IRENA
International Renewable Energy Agency

INNOVATION OUTLOOK

OFFSHORE WIND

SUMMARY FOR POLICY MAKERS

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The International Renewable Energy Agency (IRENA) is an intergovernmental organisation that supports countries in their transition to a sustainable energy future, and serves as the principal platform for international co-operation, a centre of excellence, and a repository of policy, technology, resource and financial knowledge on renewable energy. IRENA promotes the widespread adoption and sustainable use of all forms of renewable energy, including bioenergy, geothermal, hydropower, ocean, solar and wind energy, in the pursuit of sustainable development, energy access, energy security and low-carbon economic growth and prosperity. ***www.irena.org***

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SUMMARY FOR POLICY MAKERS

The case for offshore wind

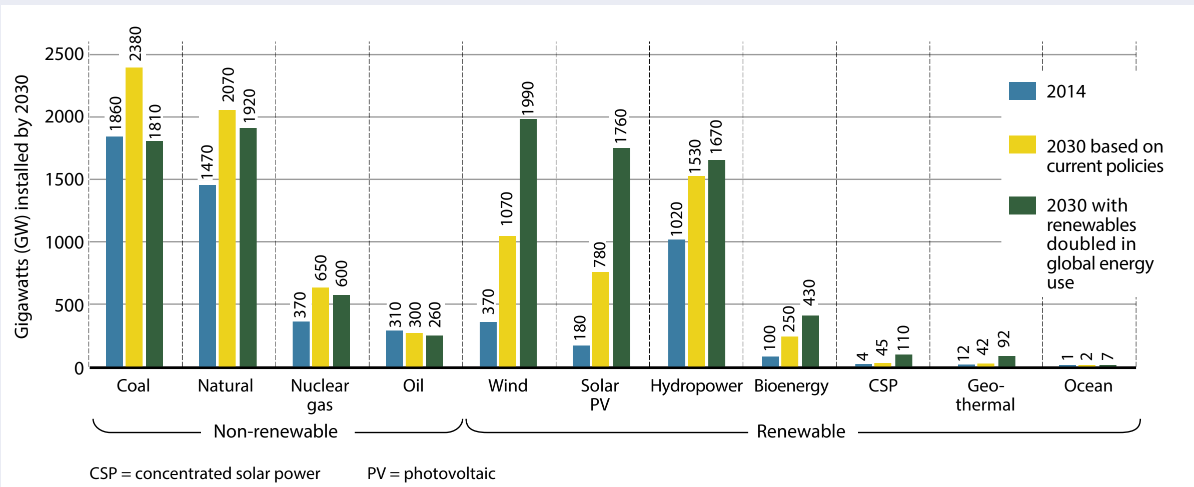
Offshore wind technology opens up sites with high wind resources. Offshore wind farms can be built quickly, at gigawatt-scale, close to densely populated coastal areas. This makes offshore wind an important addition to the portfolio of technologies to decarbonise the energy sector in a cost-effective manner.

Advances in wind power technologies continue to drive cost reduction and expansion into new markets. While onshore wind power is increasingly cost competitive against conventional power generation technologies, growing attention is being paid to technology development for offshore applications that open the door to sites with better wind resources. This combination of higher capacity factors and the availability of large-scale sites makes offshore wind an attractive alternative for utility-scale low-carbon electricity.

Wind development is essential to decarbonise the global economy. According to IRENA's analysis, wind power will have to become the leading power generation technology by 2030 to ensure a decarbonisation of the global economy. Offshore wind capacity can reach 100 gigawatts (GW) by 2030 as innovation continues as the industry takes shape. It could increase faster if policies were adopted to double renewables in the global energy mix. This ambitious decarbonisation pathway requires 1990 GW of total installed wind capacity by 2030, of which offshore wind would provide about 280 GW.

Innovation Outlook: Offshore Wind Technology aims to inform policy makers and other stakeholders about anticipated developments in the next three decades that will make offshore wind competitive on a large scale. The information in the report aims to help guide incentive programmes and policy actions supporting sustainable energy innovation.

Figure 1: Possible paths for global power generation



A sector driven by technological innovation

Offshore wind has grown from a few megawatts of installed capacity to more than 12 gigawatts in barely 15 years.

The technology's evolution started in 1991, when the first megawatt-scale offshore wind farm was commissioned in Denmark in shallow waters, close to shore, using turbines rated at only one-eighth of today's largest turbines. The first commercial-scale offshore wind plant was commissioned in 2002, also in Denmark, with an installed capacity of 160 megawatts (MW). By the end of 2015, the world's installed offshore wind capacity exceeded 12 GW, mainly off the coasts of Europe.

Offshore wind turbines are now the largest rotating machines on Earth. Developments in wind turbine technologies as well as in foundations, installation, access, operation and system integration have permitted moves into deeper waters, further from shore, to reach larger sites with better wind resources. Until 2007, offshore wind turbines were installed in water depths below 20 metres (m) and closer than 30 kilometres (km) from shore. Today, in contrast, turbines are being installed routinely in water depths up to 40 m and as far as 80 km from shore.

Figure 2: Global annual installed and operating capacity for offshore wind farms, 2001-2015

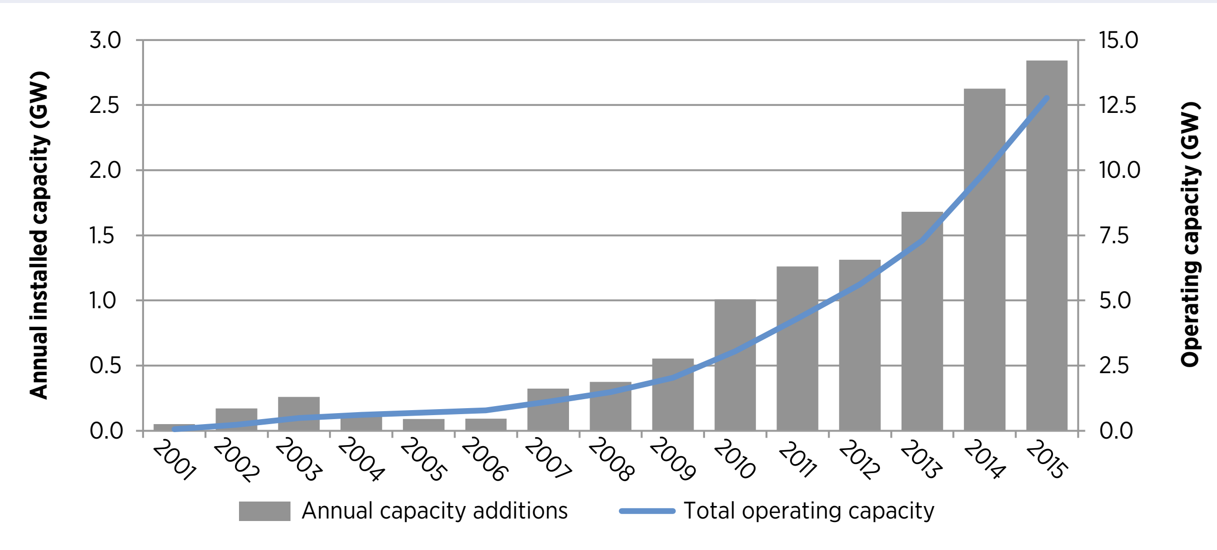


Figure 3: Distance to port for commercial-scale projects commissioned globally, 2001-2015

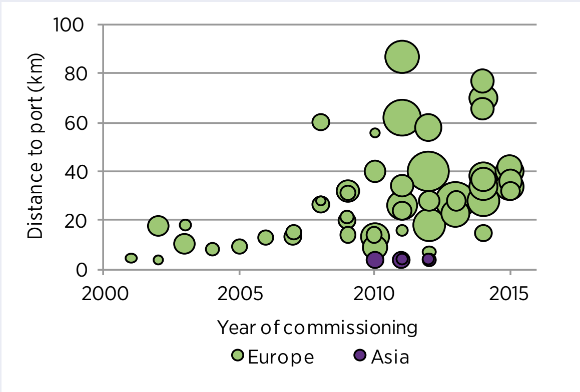
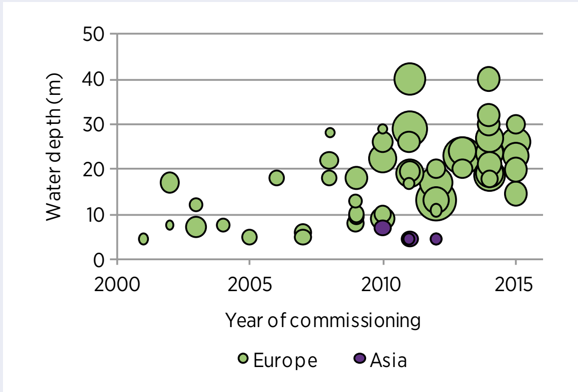


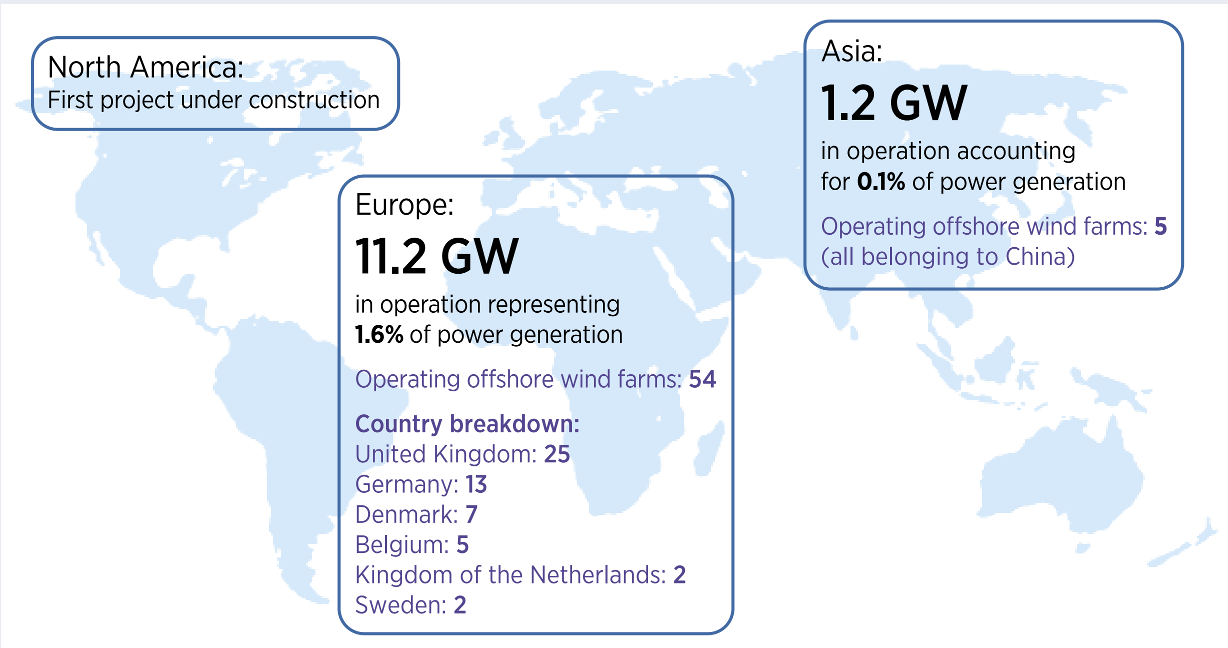
Figure 4: Water depth for commercial-scale projects commissioned globally, 2001-2015



Bubble area indicates each project's capacity in megawatts (MW).
"Port" refers to main operation, maintenance and service (OMS) port.

Most of the capacity installed or operating for offshore wind to date is located off northern Europe. Half of the capacity is in UK waters, one-third in German waters, and the rest almost entirely in other parts of the North Sea or in the Baltic Sea.

Figure 5: Offshore wind deployment at the end of 2015



Competitiveness of offshore wind

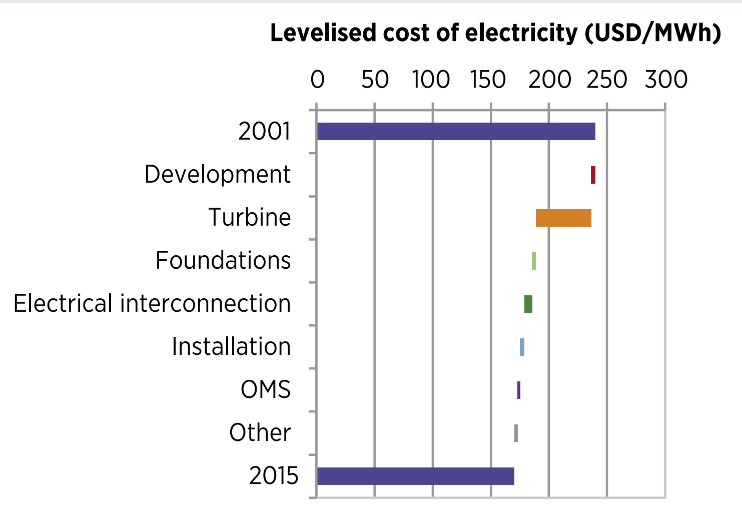
As innovation keeps driving down costs, offshore wind power could be highly competitive within a few years.

The main driver for growth in the offshore wind industry has been significant decreases in power-generation costs, driven by advances in the technology. Cost reductions have been aided by government financial support to address the security of electricity supply and decarbonisation of electricity production. Such efforts have, in turn, driven innovation in the sector, which has brought costs down as well as boosting performance.

Costs have fallen more than 30% in the 15 years since the first wind farm opened. The levelised cost of electricity (LCOE) from offshore wind, which averaged about USD 240 per megawatt-hour (MWh) in 2001, had fallen to approximately USD 170/MWh by the end of 2015.

Innovations that enabled this cost reduction include offshore-specific turbine designs, bespoke offshore wind installation vessels and advanced offshore electrical interconnection equipment. Between 2001 and the end of 2015, the rated capacity of commercially deployed offshore wind turbines grew from 2 MW to more than 6 MW. This progress not only improved the efficiency of the turbines but also resulted in cost economies across the rest of the wind farm, which is why, in Figure 6, innovation in turbines is shown as the largest contributor to reductions in the electricity cost. "Other" change shown came from changes in typical financing costs, site characteristics and other non-technological issues, including project life, competition and other supply chain levers, exchange rates and commodity prices.

Figure 6: Electricity cost reduction elements for projects commissioned in 2001-2015



OMS = operation, maintenance and service

Despite the progress made, the offshore wind sector must continue to reduce costs, ease its integration into onshore grid systems and expand the markets that it is able to address, while preserving its focus on the environment, health and safety. Technology innovation will remain a key ingredient, as well as reducing the cost of finance and savings through greater efficiency across the supply chain.

As an example, in 2015 and 2016, winning bids for auctions for pre-developed offshore wind farms in Europe, such as Horns Rev 3 and Borssele I, have indicated important further cost reductions for projects commissioned for 2020, due mainly to increased competition at the developer level for the same site and driving additional savings in a variety of areas.

Innovation prospects

Rapid strides with technology and other innovations will drive further reductions, helping expand the offshore wind market around the world.

The most significant innovations related to offshore wind technology are expected to include the introduction of next-generation turbines with larger rotors, as well as advances in electrical transmission. Other types of innovation — such as in policy-making, finance and business models — will also boost the sector over the next 30 years.

Ongoing developments in blade and drivetrain technology will allow even larger turbines with higher power ratings. Offshore wind turbines deployed at present typically have a rated capacity of about 6 MW, with rotor diameters around 150 m. Larger turbines might not have a much lower capital cost per MW of rated power than existing designs, but they deliver a lower LCOE due mainly to higher reliability and lower foundation and installation costs per MW. It is expected that the commercialisation of 10 MW turbines will take place in the 2020s, while 15 MW turbines could be commercialised in the 2030s.

Offshore installation will continue to be simplified. Several steps can be eliminated by assembling and pre-commissioning wind turbines in a harbour and installing the complete, integrated turbine (including rotor and tower) in a single operation offshore. A further innovation is to install the turbine and the foundation together, towing the turbine-foundation structure to the site via a bespoke vessel or tugboats. This innovation can be applied to bottom-fixed or floating systems. These innovations have potential to reduce installation cost and reduce exposure to health and safety risks.

Floating foundations are another area of innovation with high potential impact. They are expected to start to be commercially available by 2020. This type of foundation offers the offshore wind industry access to large areas with a strong wind resource and proximity to population centres in waters that are deeper than 50 m. In mid-depth conditions (30-50 m), floating foundations may offer a lower-cost alternative to fixed-bottom foundations due to the potential for standardisation of foundation designs, maximisation of onshore activity and the use of low-cost, readily available installation vessels.

Electrical interconnection of offshore wind farms presents multiple innovation opportunities. These include reducing the necessary amount of offshore high-voltage alternating current (HVAC) infrastructure. High-voltage direct-current (HVDC) transmission is used in preference to HVAC transmission from far-from-shore projects to reduce losses and cable costs. Reducing the cost of HVDC infrastructure could open up new markets and enable the connection of offshore HVDC substations to the first elements of international or interstate HVDC supergrids.

Many innovations in other areas are already reaching a commercial stage. For example, innovations in the development of the wind farm — such as optimisation of the site layout for better use of the wind resource, minimisation of aerodynamic wake effects and optimum use of varying seabed conditions — will enable much more informed and holistic layouts of offshore wind farms. Innovation opportunities also exist and are being harnessed rapidly in operation, maintenance and service (OMS), and this report discusses them all in detail.

Potential game changers

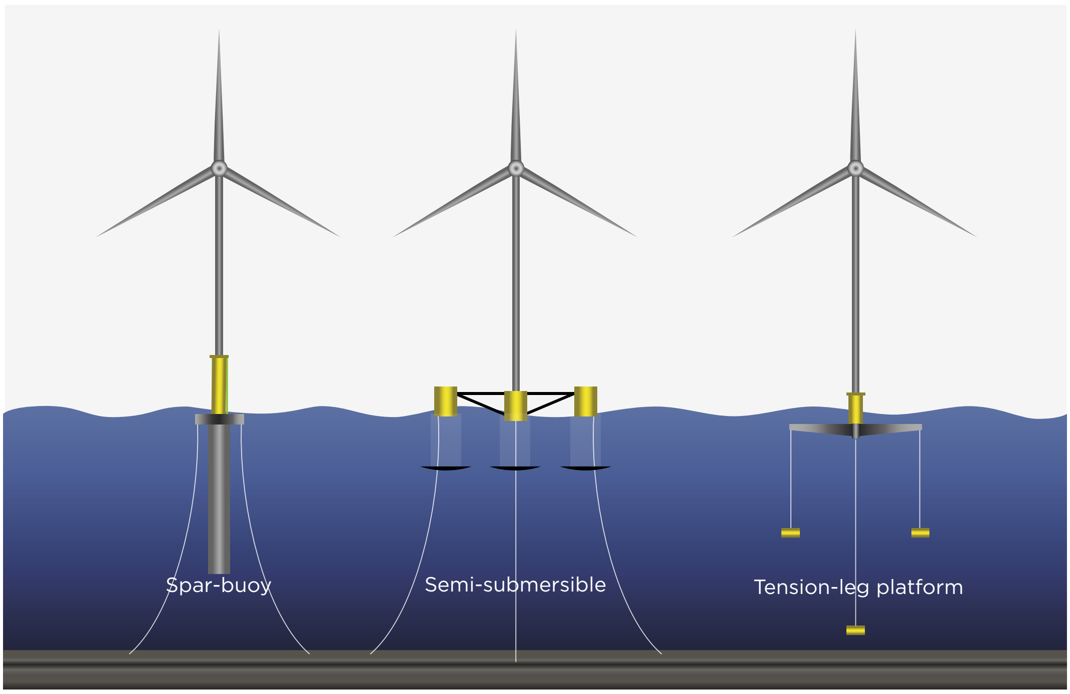
Specialised technologies such as floating foundations will reduce costs further and open up vast areas of currently inaccessible sites for turbines.

Currently, offshore wind farms have been installed in water depths below 50 m using turbine foundations that are fixed directly to the seabed. This limits access to sites with higher winds and potentially large markets. Japan and the United States, for instance, have few shallow-water sites, and existing foundation concepts would not be cost-effective. Floating foundations could be game changers in opening up significant new markets with deeper waters. Floating foundations make installation easier and cheaper by reducing the amount of offshore activity and avoiding the use of heavy-lift vessels. Floating foundations are buoyant structures maintained in position by mooring systems.

Three technologies (Figure 7) are in development at present:

- **Spar buoys**, such as the Hywind concept developed by Statoil,
- **Tension-leg platforms**, such as Glosten's PelaStar, and
- **Semi-submersibles**, such as that developed by Principle Power.

Figure 7: Different types of floating foundation for offshore wind turbines



Based on NREL

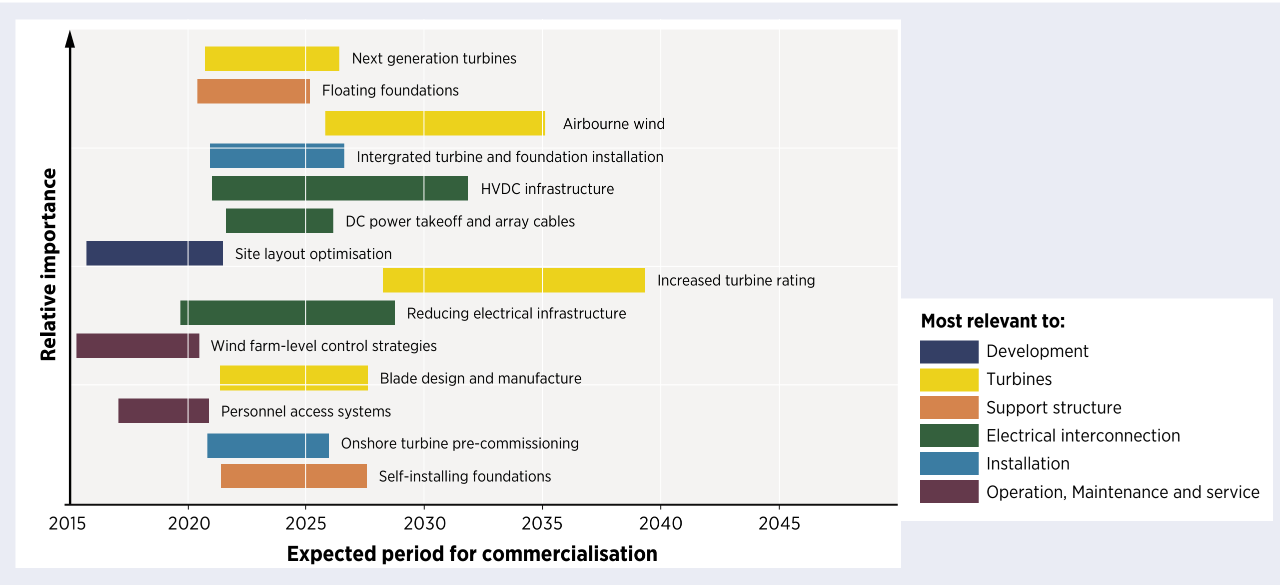
Several full-scale prototypes have been deployed, while demonstrations for new floating turbine concepts continue. The first full-scale prototype was a spar buoy in Norway in 2009, followed by a semi-submersible installation in Portugal in 2011 and three installations in Japan (spar and semi-submersible) between 2011 and 2015. No tension-leg platform has yet been deployed for a wind turbine, but variants of all concepts have been used in the oil and gas sector.

Other turbine concepts, including multi-rotor and vertical-axis wind turbines, could also prove to be game changers.

Airborne wind energy, using kites or fixed wings to reach winds higher up, has also started to receive more attention. Benefits include the increased scale and consistency of wind resources at higher altitude and lower mass and costs for materials.

Market-changing cost reductions could also be possible through extending the life of existing projects, including repowering them with the latest turbine technology.

Figure 8: Anticipated timing and importance of innovations in offshore wind technology, 2016-2045



The outlook

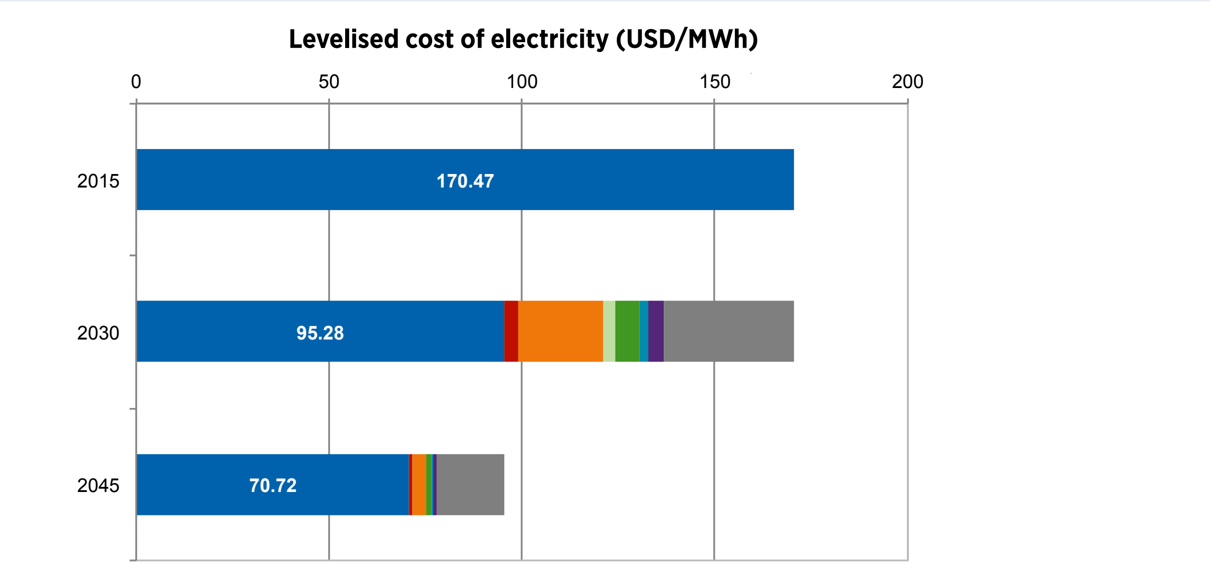
Technological advances and other types of innovation can take offshore wind power to waters deeper than 50 m, expand its geographic range and reduce costs by more than half over the next three decades.

Technological innovations, combined with various non-technology innovations, like different site choices, new market strategies and refined tools to reduce finance risks, should decrease the LCOE for offshore wind farms to USD 95/MWh by 2030 and USD 74/MWh by 2045. This excludes the potential impact of game-changing technologies. Such reductions should put offshore wind firmly in the portfolio of technologies needed to decarbonise the energy sector in a cost-effective manner.

Other significant effects relate to changes in risk and hence the cost of finance and levels of competition and industrialisation (Figure 9). This is already seen with the shift to project-specific competitive auctions in Europe. Global trends in commodity prices, especially for steel and, to some extent, copper and fuel, affect the analysis up to 2015, but the effects of commodity prices and macroeconomic conditions are assumed to remain constant over the period from 2015 to 2045.

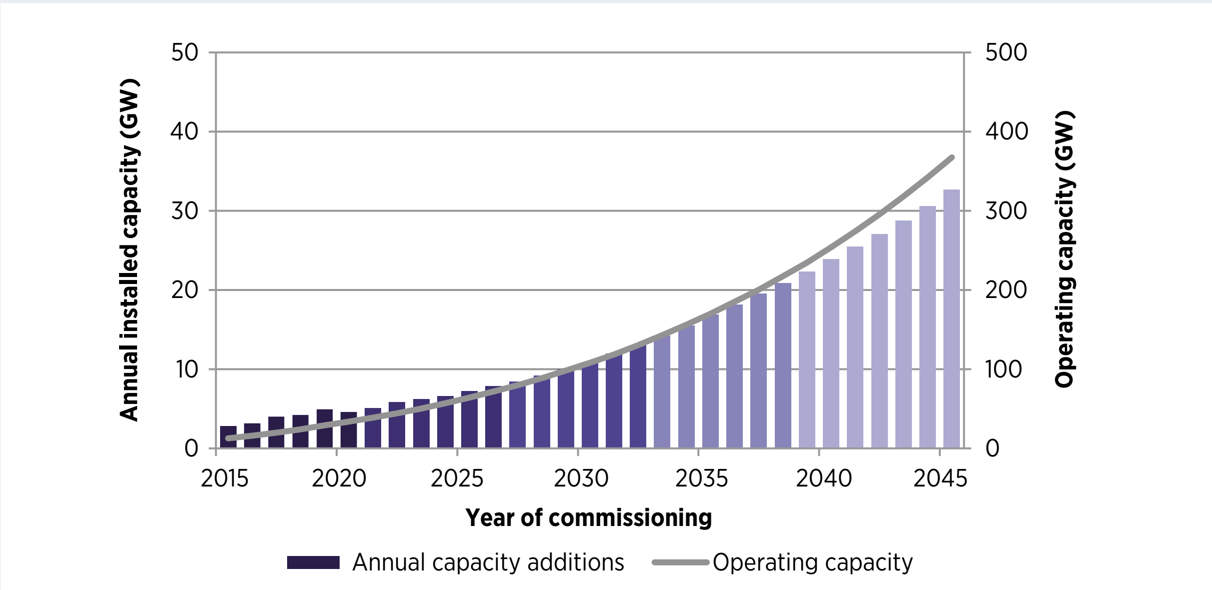
In the next three decades, offshore wind is anticipated to grow from a new commercial technology to an industrialised and important component of the global energy mix, driven by technology innovation as well as by non-technology enabling factors discussed in this report. The operating capacity is expected to grow from close to 13 GW in 2015 to roughly 400 GW by 2045.

Figure 9: Impact of innovation on energy cost elements for projects commissioned in 2015-2045



OMS = operation, maintenance and service

Figure 10: Forecasted global annual installed and operating capacity of offshore wind, 2016-2045



Policy recommendations

Concerted efforts from the public and private sectors will drive further cost reduction, making offshore wind a competitive and reliable option for clean power supply for decades to come.

Policy makers have an important role in creating a climate for investment in technology across the offshore wind industry. This involves:

- Providing as much clarity about the future market size and long-term policy direction as possible.
- Facilitating competitive environments in which reduction in the cost of energy is both rewarded through the right to deliver new projects and supported through the provision of targeted public research and development (R&D) funding.
- Establishing frameworks for the development of international and interstate transmission supergrids.
- Ensuring that public R&D funding is targeted at areas of greatest anticipated cost-of-energy impact and supplemented by incubation support.
- Supporting information sharing within the industry, including the establishment of common language and nomenclature with which to define cost elements.
- Putting in place frameworks and regulations for markets to be able to receive new technologies.
- Supporting skills and supply chain development in order to enable commercialisation of technology.

Experience so far shows the best modes of research, development and demonstration (RD&D) to advance high-impact innovations through engagement with a range of stakeholders.

Key approaches include steering R&D, maximising the impact of grant funding, and enabling demonstration of larger turbines and new concepts. Useful synergies can also be found beyond offshore wind or renewables and outside the energy sector as a whole.

Steering R&D

- Research and technology organisations should ensure that all areas of the industry progress to market in step; for example, there is little value in developing next-generation turbines if the required innovations to install them have not been developed.
- Research and technology organisations and R&D enablers should maintain technology and LCOE roadmaps and monitor progress, to steer R&D focus in an environment of evolving need.

Maximising grant impact

- Funders should focus on quantifying the cost-of-energy impact, the potential market share and the impact of innovations in relation to other industry goals.
- Funders should maximise the benefit of grant funding for small and medium-sized enterprises (SMEs) by including an incubation support element.
- Promotion of collaborative research and RD&D networks, along with public grant funding, will increase academic and SME involvement and help reduce electricity costs from offshore wind.
- R&D funding also needs to connect innovators with industry end-users in order to ensure the most direct route to market.
- RD&D funding should balance support for lower-impact, easier-to-implement innovations and game-changing technologies.

Enabling demonstration

- Relevant bodies should consider imposing conditions on developers of commercial-scale projects that they incorporate one or more locations where novel technology can be demonstrated.
- Other stakeholders also may have an important role in facilitating onshore and offshore prototype demonstration sites for larger turbines, whether relating to leases, planning approval or other potential constraints.

Collaboration in other sectors

Many kinds of technological development in sectors beyond offshore wind can also serve to strengthen offshore wind. Policy makers need to appreciate such links, so that the full value of RD&D for these technologies to be reflected in co-ordination between sectors and decisions about funding.

For example:

- Funding providers can facilitate useful cross-sector collaboration, so that offshore wind benefits from new technologies while the developers of those technologies gain access to a new market.

- Communications professionals engaged in promoting wind power need to stay well informed on technology and industry trends in order to raise awareness about new technologies in the most effective manner. IRENA's *Innovation Outlook* series, comprising reports like this one on a growing range of renewable energy technologies, may be helpful in this regard.

IRENA serves as a platform for international co-operation for its member countries, as well as for researchers, funders, investors and other stakeholders. This innovation outlook aims to inform policy makers and other stakeholders on technology and industry trends and promote the best practices as technologies continue to evolve.

Driven by technological innovation and non-technological enabling factors, offshore wind will become a key part of the global energy mix. But the sector must keep cutting costs, integrate with onshore power grids and gain a foothold in key markets

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