Offshore renewable energy

A rising force in global energy

Contribution by the International Energy Agency to the Meeting of G7 Environment, Energy and Oceans Ministers

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Please see www.iea.org/weo/offshore for additional information on the outlook for offshore energy and www.iea.org/weo for details on the World Energy Outlook and the scenarios referenced in this report.

Summary

Offshore renewable energy in the ocean economy

Offshore renewable electricity generation is an up-and-coming maritime activity, small for the moment relative to offshore oil and gas production but a growing part of an ocean economy that is a vital source of the world's food, energy, minerals, health, leisure and transport. Countries around are the world are looking to reconcile the huge potential of the oceans with multiple pressures on the marine environment, including over-exploitation, pollution, declining biodiversity and climate change. Many are moving in the direction of more integrated multi-sector policy frameworks for ocean management, bringing oil, gas, wind and marine energy activities into a much wider conversation about the future of the world's oceans.

Offshore wind – the new kid on the block

Policy support, innovation and a maturing supply chain are making offshore wind an increasingly viable option for renewables-based electricity generation, harnessing the more consistent and higher wind speeds available offshore. Investment has picked up sharply in recent years and, with fewer restrictions on size and height than their onshore counterparts, offshore wind turbines are becoming giants. The height of commercially available turbines has increased from just over 100 metres (m) in 2010 (capable of producing 3 megawatts [MW]) to more than 200 m in 2016 (8 MW), and a 12-MW turbine design now under development is 260 m high. Installations are also moving further from shore to tap better quality wind resources and push up capacity factors. Aside from lowering the cost of the electricity produced, these improvements in performance also ease the challenge of integrating offshore output into electricity grids.

Based on concepts widely deployed in the offshore oil and gas sector, the first projects using floating wind turbines are now entering into operation. Cost-competitive floating technologies would widen the economic resource base for offshore electricity generation considerably. However, as with the possibilities to commercialise tidal, wave or ocean thermal energy, a significant research and investment push is still needed to move some of the promising offshore technologies into the mainstream.

A step-change in costs for offshore wind is coming into view

The promise of cost-competitive offshore wind in Europe's North Sea is opening up a major new channel for clean energy investment. With G7 economies playing a leading role, the results of recent auctions in Europe suggest a major reduction in costs for some new projects scheduled to enter into operation in the early 2020s; these include some bids that did not require any price guarantees at all, albeit at favourable conditions with the cost of grid connection taken by the transmission system operator. Such a dramatic improvement in costs, if realised in practice, would narrow the cost gap between offshore wind and other leading renewable sources of generation, thereby providing a powerful stimulus for policy support and investment elsewhere in the world. There are already signs of a new wave of interest in offshore technologies in other resource-rich countries, including countries in Asia and North America, which could lead to a virtuous circle of accelerated investment and technology learning.

Further policy support and technological improvement would be essential to bump up projected offshore wind deployment beyond the levels seen in the New Policies Scenario (where the worldwide rise from 14 gigawatts [GW] of capacity today to 160 GW in 2040 is concentrated in Europe) to those in the Sustainable Development Scenario (where the increase to 350 GW is supported by many other regions and countries). In the latter scenario, more rapid electrification of end uses and/or any limitations on onshore deployment would open up further upside for offshore developments. Already in the New Policies Scenario, offshore wind would contribute some 10% of the European Union's electricity generation by 2040.

Good policy design and integrated approaches are essential

The expanded deployment of offshore renewable energy hinges on effective policy frameworks and support, even for technologies where costs are low. All of the G7 economies have taken steps to explore and develop their potential for offshore electricity generation, and the experience with deployment in Europe provides some guidance on the distinctive policy elements that can help to underpin the development of this sector:

1. **A long-term vision for the offshore renewable sector** to support the emergence of an efficient supply chain, both via research, development and demonstration activities and by providing greater visibility and certainty on future market opportunities.
2. **Good data on good sites**: comprehensive site data on wind, water conditions and the sub-surface are important to guide investment decisions, facilitate optimised designs, lower capital costs and give greater precision to preconstruction estimates.
3. **Efficiency, consistency, and clarity in the regulatory process**, so that offshore developers, financiers and power purchasers can manage regulatory and environmental compliance in a reasonable and predictable way.
4. **Competitive tenders or other support schemes**; these schemes are evolving, but all offshore renewable developments have required some kind of support mechanism that increases revenue certainty, while incentivising cost reductions and innovation.
5. **Certainty on transmission connections**; co-ordinated development of offshore renewable projects and the transmission grid is essential, through early planning and timely implementation of new transmission connections.
6. **Relationships with other maritime industries and the marine environment**, including spatial planning to reconcile offshore renewable energy development with competing interests such as shipping routes and fishing areas, and careful consideration of impacts on coastal communities and marine life and habitats.
7. **Synergies with other offshore energy activities and supply chains**; there is significant potential to use the expertise and infrastructure of the offshore oil and gas sector to bring down costs for renewable energy projects; renewable output can also improve the environmental performance of oil and gas installations.

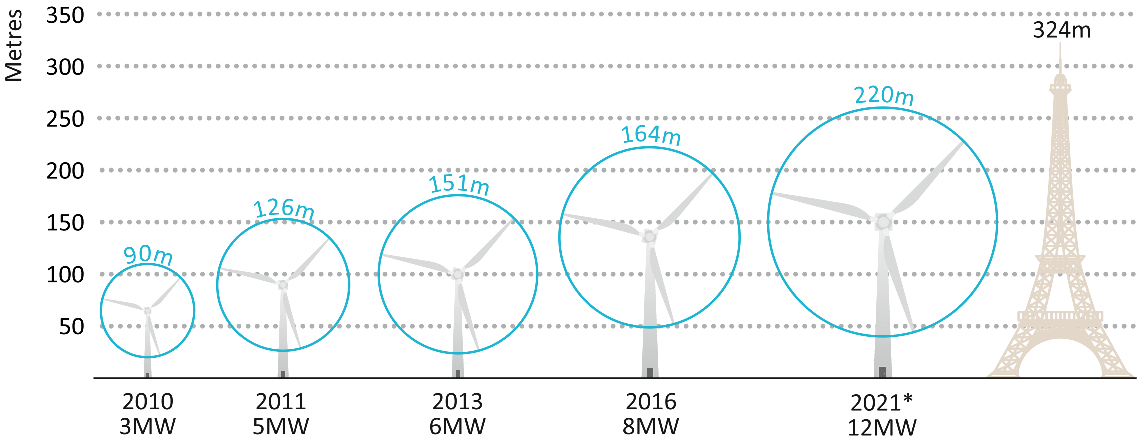
The North Sea, a relatively mature oil and gas basin with a thriving renewable electricity industry, is already seeing significant crossover between the sectors. It is likely to be the laboratory that tests the technical and commercial validity of longer-term concepts for offshore energy collaboration. However, the potential synergies are not confined to Europe, and the need for integrated offshore thinking extends well beyond the energy sector to encompass shipping, port infrastructure, other maritime industries and all aspects of the marine environment.

Offshore renewable electricity today

The role of electricity in our economies and societies is growing rapidly. Global electricity demand doubled between 1990 and 2016, outpacing growth in consumption of fuels. For the moment, the vast majority of this electricity is generated onshore and the overwhelming share of offshore energy activity relates to hydrocarbons supply (more than one-quarter of global oil and gas production comes from offshore fields). But offshore generation of electricity from renewable sources has been gaining momentum, mainly from offshore wind and, to a lesser extent, from other marine technologies.

Installed offshore wind capacity has risen from 3.2 GW in 2010 to 18.7 GW in 2017, by which time it contributed some 56 terawatt-hours (TWh) or 0.3% of global electricity generation. The key factor behind the rise of offshore wind has been a concerted series of public-private initiatives undertaken by countries bordering the North Sea in Europe. More than 80% of global offshore wind capacity is located in Europe, led by the United Kingdom with installed capacity of 6.8 GW and Germany with 5.4 GW. Beyond Europe, only the People's Republic of China (hereafter, "China") has large-scale offshore wind capacity, at 2.7 GW, while smaller offshore wind facilities are located in the United States, Korea and Japan.

Figure 1.1 • Largest available commercially available wind turbines



* Announced expected year of commercial deployment.

Note: Figures in blue indicate the diameter of the swept area.

Key message • With fewer restrictions on size and height than their onshore counterparts, offshore turbines are becoming giants, a key factor behind anticipated declines in costs.

Although it uses a similar technology to onshore wind, offshore wind is distinctive in that projects are able to tap more consistent and higher wind speeds further from shore, and there are fewer restrictions on ground area and height. As a result, project sizes and turbines are typically larger (Figure 1.1) and performance indicators for offshore wind farms are higher. The potential for electricity generation offshore is huge. It is estimated that by 2027 there will be a technical potential of over 2 000 GW and an economic potential of 144 GW for offshore wind development on the east coast of the United States (NREL, 2016; NREL, 2017). A recent estimate for Northern Europe is 2 700 GW of offshore wind technical potential, with as much as half of this considered economically viable by 2030 (Wind Europe, 2017).

The technical potential for other marine technologies is likewise large, but the economic barriers are significant, especially given the cost advantages of offshore wind (Box 1.1). Continued support for research and development is warranted and, in our judgement, marine technologies could play an important role in specific areas with favourable local resources. A particular opportunity for marine power is to provide sustainable energy to island or remote communities, which would otherwise be dependent on relatively expensive and polluting diesel generators.

Box 1.1 • Can marine power technologies move into the mainstream?

Wind is the dominant offshore technology for electricity generation, but it is not alone (OES, 2018). As of 2017, global marine power capacity was 0.6 GW, generating 1.4 TWh. Two countries account for 90% of this capacity: the 240 MW la Rance Tidal Power Station in France has been operating since 1966 and the 254 MW Sihwa Lake Tidal Power Station in Korea started in 2011. The next largest facility is the 20 MW Annapolis Tidal Power Plant in Nova Scotia, Canada, operating since 1984. Today's main marine generation technology is tidal range, with 99% of total capacity. Tidal range technology shares characteristics similar to hydropower, essentially leveraging the height difference of two bodies of water created by a dam or barrier in order to produce electricity.

Tidal range is evolving with the concept of tidal lagoons: these are artificial basins built in bays and estuaries. A number of sites and projects have been proposed, notably in the United Kingdom, although the UK government decided in June 2018 not to provide funding for the proposed 320 MW Swansea Bay Lagoon project in Wales. The reasons given for this decision are instructive of some of the challenges facing marine technologies: the government noted that the electricity generated by the proposed facility (for a projected cost of GBP 1.3 billion) over 60 years would cost only around GBP 400 million if it came from offshore wind at today's prices, and that there was only limited scope for innovation and cost reduction (estimated at 5%) in the construction of subsequent tidal lagoon facilities.

Other ocean energy technologies in various stages of development include tidal stream, wave power, ocean thermal energy conversion (OTEC) and, most recently, floating solar arrays. Tidal stream is a very predictable energy resource; water currents are harnessed by turbines that could be fixed to the seabed or that float with moorings attached to the seabed (WEC, 2016). Besides tidal streams, it could be possible to harness other streams in the oceans to produce electricity along some coasts or islands; economic exploitation however would require investment in submarine stream-concentrating structures or innovative technologies to compensate for the low speed of the streams.

Wave energy technologies capture the movement of waves to generate electricity. They can be installed along the shoreline or near shore, but they face limitations on the potential resources that can be captured as energy is lost due to friction with the seabed. They could also be located offshore, in depths of tens of metres where there are better energy harnessing potentials. Pilot projects are currently being developed, mostly in the United Kingdom, Portugal and Ireland. Two grid-connected OTEC plants are currently in operation, one in Japan and one in Hawaii, and several other pilot and commercial OTEC projects are planned around the world. In addition, variations in water temperature can serve as a source for heat pumps or cooling devices, with the potential to provide district heating and cooling services in coastal urban areas, as with the Toronto Deep Lake Water Cooling System. Floating solar is a concept that has already been deployed in a number of inland lakes and reservoirs; the largest is a 40 MW plant that opened in Huainan in China in 2017. The first major offshore pilot project is planned in the Netherlands.

Prospects for accelerated deployment

The prospects for growth in offshore renewable electricity generation depend on the interplay of two main elements: costs and policies. These are closely interrelated. Support for deployment accelerates technology learning, innovation and supply chain efficiencies, bringing down costs. Lower costs in turn encourage further support for deployment in other areas with promising resources. Transparent and well-managed procedures for siting and permitting can effectively address concerns about the impact of offshore projects on the marine environment and ease relationships with other maritime industries. We look below at these two areas: the primary focus is on offshore wind, as this technology has the clearest pathway to large-scale deployment, but consideration is also given to marine power technologies.[1]

Costs

Offshore wind technologies are in a particularly dynamic phase of development. A key trend highlighted already is the increasing physical size of turbines. This is having an impact on all cost aspects for offshore wind: increased size puts upward pressure on capital costs as a result of more challenging construction and larger subsea structures; while reduced operation and maintenance and increased performance ultimately lead to lower levelised costs of electricity (LCOE). A second key trend in offshore wind is that installations are moving further from shore and into deeper waters, enabling the industry to tap better quality wind resources, resulting in higher capacity factors. Greater operational experience, coupled with the design of new high-voltage direct cables specifically for harsh marine environments, means that new bottom-fixed offshore wind installations can now be located more than 80 kilometres (km) from shore (versus 20 km previously) and in deeper waters (more than 40 m), with an average distance to the nearest port of more than 40 km in 2016 (WindEurope, 2018). The development of floating offshore technologies is also moving forward, with the aim of tapping additional potential in deeper waters (Box 1.2).

The capital costs per unit of new offshore wind capacity vary widely, depending on project type and location, but average costs for projects actually entering into operation have not come down appreciably since 2010 (IRENA, 2018). However, the performance of these projects has been improving rapidly: the capacity factor of new projects has increased from less than 30% to about 40% for projects commissioned in 2016. Individual projects have been able to achieve notably higher rates, pushing beyond 50% in several cases. Higher capacity factors not only help reduce the LCOE (increasing the capacity factor by ten percentage points to 50% reduces the LCOE by about one-fifth), they can also potentially lower the associated integration costs for offshore wind projects compared with other variable renewable resources, such as onshore wind and solar photovoltaics (PV). This can be an important advantage for offshore wind, and it is especially so where the output profile is well matched to the shape of demand or is complementary to the output of other variable renewables in the system.

[1] Detailed projections for all forms of offshore energy supply, in different scenarios, are available in the *Offshore Energy Outlook* (IEA, 2018).

Other important elements of the overall cost calculation are operation and maintenance costs, the economic lifetime of projects, and the financing costs. Operation and maintenance costs for offshore wind are significantly higher than for onshore projects, owing to the harsh operating conditions and difficulty in servicing turbines in those conditions. Challenging offshore conditions could also affect the expected lifetime of the turbines, although experience is limited to date given that the vast majority of offshore wind capacity is under a decade old. For the purposes of an LCOE calculation, we assume that the economic lifetime of offshore wind is 20 years, the same as for onshore wind, while the technical lifetime for both is most likely in the range of 20 to 30 years.

Financing costs represent a significant portion of the LCOE for offshore wind projects as they do for many other renewable energy technologies. In large part, these costs are a reflection of the risks involved in a project. Where the business case depends on wholesale market revenues, exposed to market price risk, financing costs can make up almost half of the total LCOE. However, policy support can dramatically reduce these risks, especially where price certainty is provided for an extended period as is the case in long-term power purchase agreements or feed-in tariffs.

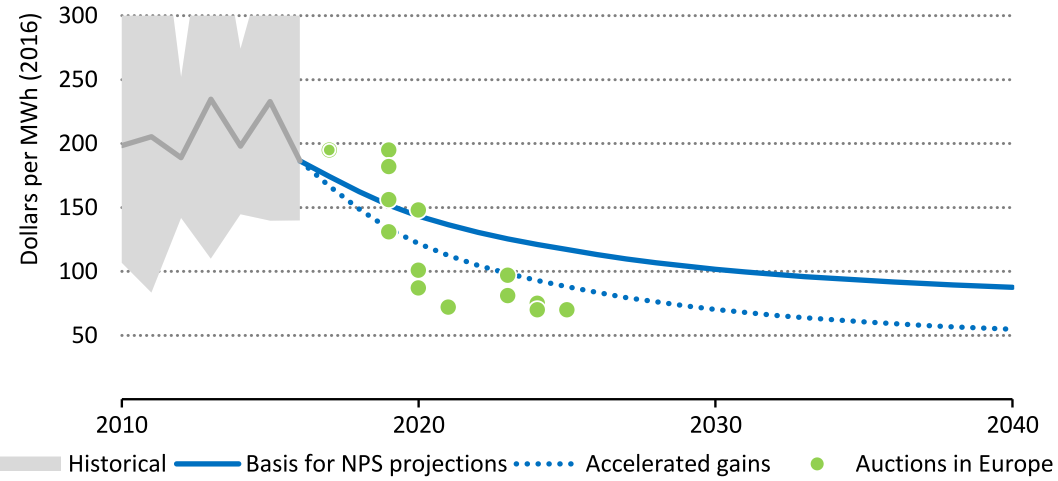
Box 1.2 • How could floating wind turbines change the game?

One of the most advanced innovations for offshore wind is floating structures, which are based on concepts well known and widely deployed in the offshore oil and gas sector. Floating wind turbines allow access to deepwater sites with stronger and more consistent wind speeds, where traditional fixed-bottom wind turbines become prohibitively expensive and difficult to install. The economic potential for floating offshore wind is highly uncertain and sensitive to technology cost declines and prevailing market prices (WindEurope, 2017). However, if it became a commercially competitive technology, it would widen the resource base for offshore wind significantly, given the large share of the resource base located in water depths greater than 60 m. Another consideration is that floating wind turbines could lead to cost savings from greater standardisation of foundation designs and the use of low-cost, readily available, installation vessels. The costs for floating offshore wind are high for the moment but are expected to show a steeper rate of cost reduction over the next 15 years than fixed-bottom technologies, with the potential for approaching cost parity with fixed-bottom offshore wind turbine technology by 2030.

The leading countries in the development of floating offshore wind include G7 economies France, Germany, Japan, United Kingdom and United States, alongside Norway and Portugal. Key demonstration projects for floating offshore wind include spar-buoy projects by Statoil in Norway and Scotland (30 MW commenced operations in October 2017), and multiple testbeds utilising different technologies in Japan. Upcoming demonstration projects include four pre-commercial floating wind farms (each about 24 MW) supported by France through a tender in 2015, a 25-MW project in Portugal and two projects in Scotland, one of which is the largest near-term floating project at almost 50 MW. Other floating technologies being explored include multi-rotor systems, vertical-axis turbines and airborne wind solutions. Floating technologies could provide a valuable option for island systems and they also have the potential to be a game-changer for countries with deep offshore coastal areas, like Japan.

Overall, the global average LCOE from offshore wind projects declined slightly from about USD 200 per megawatt-hour (MWh) in 2010 to an estimated USD 187/MWh in 2016, fluctuating from year-to-year (Figure 1.2). Over this period, a wide range of project-level costs have been reported, including less than USD 100/MWh for one project completed in 2011, to projects more than three-times that level as recently as 2015. At these levels, offshore wind has been relatively expensive to date compared with other renewable energy technologies. For projects commissioned in 2016, the global average LCOE of offshore wind was 150% higher than that of onshore wind and more than 50% higher than that of utility-scale solar PV.

Figure 1.2 • Historical and projected global average LCOE of offshore wind and adjusted strike prices from recent auctions in Europe



Notes: NPS = New Policies Scenario. Auctions refer to adjusted strike prices from recent European offshore wind auctions, with development cost, grid costs and contracted lengths adjusted if necessary (NREL, 2017). LCOEs assume a weighted average cost of capital of 8%. The NPS projections in this report assume an 11% learning rate for capital costs and average capacity factors rising beyond 50% for new projects. Accelerated gains case assumes a 20% learning rate and capacity factors reaching 60% for new projects globally.

Sources: NREL (2017) with IEA analysis.

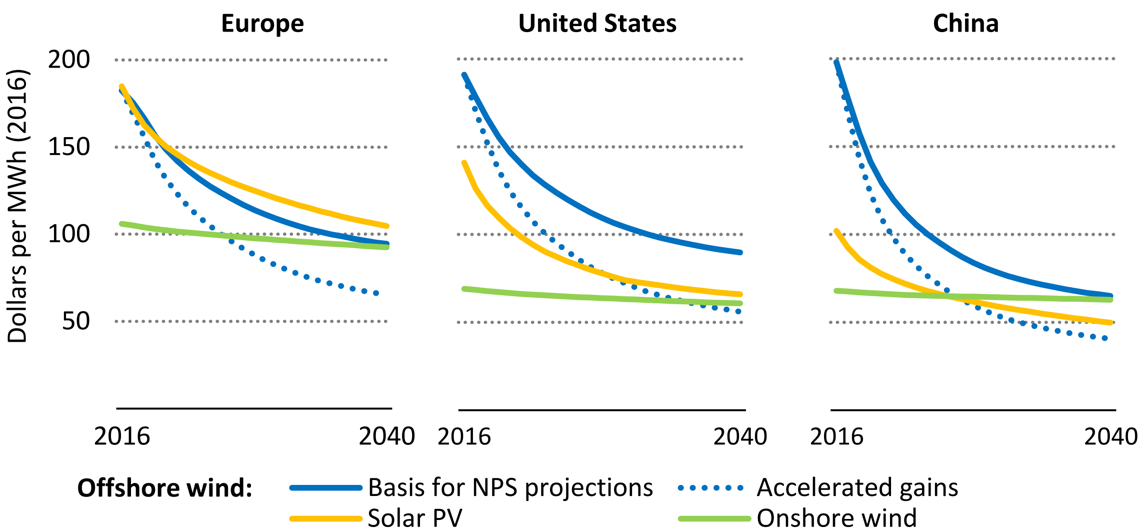
Key message • Recent auction results in Europe, if realised, would mean a step change in costs for some new projects scheduled to enter into operation in the early 2020s.

This is set to change. Based on projected deployment in our New Policies Scenario to 2040 (a pathway that reflects today's energy policy frameworks and announcements), the global average LCOE of offshore wind declines by more than one-third by 2025 and more than half by 2040, based on projected deployment in the New Policies Scenario. More optimistic assumptions about the pace of technological progress and learning (a 20% reduction in cost for each doubling in cumulative capacity, as opposed to the 11% in the New Policies Scenario) and higher assumed capacity factors for new projects (rising to an average of 60% for new projects by 2040, as opposed to just over 50% in the New Policies Scenario) would bring the global average LCOE to half of today's level by 2025 and 70% below in 2040.

Adjusted strike prices from recent European offshore wind auctions point to the possibility of a strong pace of cost reductions, with projects approaching USD 70/MWh by 2025 (Figure 1.2). If these projects prove to be representative of the typical costs of new projects, it would drastically change the relative competitiveness of offshore wind among renewable technologies, as well as with fossil fuels and nuclear power. At the very least, these auction results represent a vote of confidence in the future of offshore wind and reflect the growing optimism about the benefits of ever-larger turbines coming to the market.

In Europe, the trajectory for offshore wind LCOEs in the New Policies Scenario would bring them below those projected for solar PV and towards parity with onshore wind. In the United States, the situation would be somewhat different: even if costs for European projects were translated directly to the US context, offshore wind would remain more expensive than onshore wind and solar PV. This does not rule out deployment, especially for projects located close to demand centres along both the east and west coasts, though floating turbines would be imperative for development in the deep waters on the west coast.

Figure 1.3 • Projected LCOEs of offshore wind, onshore wind and solar PV



Notes: All technologies are evaluated based on the same WACC: 8% in real terms in Europe and the United States, and 7% in real terms in China.

Key message • Although relatively expensive to date, falling costs for offshore wind are set to change its competitive position among renewables and other sources of generation.

However, if offshore wind were to achieve an accelerated pace of cost reductions, while other technologies remain on the pathway used as a basis for the New Policies Scenario, then offshore wind would become the least expensive renewable source of electricity in Europe, the United States and China by 2040. On this cost trajectory, it would also be likely that offshore wind power would also become one of the cheapest sources of new electricity across all power generation technologies.

The potential upside would be particularly pronounced in Europe, especially if there is opposition to new onshore sites for wind and solar PV. Offshore wind could also benefit in scenarios that see even very rapid electrification of end uses and/or in which policy encourages industrial users to switch to hydrogen, ammonia or other hydrogen-rich chemicals and fuels that could be produced using the ample offshore wind resource. In the United States, although faster cost reductions would surely energise the industry, the impact would likely be more limited since onshore wind and solar PV (and gas-fired power plants) hold on to a cost advantage well into the 2030s. In China, the effect of such rapid cost reductions could also be sizeable, with the potential for offshore wind to displace output from existing fossil-fuelled power plants. Beyond these three leading markets, more rapid cost reductions would spark increased attention in interested countries, including Japan and Korea, and could help further expand the market for offshore wind.

Marine power technologies remain nascent in most markets to date and, even more so than for offshore wind projects, site-specific factors are critical to the cost calculation. For tidal range technology, the LCOEs of the two large plants in operation in France (240 MW) and Korea (254 MW) are estimated at $44/MWh and $22/MWh respectively (IRENA, 2014). However, the very favourable conditions underpinning these projects may not be easy to replicate: estimated costs for tidal range technologies in general stood at $440/MWh and wave energy at $500/MWh in 2015 (WEC, 2016). Looking forward, a study by the IEA Technology Collaboration Programme for Ocean Energy Systems (OES) in 2015 estimated ranges for the LCOEs for commercial-scale projects for tidal stream at $130-280/MWh, wave energy at $120-280/MWh and OTEC at $150-280/MWh (OES, 2015).[2] Additional targeted research, development and deployment support would be essential to unlock technological innovations and drive down these costs and bring them closer to other renewable sources of generation.

Policies

The expanded deployment of renewable energy hinges on effective policy frameworks and support, even where costs are low. Several countries have identified offshore wind as a key component of their renewables policies, and a growing number of jurisidications have announced capacity targets and supportive policies. Targets and support schemes for offshore wind and marine power are, for the moment, not as widespread as those for solar PV and onshore wind.

Among the G7 economies (and indeed among all countries worldwide), the most ambitious capacity targets for offshore wind are in the United Kingdom and Germany. The United Kingdom announced in July 2018 its intention to hold auctions every two years from 2019; depending on the auction prices, this could see 1-2 GW of new offshore wind installed every year in the 2020s. Germany is targeting 6.5 GW of offshore wind by 2020 and 15 GW by 2030. France has a target of 3 GW by 2023 and an additional 6 GW by 2030. Italy has a strong overall goal for wind generation in its national energy strategy, although the extent to which offshore resources will contribute to this objective is not yet clear. Other countries with specific commitments to offshore wind in the European Union include the Netherlands, Denmark and Sweden.

Japan has long considered offshore wind as part of its renewable energy strategy and the enhanced emphasis on decarbonisation in the 5th Strategic Energy Plan approved in July 2018 could bode well for its deployment. Major Japanese utilities, including the Tokyo Electric Power Company, have signalled a readiness to boost the nascent Japanese market for offshore wind, including the development of floating technologies. The United States has large offshore wind potential, although the only offshore wind project currently in operation is the 30 MW Block Island facility off Rhode Island, after the cancellation of the 468 MW Cape Wind project off the coast of Massachusetts due to permitting difficulties and opposition from some coastal communities. However, there are clear signs that the cost reductions seen in

[2] Estimated LCOE for a 100 MW plant.

recent auctions in Europe are sparking a new round of interest. There are already some state-level initiatives. Massachusetts has mandated 1.6 GW to be installed by 2027 and New York is targeting 2.4 GW by 2030. In Canada, the government is proposing a new legislative regime that will establish a regulatory framework for renewable energy projects in federal offshore areas hence providing greater certainty for industry and stakeholders for the regulatory review of these projects. Funding available as part of the Pan-Canadian Framework on Clean Growth and Climate Change is set to spur increased activity in a range of renewable technologies.

Among other global players, China is a major market for offshore wind and, as part of its 13th Five-Year Plan, has a target of 5 GW installed by 2020. Chinese Taipei recently upped its 2025 target from 3 GW to 5.5 GW. Authorities in India have announced plans for auctions for 5 GW of offshore wind projects by 2022. Korea has made offshore wind together with solar PV a key priority in order to meet the country's renewable energy targets, including the aim (in the new 8th Basic Plan for Electricity Supply and Demand, announced in late 2017) to build 10 GW of offshore wind capacity by 2031.

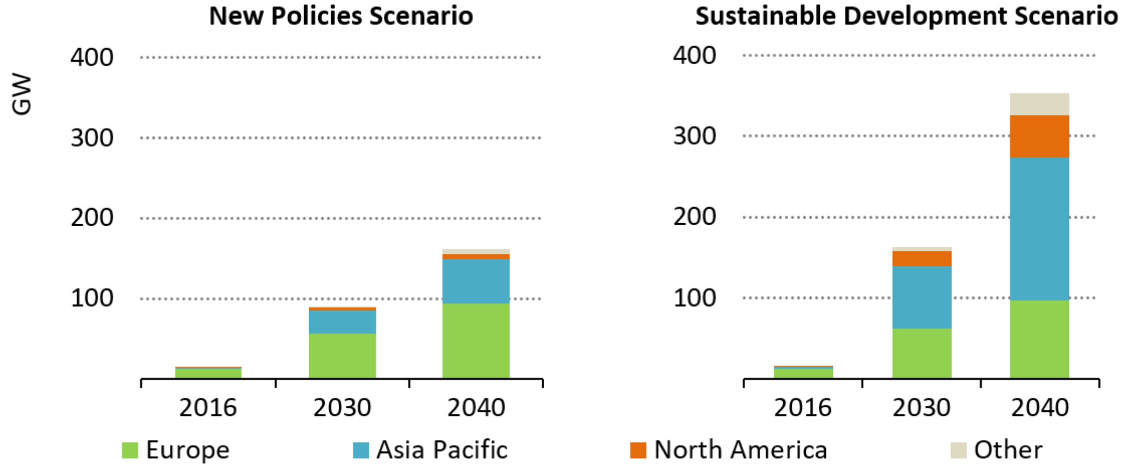
Many G7 economies also have policies in place supporting marine power technologies; these are typically action plans or strategic documents that set out a vision for the actions required – both by private and public sectors – to facilitate technology development and deployment. Canada, Japan and the United Kingdom also have specific roadmaps that can mobilise national efforts in support of a long-term deployment pathway. The pathways typically cover ways to enhance the economic competitiveness of the various technologies, alongside considerations of employment and energy security. As of end-2017, most G7 countries also have market deployment policies in place, such as feed-in tariffs (or, in the case of the United Kingdom, contracts for difference), that are available to support tidal and/or ocean energy (OES, 2018).

In the New Policies Scenario, we assess how the energy system might evolve if countries follow through with existing and announced policies. Given the continued reliance of offshore deployment on supportive policies, this means that countries that have not yet announced plans for offshore renewable energy development are not assumed in our scenarios to install capacity before 2040; the projections should therefore be considered a "floor" projection for the future (assuming all countries achieve their stated ambitions). It is *not* a forecast; as we have seen, countries could well increase their ambition in the future, leading to higher deployment and to further cost reductions, reflecting learning effects.

Overall, installed offshore wind capacity grows to around 160 GW in the New Policies Scenario, generating 580 TWh by 2040. Marine technologies see increased growth after 2030, albeit from a low level. Offshore power generation increases its share in the global generation mix to just over 1.5% in 2040, making up 4% of the 15 700 TWh of total renewables-based power generation (Figure 1.4). Growth is dominated in this scenario by Europe: considering only the European Union (in its 2018 composition), the share of offshore power in total generation approaches 10% by 2040.

In the Sustainable Development Scenario (a scenario in which the world meets air quality and climate change goals, as well as securing universal access to modern energy), offshore electricity production gets a major boost via enhanced policy support and lower costs. Worldwide installed offshore wind capacity rises above 350 GW in 2040, more than double the level in the New Policies Scenario, and generation increases to 1 200 TWh. The relatively minor upswing for offshore wind in Europe in this scenario reflects the favourable costs of onshore wind, but – as noted above – this balance could well shift if there are any restrictions on onshore development or if cost declines for offshore wind are steeper. The outlook for marine power technologies shows some upside compared with the New Policies Scenario, but their competitiveness relative to other low-carbon options remains a barrier to a major acceleration in deployment.

Figure 1.4 • Global offshore wind capacity by scenario



Notes: All technologies are evaluated based on the same WACC (weighted average cost of capital): 8% in real terms in Europe and the United States, and 7% in real terms in China.

Key message • As things stand, Europe is set to dominate the offshore wind market, but cost reductions in the North Sea could spark a virtuous circle of accelerated deployment and technology learning elsewhere.

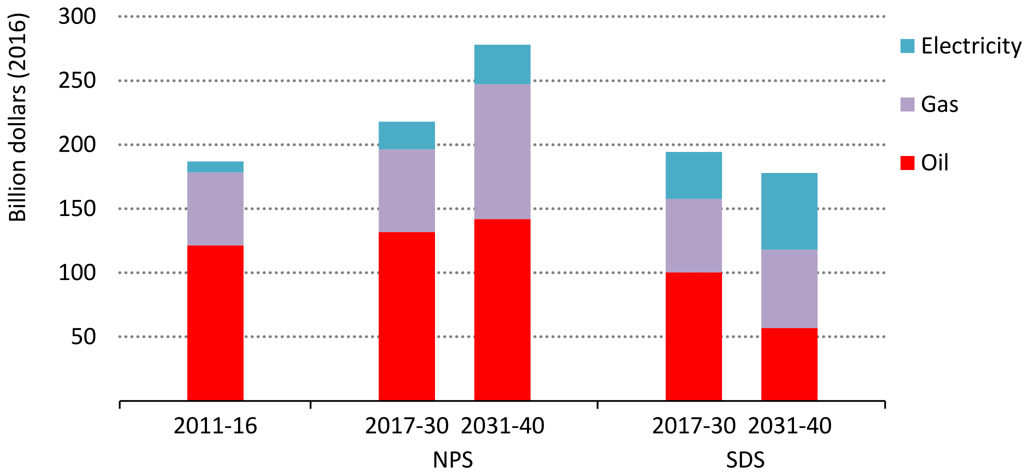
Countries in the Asia Pacific region install almost 180 GW of offshore wind by 2040 in the Sustainable Development Scenario, compared with less than 60 GW in the New Policies Scenario. China adds more than 100 GW of capacity, while India, Japan and Korea each add substantial amounts. Offshore wind capacity increases significantly in the United States, making it the third-largest market for this technology after China and Europe. Deployment spreads beyond these core markets, with countries such as Australia, Brazil, Canada, Mexico and the Russian Federation all becoming important markets for offshore wind. In this scenario, Investment in offshore electricity generation picks up strongly in this scenario, reaching rough parity with investment in offshore oil or in offshore natural gas by the 2030s (Box 1.3).

Each G7 economy faces specific circumstances and there is no one-size-fits-all approach to fostering an offshore renewable electricity industry. Moreover, many aspects of offshore policy and regulation are included in existing frameworks for the electricity or renewable sectors, or are covered under broader initiatives for marine development. That said, the experience thus far also suggests some distinctive policy and regulatory elements that can underpin the development of offshore renewables. Much of the experience accumulated thus far comes from Europe, and is concentrated in the offshore wind sector (see, for example, Danish Energy Agency, 2017). But many of the lessons apply to other power technologies: all offshore renewable projects have to operate in the same marine environment, and all stand to benefit if suitable supply chains and grid infrastructure are developed.

Box 1.3 • Investment in offshore energy supply

The offshore energy sector, encompassing oil and gas production as well as electricity generation from wind and other marine technologies, requires major investment in both our scenarios: some USD 5.9 trillion in cumulative capital spending to 2040 in the New Policies Scenario and USD 4.6 trillion over the same period in the Sustainable Development Scenario. The composition of this investment varies by scenario and shifts over time (Figure 1.5).

Figure 1.5 • Average annual global offshore energy investment by scenario



Notes: The figures for new investment cover capital expenditure, i.e. the creation or refurbishment of assets that extract, transform or transport energy. They do not reflect operating expenditure, i.e. to ensure the day-to-day functioning of the asset, nor the costs of decommissioning. NPS = New Policies Scenario; SDS = Sustainable Development Scenario.

Key message • Although the composition shifts, overall offshore investment activity remains robust in both scenarios, a reassuring picture for the offshore supply and services industry.

A cumulative USD 530 billion of capital investment in offshore wind is required from 2017 through to 2040 to meet the projections in the New Policies Scenario, averaging USD 22 billion per year but in practice increasing at a compound average annual growth rate of almost 2% per year from today. The cumulative figure almost doubles to just below one trillion dollars in the Sustainable Development Scenario, growing at 3.5% per year from today.

The cost of the turbines themselves is the largest single element of capital expenditure, accounting for around 40-60% of capital costs. Using this range as the minimum and maximum of the annual average investment in both scenarios, the annual average market for offshore wind turbines is between USD 9-13 billion in the New Policies Scenario and between USD 16.5-25 billion in the Sustainable Development Scenario. Offshore wind foundations (15-30%) and installation costs (10-25%) are the next biggest shares of capital costs. This implies that average annual spending on foundations range between USD 3-6.5 billion in the New Policies Scenario and USD 6-12.5 billion in the Sustainable Development Scenario, while the potential annual market for offshore wind installations is USD 2-5.5 billion in the New Policies Scenario and USD 4-10.5 billion in the Sustainable Development Scenario.

1. A long-term vision for offshore wind

Such a vision is very important to support the emergence of an efficient offshore supply chain, both via support for research, development and deployment (RD&D) activities and by increasing confidence in long-term market opportunities. Public support for RD&D helps to bring advanced technologies to the stage at which they can be commercialised; this is particularly important for marine power technologies, many of which are in the pilot or demonstration phase: in Europe, for example, more than $3 billion has been spent on ocean energy over the last decade, one-third of which was public funding via EU and national programmes, in order to develop and test new technologies (European Commission, 2018). In the case of offshore wind, research efforts are still required for emerging areas such as floating wind turbines, as well as to adapt existing European technologies to the prevailing conditions in other markets.

A long-term vision typically incorporates targets for deployment and considers not only the direct supply chain (including transmission infrastructure), but also broader elements such as port and vessel requirements, interactions with other maritime industries and offshore activities, and the availability of relevant skills and expertise. The need for a resilient and specialised logistics capability is much greater for offshore projects than for their onshore counterparts. Reasonable visibility on the pipeline of future projects and the likely size and timing of future market demand is also vital to develop a mature and efficient offshore wind industry. A phased outlook, co-ordinated with anticipated power demand and system requirements, can help to avoid construction peaks and troughs.

2. Good data on good sites

Good site data on wind, water conditions and the sub-surface help to optimise project designs, lower capital costs and give greater precision to preconstruction estimates. In the case of offshore wind, many potential project sites with significant wind potential lack good information on meteorological, oceanographic and other conditions. This means higher uncertainty for potential developers, which translates into higher risk and therefore increased financing costs. Sites for offshore wind projects also need to be of sufficient size to allow for economies of scale. In the case of marine power technologies, ocean testing facilities play a vital role in providing infrastructure and expertise to measure the resource.

3. Efficiency, consistency, and clarity in the regulatory process

Offshore developers, financiers and power purchasers need to be able to manage regulatory and environmental compliance in a predictable way. Some European countries have facilitated this process by establishing a one-stop shop, i.e a single entry point for all regulatory and permitting issues for new offshore wind projects. This reduces uncertainties over timelines and also shortens the time period between the moment when costs are calculated and when contracts are concluded with suppliers. As part of this process, some jurisdictions conduct all preliminary investigations in advance – including all necessary Environmental Impact Asessments – so that the designated sites are ready, limiting risks for investors and developers.

4. Competitive tenders (or other support schemes)

There is a variety of such schemes in place, and they are evolving as costs come down, but all offshore renewable energy developments have required some kind of mechanism that increases revenue certainty, while incentivising cost reductions and innovation. A notable recent trend (across many renewable technologies) is the increasing prevalence of auctions as a way of determining the level of support required, rather than administratively set subsidies such as feed-in tariffs. The scale and longer lead times of offshore wind, relative to most other onshore utility-scale renewable projects, underscore the advantage of auctions for this technology as a means to spur competition and innovation. Some recent European auctions generated some bids that did not require any price guarantees at all, albeit at favourable conditions with the cost of grid connection taken by the transmission system operator. Well-designed auctions typically include pre-qualification requirements for bidders as well as penalties for failure to deliver.

5. Certainty on transmission connections

Offshore electricity generation projects have unique transmission needs and co-ordinated development of the offshore wind farms and the transmission grid is essential. Proximity to major consumption centres and the requirement for transmission infrastructure needs to be an integral part of site selection, with planning and implementation of new transmission connections starting well in advance of project start-up dates in order to reduce the risk of delay and cost overruns. The prices of offshore wind can be reduced significantly if the investor is sure that the grid can take output as soon as the project is ready.

Large-scale deployment of offshore wind is likely to require moving beyond a project-by-project approach (in which each project has an individual connection to the onshore grid). There are significant financial, technical, and environmental benefits to be gained from a more coordinated strategy, whereby neighbouring wind farms are grouped and connected together to shore, as reflected in a number of initiatives in Europe's North Sea. However, alongside more systematic infrastructure planning, there is also a need for technology development in the construction and operation of meshed DC cable networks, and for a regulatory environment that adequately covers the development and operation of the offshore grid. In many cases, the crossover between the DC cables and the onshore AC network is problematic, as the amount of electricity landed from a large offshore wind development can create congestion. In most countries the regulatory treatment of this is still unclear.

6. Interactions with other maritime industries and the marine environment

Large-scale deployment of offshore renewable energy requires that direct impacts on wildlife, sensitive habitats, and existing uses are properly managed. An integrated approach to different maritime activities and to the marine environment can help to resolve potential conflicts, and early consultation and good-faith efforts to reach compromise can avoid multiple problems down the road. This means careful consideration of competing interests such as shipping routes, areas for fishing and other maritime activities, and potential impacts on coastal communities as well as on environmentally sensitive sites.

Maritime spatial planning is an important policy tool to reduce the potential for conflicts between offshore interests, as well as to capture efficiency gains (e.g. via clusters of offshore wind projects, grid planning and cable hubs) and to allow tidal and wave projects to benefit from shared infrastructure (e.g. vessels, cables, anchoring). Regular monitoring of the impacts of offshore renewable energy developments helps to improve policy design and to inform a reliable assessment of the benefits and costs of offshore projects for stakeholders and the public debate.

7. Synergies with other offshore energy activities and supply chains

The scale and size of offshore wind projects and the need to work in a difficult marine environment creates significant potential for productive relationships between offshore wind and other offshore energy activities (Box 1.4). The North Sea, a relatively mature oil and gas basin with a thriving renewable electricity industry, is already seeing significant crossover between the sectors. As its energy profile gradually changes, the North Sea is also likely to test the technical and commercial validity of other, longer-term concepts for collaboration. However, the potential synergies are not confined to Europe; and the need for integrated offshore thinking extends well beyond the energy sector to encompass shipping, port infrastructure, other maritime industries and all aspects of the marine environment.

Box 1.4 • Can oil and gas give offshore renewables a helping hand?

Many of the competencies required to construct and maintain offshore energy projects are transferable across different types of activity, opening up a broad span of potential interlinkages between oil, gas and offshore renewables. Large-scale project management capabilities and the ability to work in harsh offshore conditions have already brought a number of large oil and gas companies into offshore wind projects in the North Sea.

There is also significant overlap in the supply and services components. While there is relatively little complementarity in the manufacture of turbines, the construction of the turbine foundations can leverage the considerable experience of the oil and gas industry with subsea structures: this would apply also to floating facilities and their associated anchors and moorings. There is also a variety of equipment and support services during the installation phase that have cross-over potential, as well as some significant possibilities to provide maintenance and inspection services – an area where oil and gas practices and safety standards overlap. Overall, we estimate that about one-third of the components in the full lifetime costs of a standard offshore wind project may have significant synergies with the offshore oil and gas sector.

Offshore oil and gas installations also require a lot of electricity, typically generated at present via relatively inefficient diesel or gas-fired turbines on the platforms. There is the possibility to electrify offshore oil and gas operations where there are wind farms nearby, or via floating turbines, reducing the need to run generators on the platform and bringing down emissions of CO_2 and air pollutants. The intermittency of power from offshore wind is a challenge, although there are operational and technical measures (including battery storage) that could mitigate this issue.

Electrification would keep the door open to a range of potential options for re-use or re-purposing of offshore oil and gas platforms once they reach the end of their operational life. We estimate that between 2 500 and 3 000 offshore oil and gas projects are likely to require decommissioning between now and 2040. Currently the industry decommissions around 120 structures per year, mostly in North America, but this becomes a much wider issue as more facilities in other regions reach the end of their operational lifetimes.

Removing offshore infrastructure is typically the best way to minimise environmental and safety risks, but there is scope in some cases for other approaches: more than 500 platforms in the Gulf of Mexico, for example, have already been converted to permanent artificial reefs. There are also energy-related applications: for example, platforms could provide offshore bases for maintenance of wind farms, be used to inject CO_2 into depleted fields, or – looking further ahead – even house facilities to convert power to hydrogen or to hydrogen-rich fuels.

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