The Atmosphere

- The Austrian **AI4Wind** project investigates the impact of climate change on wind power, using artificial intelligence (AI).

- The Dutch **GeoWin** (geophysical wind farm surveys to reduce cost) is conducted by Fugro and TU Delft. For the development of an offshore wind farm, it is mandatory to assess the location's geotechnical feasibility. This is conventionally done with classical geotechnical approaches like cone penetration tests, borehole investigations, as well as high-resolution seismic surveys to image the near subsurface structurally. This project aims to develop and build a non-invasive, compact, environmentally friendly, autonomy-ready geophysical system to map topography, structure and properties of the ocean floor up to geotechnically relevant depths below the seafloor. Two techniques are developed, Synthetic Aperture Sonar on an Autonomous Surface Vessel (SASV) and Silent Seismic operated from an unmanned underwater vessel.

- The German project KliWiSt is focusing on investigating the already existing and projected climate changes of wind and its impact on wind farm yields in the near future and will integrate them mainly in the industrial context of the site assessment application. The project mainly focuses on wind potential. In addition, other yield-relevant aspects, such as the influence of climate change on icing risks and flight conditions of bats, will be analysed. From these results, new uncertainties for wind energy yields will be calculated and recommendations for action for the wind energy industry will be derived.

The Turbine

- The Danish project **extra-large 3D printed wind turbine towers produced on site on demand** is a new industry-led R&D project using 3D construction printing. A structural design for 160 m tall hybrid towers, with the first 80 m being 3D printed and the remaining height either being 3D printed concrete or a steel tower will be developed. A 6 m tall scale prototype is planned to be 3D printed in 2025 for general design and concept verification. If successful, the data collected will enable the procession of a follow-up project: building a complete prototype 161 m tower with a 5 MW wind turbine generator based on verified technical feasibility and cost savings.

- The EU project **WHEEL** aims to demonstrate and achieve a pre-commercial Technology Readiness Level (TRL) for an innovative floating wind technology suited for deep water locations, effective industrialisation strategies, breakthrough cost reduction and minimised carbon footprint. This shall enable a radical step forward for LCoE reduction while also addressing scalability, harbour infrastructure suitability and availability, and the sustainability and circularity of floating offshore wind. The development and demonstration needed to reach the pursued TRL will be achieved through the design, installation, certification and testing of a fully operative 6 MW pilot unit.

- In Italy, Roma Tre University with financial support from the Ministry of Economic Development (MISE, now MASE), developed a controller for the **reduction of floating**

Photo: Tsuyoshi Kozu / Unsplash

offshore wind turbine vibratory loads which is based on Individual Pitch Cyclic control and resonant control. The combined use of the two strategies has demonstrated its effectiveness in cumulative fatigue load reduction.

- In Japan, NEDO supports research and technology development projects on a **low-cost floating offshore wind power generation system** at water depths of 50 to 100 meters. NEDO has also commissioned a feasibility study including selection of technical issues and cost evaluation with an eye on commercialising floating offshore wind power generation.

- Korea supports a portfolio of projects on **floating offshore wind technologies** (FOWT) such as development of design technology for a TLP-type floating offshore wind turbine system and scaled model test technique, development of a 70 kV dynamic cable system technology for FOWT, design technology development for innovative LCoE saving substructures of 20 MW+ ultra large floating offshore wind turbine system, and development of deep-sea suction anchor technology for floating offshore wind.

The Plant and Grid

- The Belgian **ETF STERNA2050** (Industrial and fundamental research and scenario analysis of the potential contributions of superconducting offshore connection systems - aimed at long distance, high capacity, loss-free power transmission - to the decarbonisation and security of supply of Belgium by 2050), investigates the potential contribution of superconducting system technologies to supply security, and the increased share of renewable energy for Belgium and the associated socio-economic impact. This will be combined with a comprehensive assessment of the environmental impact, material usage, and economic impact over the system's lifespan.

- The German **GruenWinT** aims to significantly shorten the waiting time until a wind turbine can be founded on freshly recultivated lands of opencast mines. The large thickness of the recultivated lands and their material inhomogeneity are main challenges in that respect. Based on a field test and numerical simulations a concept is being developed which allows to reliably judge the suitability of a place for an early foundation of a wind turbine. Furthermore, it is numerically investigated if foundation concepts developed for offshore conditions, particularly the vibratory installation of single large-diameter monopiles, can be applied to allow an early foundation of wind turbines in the freshly dumped ground.

- The Swedish project **Grid-forming wind power plant** has developed a coordinated control strategy between the wind power plant and the energy storage system to provide the wind plant with the same grid-forming properties

Photo: Katie Moum / Unsplash

as a conventional synchronous generator. Control strategies for operations under normal and fault conditions were analysed and implemented. New ancillary services for the power system can be enabled thanks to the control coordination that was investigated. A feasibility study of the most suitable energy storage media and the necessary power electronic interface for the energy storage was carried out. Proper dimensioning of the energy storage system was conducted to reduce the storage requirements compared to today's solutions.

- In the U.S., **The West Coast Offshore Wind Transmission Literature Review and Gaps Analysis**, published in 2023, cleared the way for the launch of a transmission options study to support offshore wind energy development along the West Coast through 2050. A separate offshore wind transmission study on the Atlantic Coast from Maine to South Carolina was underway in 2023.
- In Portugal, project **GREENH2ATLANTIC** is planning to build a 100 MW hydrogen production hub, coupled with local hybrid renewable power plants (wind – onshore and future offshore - and solar) in Sines. This project is particularly compelling since it enables the transition of a former coal-fired power plant into an innovative renewable energy production hub in alignment with Europe's decarbonisation and energy transition strategies.

Environmental Co-design

- Following an open call for projects, the French Biodiversity Office (OFB) selected and granted EUR 2 million (USD 2.1 million) to three research projects aiming at understanding the interactions between **offshore wind turbines and the marine environment** and developing solutions to avoid, reduce or compensate their impacts.
- The Swiss **Autonomous Multisensory Monitoring (AMM) Fauna** mitigation project is about autonomous multi-sensor monitoring of birds to assess collisions and flight avoidance near wind farms project. An optical monitoring system for wind turbines to detect possible collisions with bats has been developed and documents the context of the collisions and proximity flights of bats. The project is still ongoing, in 2024 the system will be further tested aiming at operating in a range of weather conditions and widening the target acquisition.
- In Scotland, U.K., the **Bird Collision Avoidance Study** undertook field investigations at Vattenfall's European Offshore Wind Deployment and revealed how seabirds avoid offshore wind farms. Pioneering radar and artificial intelligence technology was used to collect fine-scale data about seabird movements.
- In the U.S., the new Wind Energy Technology Office (WETO) funding announced in 2023, included five projects that will **advance bat deterrence around wind turbines:**

1) Reducing Bat Fatalities at Wind Turbines Using Aircraft Detection Lighting Systems as a Passive Deterrent; 2) Designing an Effective Acoustic Deterrent to Protect Bats; 3) Evaluating Deterrent Efficacy Through 3D Bat Behaviour Monitoring at Wind Energy Facilities; 4) Advancing Aerodynamic Whistle-Based Ultrasonic Bat Deterrence Technology to Enable Ultra-Large Wind Turbines; and 5) Using Sensory Modalities and Behavioural Context to Design Deterrent Systems for Bats.

Social Science

- The Finnish project **LandUseZero**, funded by the Ministry of Agriculture and Forestry, looked at different land use and land management options in Finland, wind power construction being one of them. The project partners studied the acceptance and perception of wind power, its impact on wildlife and people and land value, and how the siting of wind farms and management of land and forests around wind farms can affect the acceptance of wind power in the area.
- The German **AR4Wind** project focuses on how a realistic experience of planned projects may impact the overall acceptance of wind turbines. The development and use of mobile augmented reality (mAR) technologies in public participation processes is proposed to achieve a high level of acceptance in the planning phase. The project envisages an agile and user-centred approach on a workable mAR visualisation system to be used in public participation processes with intensive integration of real demonstration scenarios by the use of mobile phones and tablets.
- The Irish project **Co-Wind** (Community Engagement in Wind Energy: Innovative approaches to achieving a social license) is a University College Cork project funded by the Sustainable Energy Authority of Ireland, that is aimed at better understanding the ways in which community engagement in wind energy can be improved through combined measures focused on 1) public participation in decision-making, 2) direct investment and co-ownership in projects by the public and 3) enhancing current practices by developers in establishing community benefits schemes.

Test Facilities and Demonstration Projects

- In Belgium, the wind turbine gearbox and drivetrain manufacturer ZF Wind Power invests in a **new test and prototype centre, including a 30 MW validation test bench. The test bench** will be used to test and validate the durability and lifetime of multi-MW prototypes that need to operate in extreme offshore conditions.
- In China, the **full-scale test benches for blades** more than 180 m long have been under construction and the **test benches for the whole nacelle** of 28 MW wind turbines have been planned and prepared for construction by industry independent third parties, such as CGC (China General Certification Center).
- The Greek **GREEN ISLAND – Agios Efstratios** deals with the conversion of a small, isolated island grid into a RES powered system. Main power sources on the island will be an 800-900 kW wind turbine and 100-200 kW PV array. A 2.5 MWh Li-Ion battery bank is foreseen for short term energy storage, while thermal storage for district heating will provide load balancing to limit power shredding and medium-term storage. Diesel generators, currently covering the total electricity demand on the island, will be limited to back-up operation only. Construction work started in 2022 and the plant is expected to be fully operational in Q2 2024

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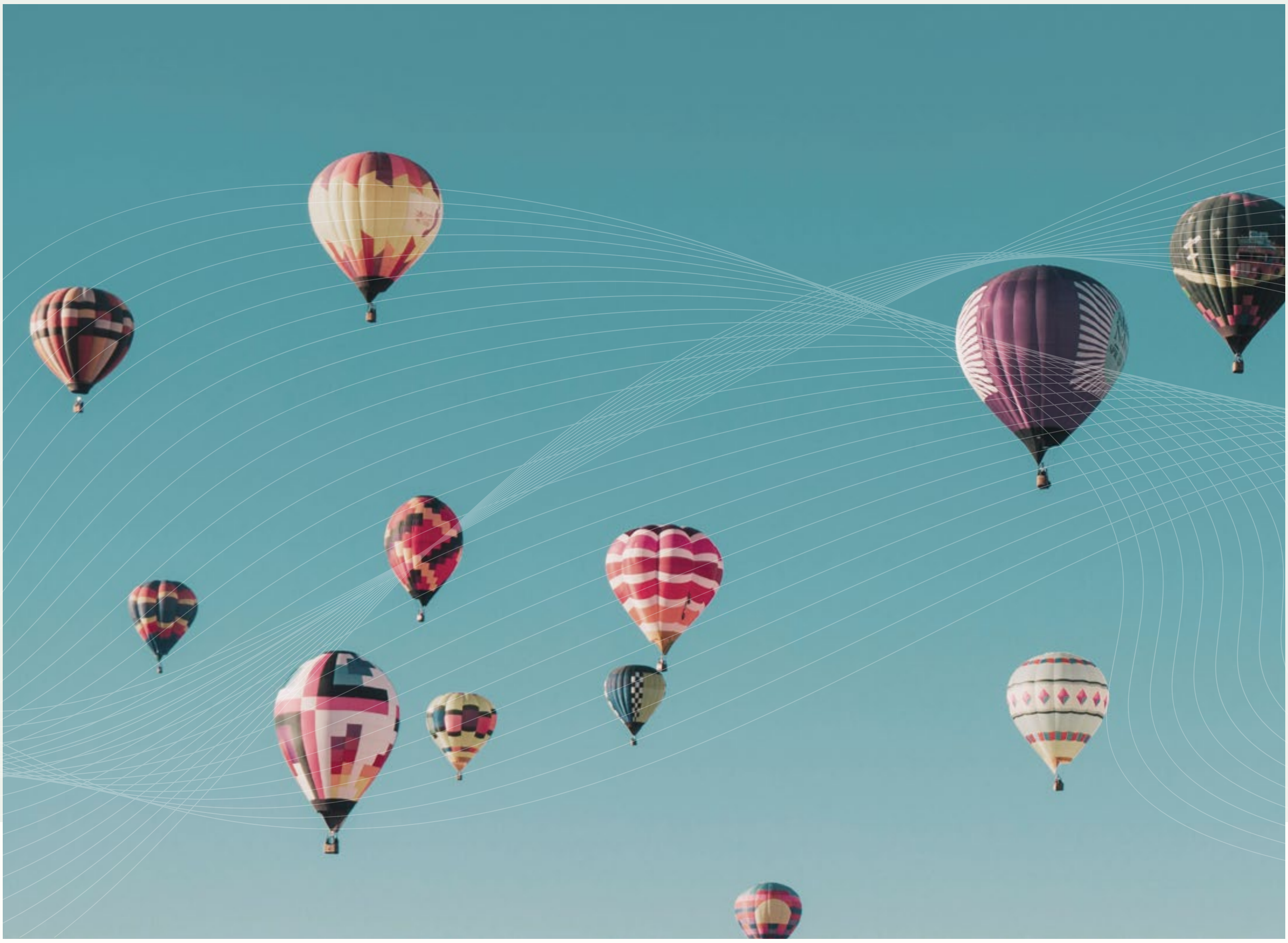
- The **MegaAWE Airborne Wind Test Site** in Ireland is led by Mayo County Council in partnership with Ampyx Power, RWE, Airborne Wind Europe and other organisations across Ireland, Europe and the U.K. The test site is based in Bangor Erris, County Mayo on land leased from Bord Na Móna. The overall objective of the project is to test large-scale multi-megawatt Airborne Wind Energy. Testing commenced on the site in 2023.
- The Norwegian **Marine Energy Test Centre (MetCentre)** – already housing two floating wind turbine demonstrators – was awarded a license to increase their allowed installed capacity to 82.7 MW and a new grid connection with 66 kV in transmission voltage. A part of this grid connection shall be a subsea collector provided by Aker Solutions. This will be the world's first of its kind, providing a subsea grid connection point for the planned expansion of the test centre.
- Spain has granted more than EUR 100 million (USD 107.3 million) to **floating offshore wind pilot projects and testing platforms.** The RENMARINAS-DEMOS programme is divided into four sub-programmes: 1) Test platforms for marine renewables by research organisations; 2) Other testing platforms for marine renewables; 3) Marine renewable technology demonstrators; and 4) Joint projects for marine renewable technological testing platforms and demonstrators.

A list of test and demonstration facilities in the IEA Wind TCP countries is 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:

The Atmosphere	
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 54	Cold Climate Wind
Task 57	Joint Assessment of Models (JAM)
The Turbine	
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)
The Plant and Grid	
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
Task 55	Reference Wind Turbines and Plants (REFWIND)
Environmental Co-design	
Task 34	Working Together to Resolve the Environmental Effects of Wind Energy (WREN)
Task 42	Wind Turbine Lifetime Extension
Task 45	Recycling of Wind Turbine Blades
Social Science	
Task 28	Social Acceptance of Wind Energy Projects
Task 39	Quiet Wind Turbine Technology
Task 53	Wind Energy Economics
Collaborative Communication	
Task 11	Strategy, Collaboration & Outreach on Urgent Topics of Wind Energy Research (Wind SCOUT)



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References

[1] GWEC (2024)
Global Wind Report 2023.
Download from
https://gwec.net/global-wind-report-2024/

[2] IEA (2023).
Skills Development and Inclusivity for Clean Energy Transitions.
https://www.iea.org/reports/skills-development-and-inclusivity-for-clean-energy-transitions

[3] IRENA and ILO (2023),
Renewable energy and jobs: Annual review 2023, International Renewable Energy Agency, Abu Dhabi and International Labour Organization, Geneva.
Renewable energy and jobs: Annual review 2023 (irena.org)

[4] GWEC,
Global Wind Organisation (2023),
Global Windforce Outlook Insights 2023-2027.
Global Wind Workforce Outlook 2023 - 2027 PR - Global Wind Energy Council (gwec.net)

[5] L. Bennun, J. van Bochove, C. Fletcher, D. Wilson, N. Phair, G. Carbone, (2021).
Industry guidance for early screening of biodiversity risk for offshore wind development.
Industry guidance for early screening of biodiversity risk for offshore wind energy development - resource | IUCN

[6] World Bank (2024),
Integrated environmental & social sensitivity mapping. Guidance for early offshore wind spatial planning.
Integrated Environmental & Social Sensitivity Mapping | Guidance for Early Offshore Wind Spatial Planning | ESMAP

[7] Swedish Energy Agency,
Vindbrukskollen
Vindbrukskollen (lansstyrelsen.se)

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