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Foreword

The dynamics of offshore energy are changing. Oil and natural gas produced offshore are major elements of global supply, with gas production showing most of the growth in recent years. Offshore electricity generation, negligible a few years ago, is rising rapidly, led by offshore wind developments in Europe's North Sea. Offshore energy resources are huge and costs for new projects are coming down, but many developments still face significant market, policy and, in some cases, technology uncertainties. In the case of oil and gas, the shale revolution has opened up a major new onshore opportunity, meaning that offshore projects face a much more competitive environment in the near term. Decisions to go ahead with large, capital-intensive oil and gas projects also have to consider questions over long-term demand. Meanwhile, there is unmistakeable momentum behind the offshore wind industry, which can tap higher and more consistent wind speeds away from land; but investments have to prove their worth against other generation options, including onshore wind and solar.

This new report, in the flagship *World Energy Outlook* series, addresses all aspects of offshore energy production, how they are today and how they might evolve in various scenarios in the future. It highlights not only the individual components of the offshore picture, but also the synergies between them, and underscores the strengths of the IEA's all-of-energy approach. What emerges is that offshore energy activity looks full of promise for the future, even as the profile of this activity continues to change. Governments and industry need to be constantly attentive to the need for innovation, for high standards of safety and environmental performance, and for integrated thinking about the linkages between the various supply chains and infrastructure, as well as the place of energy in the wider ocean economy. What is also clear is the vital role that the IEA family is playing in this area, especially with the entry over the last year of Mexico as the 30th IEA member country and of Brazil as an Association member, and the participation in the Agency of all of the pioneering countries for offshore wind. I am very pleased that the IEA, thanks to the excellent efforts of Tim Gould, Brent Wanner and the *World Energy Outlook* team, can contribute to the debate on this important issue.

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Executive Summary

Energy produced offshore is a major component of global oil and natural gas supply and could provide an increasingly important source of renewable electricity. Resources are enormous, but offshore projects have to prove their worth in a changing market and policy context, amid a variety of pressures on the world's oceans. More than a quarter of today's oil and gas supply is produced offshore, mostly in the Middle East, the North Sea, Brazil, the Gulf of Mexico and the Caspian Sea. While offshore oil production has been relatively stable since 2000, natural gas output from offshore fields has risen by more than 50% over the same period. Offshore electricity generation, mainly from wind, has increased rapidly in recent years, notably in the relatively shallow coastal waters of Europe's North Sea. But it is not all plain sailing. The 2010 Deepwater Horizon accident and spill in the Gulf of Mexico was a major setback for the offshore hydrocarbons industry; prospects for offshore oil and gas have also been shaken by the shale revolution and by lower prices, and must cope with longer-term uncertainties over demand. Offshore wind is a rising force, but remains for the moment a relatively marginal one at 0.2% of global electricity generation; wind and other marine technologies face stiff competition from a range of onshore options, including other low-carbon sources of generation. This new report in the *World Energy Outlook* series provides a detailed assessment of the outlook for offshore energy against a dynamic backdrop of energy market, policy, technology and environmental considerations.

Offshore energy activity looks set to rise

In our projections to 2040, the amount of energy-related offshore activity is poised to increase in both scenarios, although the fortunes of oil, gas and wind power vary depending on the policies in place. This resilience is good news for the offshore supply and services industry; the world's continued need for offshore energy is also good reason for regulators to pay close attention to operational and environmental performance. In the New Policies Scenario, in which we explore the evolution of the global energy system in line with existing policy frameworks and announced intentions, offshore oil production edges higher, while gas surges ahead to become – in energy-equivalent terms – the largest component of offshore output. Generation from offshore wind rises by more than ten times to 2040, helped by supportive policies in Europe, the People's Republic of China (hereafter, "China") and elsewhere. In a Sustainable Development Scenario, in which the world gets on track to attain its climate, air quality and energy access goals, the balance of offshore activity shifts, but the overall level remains substantial. By the 2030s, offshore investment in this scenario – currently heavily weighted towards oil – is split into three roughly equal parts as oil and (to a lesser extent) gas output growth is lower than in our main scenario, while offshore electricity generation grows twice as fast and provides 4% of global power generation by 2040. Overall, the Sustainable Development Scenario requires $4.6 trillion in capital investment in all types of offshore energy over the period to 2040, compared with $5.9 trillion over the same period in the New Policies Scenario.

Offshore oil and gas projects are being re-engineered for a lower price world

The costs of many offshore oil and gas projects have come down sharply in recent years, as companies try to ensure their viability in a shale-inspired lower price environment. In the aftermath of the oil price fall in 2014, proposed new deepwater projects were generally among the first to be delayed or cancelled as the industry moved towards shorter cycle investments, including shale. But offshore projects are now coming back into the picture, typically looking much leaner and fitter than they did before: only the best projects are going ahead, but capital investments in the Norwegian offshore and in the US Gulf of Mexico that once required a breakeven oil price of $60-80/barrel are now claimed to be robust at $25-40/barrel. Designs are being simplified, standardised and (in some cases) downsized, and a large overhang in the market for offshore services and equipment is also helping to exert downward pressure on costs – although this could be reversed as activity levels pick up. Digitalization of offshore operations is being widely pursued as the next frontier for efficiency gains and cost reductions.

In a world in which natural gas demand rises by almost 50% to 2040 and oil consumption continues to grow, the interest in offshore hydrocarbon resources remains strong. Shallow water oil production from more mature basins falls in the New Policies Scenario, but this is offset by a rise in deepwater output. Although exploration activity has tailed off recently, deepwater has accounted for around half of discovered oil and gas resources over the last ten years. Brazil remains the global leader in deepwater production; Mexico also sees rapid growth as a result of successful bidding rounds since 2016, alongside the United States, African producers and some new players including Guyana and Suriname. A 700 billion cubic metre (bcm) rise in offshore gas production to 2040 is split equally between shallow and deepwater developments, bringing the share of offshore production in total gas output above 30% by 2040. Many countries and regions contribute, from Brazil to Australia and the Eastern Mediterranean, but the largest growth comes from the Middle East, with continued development of the world's largest gas field (called South Pars for Iran, the North Field for Qatar) and from Africa, notably due to the development of the huge gas finds off Tanzania and Mozambique. The prospects for offshore gas remain relatively robust in a Sustainable Development Scenario, but a decline in oil demand in this scenario weighs against new capital-intensive offshore oil projects.

Watch out for a wave of decommissioning

Offshore oil and gas activity is not limited to new investments: between 2 500 and 3 000 projects are likely to require decommissioning between now and 2040 as they reach the end of their operational lifetimes. The types of projects being decommissioned are also set to evolve: most activities to date have involved steel platforms in shallow water but the future will also require dismantling more complex structures in deeper water. Removing offshore infrastructure is typically the best way to minimise environmental and safety risks, but there is scope in some cases for re-use or re-purposing. More than

500 platforms in the Gulf of Mexico, for example, have already been converted to permanent artificial reefs. There are also potential synergies with other ocean industries, including offshore wind.

Offshore wind – the new kid on the block

Policy support, technology advances 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, tapping better quality wind resources and pushing 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. The first projects using floating wind turbines are also now entering into operation, based on concepts widely deployed in the offshore oil and gas sector; 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 nascent offshore technologies into the mainstream.

The promise of cost-competitive offshore wind in Europe's North Sea could spark a virtuous circle of accelerated deployment and technology learning elsewhere, but there are still uncertainties over future competitiveness. The costs of offshore wind projects commissioned in 2016 vary widely, but on average are 150% higher than onshore wind and more than 50% higher than utility-scale solar photovoltaic (PV) projects. However, the results of recent auctions in Europe suggests a step change 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 provide a powerful stimulus for policy support and investment elsewhere in the world. This would be essential to bump up offshore wind deployment beyond the levels seen in our main scenario (where the rise from 14 gigawatts [GW] of capacity to 160 GW is concentrated in Europe and China) 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, in which the power sector is almost completely decarbonised by 2040, more rapid electrification of end-uses and/or any limitations on onshore deployment – for example, due to public opposition to wind farms or new hydropower projects – would open up further upside for offshore developments.

Integrated thinking on energy and the ocean economy

The growth of offshore wind creates potential synergies with the offshore hydrocarbons sector; integration could bring benefits in terms of reduced costs, improved environmental performance and utilisation of infrastructure. The interlinkages between the different offshore energy industries are in three major areas:

- The **overlapping competencies** required to construct and maintain offshore projects and to operate in harsh marine environments. We estimate that around one-third of the full lifetime costs of an offshore wind project (including operation, maintenance and service costs) may have significant synergies with the oil and gas supply chain.
- The possibility to **electrify offshore oil and gas operations** where there are wind farms nearby, or via floating turbines, reducing the need to run diesel or gas-fired generators on the platform and reducing emissions of carbon dioxide (CO_2) and air pollutants.
- The scope to find **new uses for existing offshore infrastructure** once it reaches the end of its operational life, in ways that might aid energy transitions: for example, platforms could provide offshore bases for maintenance of wind farms, house facilities to convert power to hydrogen or ammonia, or be used to inject CO_2 into depleted fields.

The North Sea, a relatively mature oil and gas basin with a thriving renewable electricity industry, is already seeing some crossover between the sectors: some large oil and gas companies are major players in offshore wind; one former oil and gas company, Ørsted in Denmark, has moved entirely to wind and other renewables. As its energy profile gradually changes, the North Sea is also likely to be the laboratory that tests the technical and commercial validity of the 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.

Purpose and scope

Offshore energy production is a major element in the global supply picture. More than a quarter of the world's oil and natural gas is produced offshore, and the waters around many countries and islands are also now seen as a major potential source of electricity supply as well; primarily, although not exclusively, from offshore wind power.

Offshore energy resources are abundant, and many of the technologies to produce them are well placed to deliver competitive products. Nevertheless, questions remain as to how offshore energy production will fare in the period to 2040. Many of today's major offshore oil and gas provinces – such as the North Sea, the Gulf of Mexico and the Niger Delta – are relatively mature, and the next wave of offshore resources are generally in deeper water and further from shore, bringing new technological, logistical and cost challenges. The shale revolution has brought a major onshore resource into play, and some investment opportunities in offshore oil and gas have struggled in a shale-inspired lower price environment. For electricity, the potential to generate power offshore is huge, but offshore wind and other marine power projects compete against a range of onshore generation options, including other low-carbon technologies. The outlook for offshore energy also has to be seen in the context of broader pressures on ocean resources and space (Box 1).

Box 1 ▻ Offshore energy in the overall ocean economy

The ocean economy is a vital source of food, energy, minerals, health, leisure and transport. The traditional maritime economy includes shipping, fishing, recreation and tourism and, for the past 50 years or so, offshore oil and gas production. Offshore electricity generation is one example of an up-and-coming maritime activity, alongside aquaculture, seabed mining, maritime surveillance and marine biotechnology.

Overall, the ocean economy was estimated to be worth $1.5 trillion in 2010, of which offshore energy accounted for more than one-third (almost entirely from oil and gas). The potential for growth is huge, with modest growth in some large sectors such as oil and gas accompanied by faster rates in emerging sectors such as offshore wind. The contribution of the entire ocean economy could grow to more than $3 trillion by 2030 under a business-as-usual scenario, by which time it might support more than 40 million jobs worldwide (OECD, 2016).

The linkages between different ocean industries are set to be an increasingly important element of the policy debate in the coming decades, as countries look to reconcile the huge potential of the oceans with rising pressures on the marine environment, including over-exploitation, pollution, declining biodiversity and climate change. As a result, some countries are moving in the direction of more integrated multi-sector policy frameworks for ocean management, rather than the individual sector models that are more prevalent today. This is bringing oil, gas, wind and marine energy activities into a much wider conversation about the future of the ocean economy.

The aim of this report is to explore how the contribution of offshore resources to global energy supply might evolve, in different scenarios, to 2040. The consideration of different scenarios is vital. Costs and technology developments across the energy sector are uncertain. A key variable for the various pathways that energy policies could follow is the strength of the response to environmental concerns and climate change. A single event or accident could change the outlook: offshore hydrocarbon developments operate in the shadow of the Deepwater Horizon accident and oil spill in the Gulf of Mexico in 2010, and the knowledge that another serious accident or spill, anywhere in the world, would affect the prospects and pace of projects everywhere. Public pressure, often on social or environmental grounds, also influences the outlook for offshore wind and other marine technologies, both directly (via support for or opposition to specific projects) and indirectly (by ruling out or favouring competitive onshore low-carbon options).

We address some of these uncertainties by framing the discussion around two scenarios, derived from the *World Energy Outlook 2017 (WEO 2017)* (IEA, 2017a).[1] The scenarios are differentiated primarily by varying assumptions about the policies that governments around the world put in place:

- The **New Policies Scenario** incorporates the impact of existing energy policies and frameworks as well as an assessment of the results likely to stem from the implementation of announced policy commitments. As such, it provides an indication of the direction in which the energy system is heading (noting that this is not a forecast, as these policies and frameworks are certain to evolve in the future). The projections in the New Policies Scenario show significant progress in meeting global energy and environmental goals, with the power sector in the vanguard of the energy transition. However, a continued projected rise in global energy-related carbon dioxide (CO_2) emissions in this scenario is clearly out of step with the objectives of the Paris Agreement.
- The **Sustainable Development Scenario** is a different type of scenario, in that it does not work forward from declared policy ambitions to see where they lead, but rather works backward from a defined endpoint and assesses what would be required to reach it. The endpoint in this scenario is the achievement of the energy-related components of the United Nations 2030 Agenda for Sustainable Development: action on climate change consistent with the Paris Agreement, major reductions in the pollutant emissions that cause poor air quality and universal access to modern energy.

The roles that offshore energy plays in these two scenarios are quite distinct, generating insights about the risks and opportunities facing the relevant actors. Nonetheless, the level of overall offshore energy investment activity remains relatively high in both scenarios, a

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[1] For this report, we enhanced the way that offshore activities are represented in the World Energy Model, the large-scale simulation tool that underpins the *World Energy Outlook* analysis. Offshore energy production, for oil, gas and wind, was modelled in more detail, including detailed hourly simulations of the evolving market value of offshore wind and more granular consideration of the outlook for various oil and gas resource types and water depths.

finding that reflects the potential resilience of the offshore sector both to current market and cost challenges, and to broader uncertainties about the future.

This report is organised in four main sections. First, we provide an overview of offshore energy production today. The second section is an analysis of offshore energy production in our two scenarios to 2040, including detailed consideration of possible cost and technology developments. The third section explores the opportunities and challenges for investment. We conclude with a discussion of the potential for a more integrated approach to offshore energy to take advantage of synergies between various offshore activities.

Offshore energy today

Oil and natural gas

The year 2017 marks the 70th anniversary of the first commercial offshore oil well drilled by a "mobile" rig out-of-sight of land.[2] This well, completed in 1947 at a depth of about 5 metres (m) off the coast of Louisiana in the United States, was the start of a new chapter for the global oil and gas industry. Since then, operators have moved progressively further and deeper in search of exploration and production opportunities, aided and accompanied by rapid technological advances. The relatively shallow waters around the countries of Southeast Asia quickly attracted investment, as did the North Sea after the oil price shocks of the 1970s had turned development of this area into a major economic opportunity.

Today, offshore production is an integral part of the world's oil and gas supply, accounting for more than a quarter of global oil and gas output in 2016. Natural gas is the new growth area. While offshore oil production has remained steady at around 26-27 million barrels per day (mb/d) over the last ten years (meaning that its share of a growing oil market has shrunk), offshore gas production has grown by almost 30% to more than 1 000 billion cubic metres (bcm) per year over the same period (Figure 1). Offshore oil and gas production are in many parts of the world, with the top producing areas being the Middle East, the North Sea, Brazil, the Gulf of Mexico and the Caspian Sea. In addition to resource development, some elements of the supply chain that used to be exclusively onshore – notably liquefaction of methane and storage and re-gasification of liquefied natural gas (LNG) – are now increasingly taking place on specially designed offshore vessels.

Offshore has also been a focus of exploration activity. The largest recent oil and gas finds have all been in deepwater (defined in IEA analysis as water depth greater than 400 m): deepwater finds on average have accounted for about 50% of the discovered conventional oil and gas volumes for the past ten years. Some of these have been oil, notably the prolific "pre-salt"[3] finds in Brazil, but more than half of all the new hydrocarbon resources

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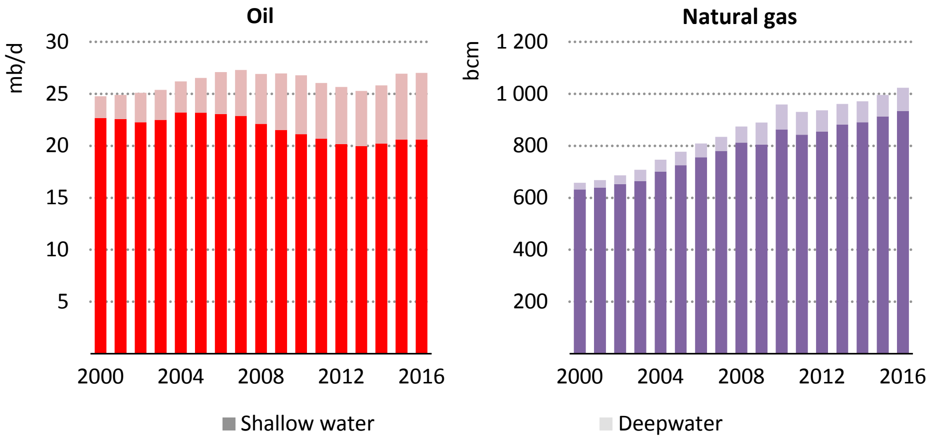
[2] Earlier wells had been drilled in inland waters in the United States and Venezuela and, from the 1920s, extensive trestle systems were also built offshore from Baku, Azerbaijan (then in the Soviet Union) for drilling in the Caspian Sea.

[3] These huge resources are called "pre-salt" because they predate the formation of a thick salt layer, which reaches up to 2 000 metres in places and overlays the hydrocarbons, trapping them in place.

discovered over the last decade have been gas, such as the Zohr and Leviathan fields in the Mediterranean, the Rovuma basin finds off Mozambique and Tanzania, and recent discoveries off Mauritania and Senegal.

Figure 1 ▻ Global offshore oil and natural gas production by water depth



Growth in offshore hydrocarbons production since 2000 has come mainly from natural gas, while oil has moved to deepwater to keep output steady around 25 mb/d

Although the record of discoveries over the last ten years has been impressive, offshore exploration activity has fallen sharply since 2014. The number of exploration and appraisal wells drilled globally (both onshore and offshore) peaked in 2008 at more than 2 000 wells: by 2014, this was down by some 20% (with most of the decline exhibited onshore). With the fall in prices since 2014, activity levels have plummeted across the board; there were only around 700 exploration and appraisal wells drilled globally in 2016. Exploration investment has more than halved since 2014 (IEA, 2017b). The count of active offshore rigs declined from an average of 320 in 2013 and 2014 to around 220 at the end of 2016 and it has remained at that level since (Baker Hughes, 2017).

Nonetheless, the stock of existing offshore reserves and the estimates of technically recoverable offshore resources (including undiscovered resources) offer significant possibilities for production growth, if the market and policy environment allows and if the industry is able to develop these resources in a cost efficient manner. Offshore accounts for some 15% of global oil reserves and close to 45% for gas reserves, as well as almost 30% of the world's remaining conventional resources in the case of oil, and a share of almost two-thirds in the case of gas (see Annex). The question, in a world where shale dominates short-term market dynamics and where there are longer-term uncertainties over demand, is the extent to which these offshore resources fit into the global supply outlook.

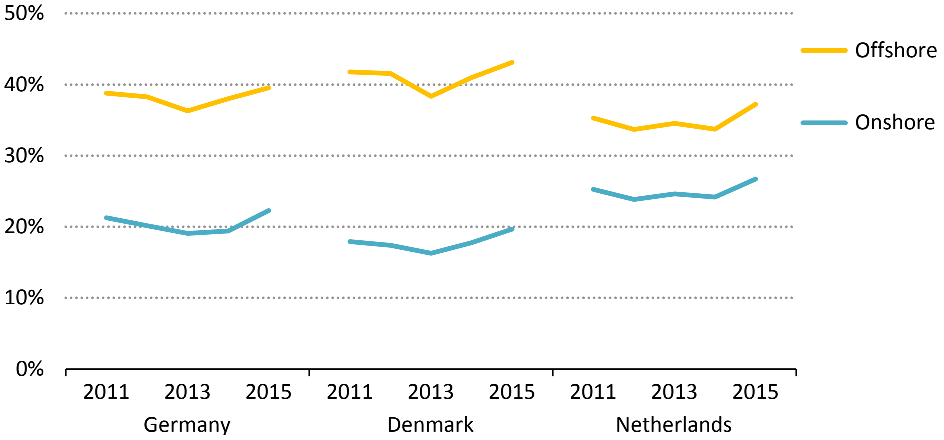
Electricity

Compared with offshore oil and gas, electricity generation in offshore areas is in its relative infancy and accounts for only a marginal part of today's global electricity generation. Nevertheless, it is gaining momentum, mainly for offshore wind generation and to a lesser extent for other marine technologies. Deployment of offshore wind has more than quintupled from 3.2 gigawatts (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 the offshore wind market is 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, of which the United Kingdom with installed capacity of 6.8 GW and Germany with 5.4 GW are the two largest countries. 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.

Although it uses a fundamentally similar technology to onshore wind, offshore wind enjoys some distinctive advantages: the main ones are that offshore installations are able to tap more consistent and higher winds speeds, and there are fewer restrictions on ground area and height. As a result, project sizes and turbines are typically larger and performance indicators for offshore wind farms are higher. Already during the period from 2011 to 2015 in Denmark, Germany and the Netherlands, offshore wind delivered about 1.5 to 2 times the average capacity factor (utilisation rate) of onshore wind (Figure 2).

Figure 2 ▹ **Offshore and onshore wind capacity factors in Germany, Denmark and Netherlands**



Access to higher and more consistent wind speeds give offshore wind the edge over its onshore equivalent, easing integration challenges

Sources: Gonzalez et al (2016); IEA analysis.

Higher capacity factors and lower variability make offshore wind a better match to electricity demand profiles than onshore wind. This can be particularly valuable in serving coastal load centres, where fewer infrastructure investments are needed to enable the connection to offshore wind. It is estimated that there is over 2 000 GW of technical potential and 144 GW of economic potential for offshore wind development on the east coast of the United States by 2027 (NREL, 2016; NREL, 2017). A recent estimate for Northern Europe is for 2 700 GW of offshore wind technical potential, with as much as half of this considered economically viable by 2030 (Wind Europe, 2017).

There are obstacles that need to be overcome before offshore wind can fulfil this kind of potential. Costs, relative to other low-carbon technologies, are a key issue (see section on costs below). Despite the vast resource potential that could be tapped with fixed-bottom configurations (i.e. turbines with foundations on the seabed), studies have found that 80% of estimated offshore wind resources in Europe are located in waters at depths greater than 60 m, with the corresponding figure being 80% in Japan and 60% in the United States (Carbon Trust, 2015). Technology advances, especially to bring down the costs of floating offshore wind technologies, will be important to tap these resources. Network infrastructure also will be critical to spur large-scale offshore wind development. In 2017, the transmission system operators in the Netherlands, Denmark and Germany signed an agreement to develop a North Sea Wind Power Hub. The aim is to construct one or more artificial island hubs at an area such as the Dogger Bank in the central North Sea. The initiative will connect various offshore wind farms located off the coast of the North Sea and has a potential connection capacity of 70-100 GW. In the United States, an electrical transmission network off the east coast to serve offshore wind farms with up to 6 GW of capacity known as the Atlantic Wind Connection was proposed in 2010, but the project has not started.

In addition, concerns about the impact of offshore wind on the marine environment and interference with other economic activities could limit the scope for offshore wind in areas with high resource potential. Several projects in Europe have been delayed or stopped for such reasons, highlighting the need for the wind industry and policy makers to continue to prioritise siting, permitting and stakeholder management issues. The European Union has adopted a Maritime Spatial Planning Directive that requires each member state to implement an integrated planning and management approach to various maritime activities.[4] In Germany, the Environment Ministry has set up a "Competence Centre for Conservation and the Energiewende" to help resolve conflicts between conservation groups and developers. In the Netherlands, consultations involving offshore wind developers, the fishing industry, military and non-governmental organisations are underway with an aim to co-operate and co-exist in offshore areas.

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[4] Directive 2014/89/EU of 23 July 2014 establishing a framework for maritime spatial planning.

Most marine power technologies are still in the early stages of development (Box 2) and other renewable technologies are readily available, so marine power is not expected to contribute significantly to global supply during the outlook period (although it may be significant at specific sites for local needs, such as in island communities). Hence, this report concentrates on offshore wind for electricity generation in the period to 2040.

Box 2 ▻ 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 megawatt (MW) la Rance Tidal Power Station in France has been operating since 1966 and the 254 MW Sihwa Lake Tidal Power Station in Korea that started in 2011. 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. Its main advantage is that is it very predictable. However, its capacity factor of 25% is not as high as offshore wind due to the nature of tidal cycles and current turbine efficiency (WEC, 2016).

Tidal range is evolving with the concept of tidal lagoons: these are artificial basins built in bays and estuaries. The UK government is considering the 320 MW Swansea Bay Lagoon project in Wales, with cost likely to be decisive in determining whether the project proceeds. Five larger tidal lagoon projects have been proposed in the United Kingdom: Cardiff (3 000 MW), Newport (1 400-1 800 MW), Colwyn Bay, West Cumbria and Bridgwater Bay.

Other ocean energy technologies in various stages of development include tidal stream, wave power and ocean thermal energy conversion (OTEC). Tidal stream is a very predictable energy resource, unlike renewables that depend on prevailing weather conditions. Technologies to harness tidal energy convert kinetic energy into electricity in a similar way as wind turbines, except in a different environment where 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, an option of potential interest in places such as Florida in the United States, countries in southern and eastern Africa, and India. 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, the magnitude of which depends on the speed, height, frequency of the waves and the density of water. They can be installed along the shoreline or near shore, but face limitations on the potential resources that could 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.

In addition, variations in temperature in the ocean 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. Two grid-connected OTEC pilot 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; a 10 MW floating offshore prototype in Martinique is expected to be commissioned by 2020.

Outlook for offshore energy to 2040

Broad energy and policy context

Some large-scale upheavals in today's energy scene provide essential context for a discussion about the prospects for offshore energy, including:

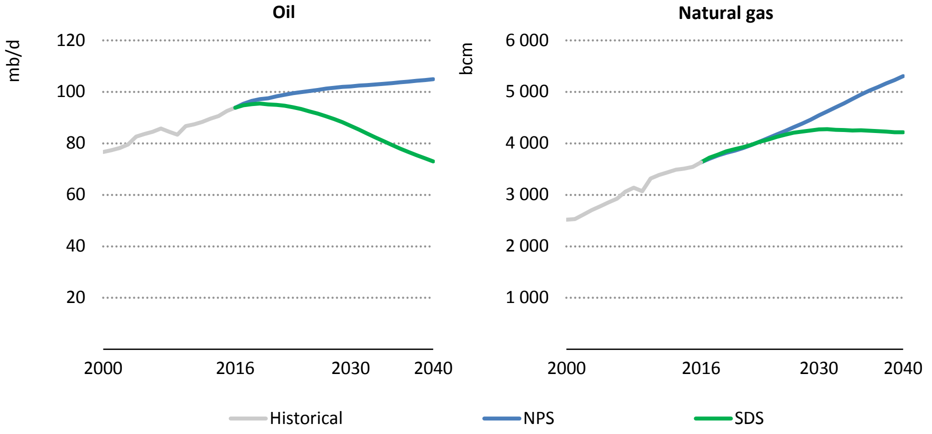
- The shale revolution in the United States, whose resilience and vitality puts shale at the centre of oil and gas market dynamics at least until the mid-2020s.
- Another revolution, this one global in scope, is the continuing cost reductions for many clean energy technologies, which is upending long-standing assumptions about how we might meet future energy needs.
- In China, the shift away from a reliance on heavy industrial sectors (and therefore on coal) and towards a cleaner energy mix, including increased use of natural gas.
- The rising importance of electricity among worldwide end-uses of energy, accounting for almost 40% of the projected growth in final energy consumption to 2040 – an even higher share of growth than oil took for the last 25 years.

These elements play out differently in our two scenarios to 2040 (under the influence of different assumptions about future policies). In the New Policies Scenario, they lead to a gradual and complex transformation of the energy system, which becomes steadily more efficient, less carbon-intensive, more reliant on renewables and natural gas, while retaining leading roles for oil (demand for which does not peak before 2040) and, in many countries, also for coal. In the Sustainable Development Scenario, the forces of change are amplified and reinforced by a determined policy push to achieve environmental and energy access goals. As a result, the shift towards a more electrified and low-carbon system becomes a dramatic one and, of the fossil fuels, only consumption of natural gas ends up higher in 2040 than today: in this scenario, coal demand goes into immediate decline and oil follows relatively soon thereafter.

Oil

The two scenarios produce quite different settings for the development of new oil projects. The New Policies Scenario, in which global demand rises to reach 105 mb/d by 2040, requires an upward drift in the oil price in order to keep supply and demand in balance.[5] This is due to the large requirement for new resource development, some 670 billion barrels over the period to 2040, most of which is needed to compensate for declines at existing fields. Especially when tight oil in the United States starts to level off (which happens in this scenario in the mid-2020s), there is a need to move to higher cost oil in more challenging and complex reservoirs; this creates a call for additional offshore projects (including deepwater projects) as well as smaller onshore fields and less productive areas for tight oil. In sum, this means that the marginal project required to balance the market in the New Policies Scenario becomes steadily more expensive, despite the assumption of continued technological progress.

Figure 3 ▻ **Global oil and natural gas demand by scenario**



The extent of efficiency improvements and fuel switching are major uncertainties for both oil and natural gas, though gas demand is higher in 2040 than today in both scenarios

Note: NPS = New Policies Scenario; SDS = Sustainable Development Scenario.

The context for offshore oil investment in a Sustainable Development Scenario is significantly more challenging, as market dynamics, efficiency trends, fuel switching (with much larger uptake of electric vehicles) and price trends are quite different. In this scenario, the resilience of US tight oil means that the upcycle that is visible in the New Policies Scenario does not have time to play out before demand peaks around 2020 (Figure 3). This limits the call on higher cost oil to balance the market and the oil price therefore stays "lower for longer". The oil market is still large in 2040 (at 73 mb/d) and

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[5] Further details on the methodology and price trajectories for the various scenarios are available at: www.iea.org/media/weowebsite/2017/Chap1_WEO2017.pdf.

overall investment needs are still substantial, but uncertainty over long-term demand also militates against committing capital to large capital-intensive projects with long-lead times – as is the case for some "frontier" offshore projects.

Natural gas

The dynamics are different for natural gas, compared with oil, as gas use expands in both scenarios until around 2030, when gas consumption flattens in the Sustainable Development Scenario. In the New Policies Scenario, global natural gas use increases by 45% in the period to 2040, and 80% of this growth takes place in developing countries in Asia, Africa, Latin America and the Middle East. The location of demand growth is significant for gas; this is a much more expensive fuel to transport than oil (or coal), so offshore resources that are proximate to a large or growing market have a significant edge. Gas pricing in this scenario becomes increasingly responsive to the supply-demand balance for gas (and de-linked from oil), as regional markets become more interconnected by an increasing share of LNG in global trade, and by the increasing flexibility of this trade to seek the most advantageous commercial destination.

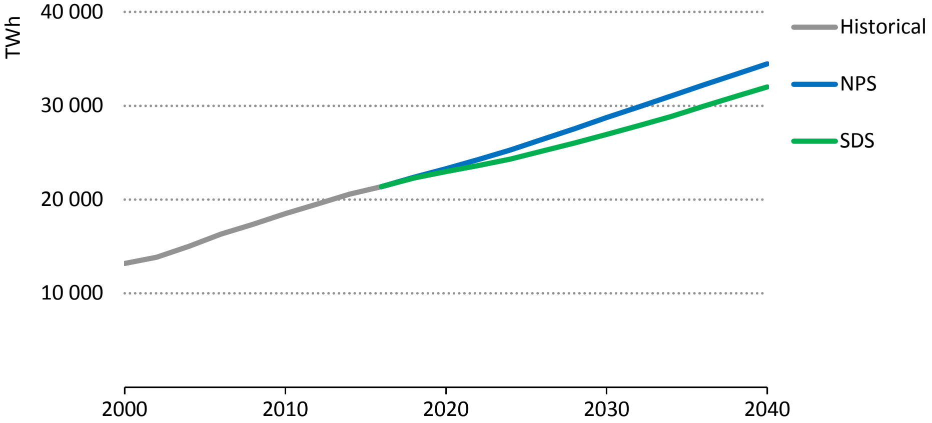
Gas demand rises less strongly in the Sustainable Development Scenario, increasing by more than 15% to 2030 before remaining broadly at this level until 2040. Gas overtakes coal in the mid-2020s and oil in the mid-2030s to become the largest single fuel in the global energy mix. However, the opportunities for gas vary greatly by sector and region, and also vary over time. In some countries, notably China and India, gas demand is actually higher in the Sustainable Development Scenario than in the New Policies Scenario, as gas plays a significant role in helping displace coal from the mix and thereby in achieving climate and air quality goals. Meeting demand from these markets supports continued growth in global gas trade and underpins new offshore developments as well (for example in East Africa). Gas has less potential to help emissions reduction in more mature gas markets, although in the United States and Europe there is a window of opportunity for gas to aid decarbonisation by accelerating the switch away from coal. Nevertheless, with the rapid ascent of low-carbon technologies in this scenario, the principal function of gas in the power sector is to provide flexibility to support the integration of variable renewables. For some industrial applications, and in some parts of the transport sector, the "bridge" for gas is a much longer one, as cost-effective renewable alternatives are less readily available.

Electricity

The outlook for electricity demand is more straightforward, even with the variations in policies across the two scenarios (Figure 4). In the New Policies Scenario, global electricity demand rises by some 60% to reach 34 500 TWh by 2040, growing at twice the rate of primary energy demand. About 85% of global growth occurs in developing countries, with the largest share in China and India. Global growth in electricity supply is dominated by wind and natural gas (23% each) and solar photovoltaics (PV) (20%). The share of fossil fuels in power generation drops to around 50% in 2040 from two-thirds today. The share of renewables increases from 24% in 2016 to 40% in 2040, while that of nuclear remains steady at around 10%.

Demand growth in the Sustainable Development Scenario is slightly lower due to stronger implementation of energy efficiency policies – only partially offset by increased electrification of heat and transport (all regions except Africa see lower demand in 2040 compared with the New Policies Scenario). Nonetheless, consumption reaches 32 000 TWh in 2040, up by 50% from 2016. Developing countries also account for the majority of growth in the Sustainable Development Scenario. On the supply side, fossil-fuel power generation's share of the mix drops to about one-fifth while the share of renewables rises to over 60% and nuclear to 15%. Electricity accounts today for just under 20% of global final consumption. This share grows to 23% in the New Policies Scenario by 2040, while in the Sustainable Development Scenario it accelerates to 27%.

Figure 4 ▻ **Global electricity demand by scenario**



The future is electrifying: demand grows strongly in both scenarios, pushing its share of final energy consumption up from today's 20%

Offshore costs

Oil and natural gas

The cost of offshore projects and the speed with which they can be developed, relative to other upstream opportunities, are critical elements of the outlook. Offshore projects, in particular those in deepwater (defined as water depths greater than 400 metres) and ultra-deepwater (greater than 2 000 metres), require high upfront capital investment, take a relatively long time to develop and typically have long payback periods. Although the Zohr project off Egypt stands out for a short period between discovery and first production (less than two-and-a-half years), offshore projects generally take longer to move from discovery to initial production: around five years for deepwater projects; five to seven years for projects at the technological frontier in ultra-deepwater areas. ExxonMobil's Liza project off Guyana provides a good current example: the first discovery was announced in May 2015; final investment decision for the first phase of development was taken in June 2017 and first oil production from the field is expected in 2020.

In the aftermath of the oil price fall in 2014, proposed new deepwater developments were among the first to be delayed or cancelled. The average annual level of resources in new deepwater and ultra-deepwater projects receiving approval between 2014 and 2016 fell to less than 1.5 billion barrels. This was 60% lower than the average annual level seen since 2000 and compares with a 35% drop in the approvals of other conventional projects.

There has been a sharp focus among offshore asset holders on reducing costs. Upstream companies are developing only their highest-value prospects, taking account of the lower level of capital available and the need to ensure competitiveness in a lower price environment. For some companies, this has meant a strategic shift away from offshore operations towards onshore projects with shorter investment cycles, notably shale. Within the offshore sector, it has meant that only the most productive or prospective new assets have a chance of moving forward to final investment decision, and that some companies are focusing on subsea tie backs or unmanned wellhead platforms linked to existing infrastructure (i.e. developing a satellite area near an existing production facility) rather than new field developments. These types of incremental development benefit from smaller capital investments and shorter payback times, although volumes are consequently lower. This type of project fits well with scenarios in which demand is highly uncertain or declining: on their own, they are unlikely to represent a way to build production in scenarios where demand for oil continues to rise.

There have also been changes in the way that projects are designed. A number of proposed projects have been "downsized" by reducing the total volume of oil that will be recovered or by lowering the planned level of peak production. Projects are also being simplified: with smaller planned production capacities, it has been possible in some instances to change the type of infrastructure installed (such as the choice of offshore platform) or to remove or reduce infrastructure (including infrastructure originally envisaged to support future developments). Standardisation – rather than bespoke design work – is becoming a new watchword for the offshore oil and gas sector (a consideration that is moving the sector closer in practice to the underlying business philosophy of offshore wind). In parallel, companies have made a major push to improve the efficiency of operations, looking for any signs of excess that might have been accumulated during times of triple-digit oil prices.

In addition, cost reductions have been facilitated by the slack in the market for supplies and services. Unit costs have dropped alongside lower raw material costs and service costs (including rig day rates and vessel charter rates). Drilling and well completion costs account for at least half of the capital expenditures and day rates for deepwater offshore rigs fell by more than 60% over the 2014-17 period.

Overall, it is estimated that the average capital cost of developing conventional oil projects (both onshore and offshore) dropped by over 40% between 2014 and 2016. Offshore costs have dropped slightly more than the average, due to the steeper drop in activity in the offshore sector compared with the onshore sector and the higher overcapacity in the offshore supply chain.

The implications of this for the overall cost of new offshore projects have been striking. In the Barents Sea, for example, the Johan Castberg field saw a 50% reduction in capital costs between the initial design proposed in 2013 and the design that received approval at the end of 2017. The giant Johan Sverdrup shallow water field in the North Sea has been able to cut the capital costs of the second phase of the field development in half. According to Statoil, operator of both fields, the breakeven price of Johan Castberg fell from over $80/barrel to less than $35/barrel and the full field development of Johan Sverdrup will be below $25/barrel. In Brazil, the operator Petrobras is aiming to bring the breakeven price for the ultra-deepwater Libra field (one of the largest pre-salt discoveries) down to $35/barrel. In the US Gulf of Mexico, the development cost of the ultra-deep Mad Dog II project fell by 50% between the initial design in 2013 and the design that received final investment approval; BP has indicated that its breakeven price is now around $40/barrel. Also in the US Gulf of Mexico, Shell indicates that it has reduced the capital cost of its Kaikias development by nearly 50% through project design simplification; the company estimates that the project’s breakeven price is now below $40/barrel.

Looking forward, a critical consideration is to what extent these reductions are structural, i.e. permanent, and which are more cyclical in nature. There is no simple answer to this question and, as with many elements of our discussion, the available answers vary by scenario. Some clues can be found by breaking down the various elements of the cost reductions seen since 2014. We estimate that changes in unit costs account for nearly 60% of these overall reductions. This is a cyclical element and could therefore be reversed once activity picks up and the market for services and supplies starts to tighten (with the caveat that there remains a large overhang in the availability of offshore equipment and services, which could slow considerably the reaction in unit costs). Cost reductions related to the “high-grading” of assets are also, by definition, short-lived; the stock of highest-value projects naturally diminishes as they are developed and companies have to move to slightly less productive or more complex areas. But gains related to new technology, digitalisation, standardisation, simplification and improved efficiency (including closer and earlier collaboration between oil companies and suppliers, new contracting practices with different distribution of risks and rewards, and a shift towards more functional requirements that opens up incentives for accelerated innovation) could indeed be more structural. In the case of efficiency, this would require that these changes in corporate behaviour are lasting, rather than only an emergency response to prevailing prices.

How these cost pressures play out in our projections varies by scenario, although the large current oversupply of services and supplies in the offshore sector keeps costs on a similar trajectory in the short term. Rigs that were ordered in the period 2011-14 are still coming into the market, even though drilling contractors have in many cases tried to delay or cancel the delivery of new-build rigs. The offshore installation sector is experiencing lower pricing with day rates being in the order of 30-35% lower than in 2014. Oversupply in this market, combined with 30 new offshore units that were delivered in 2016, has contributed to declining utilisation rates (IEA, 2017b).

Looking further ahead, the differences in market environment and prices between the scenarios mean that cost outlooks start to diverge. In the New Policies Scenario, investment needs to pick up quickly to balance a market in which oil demand continues to rise strongly over the period to 2025. As a result, supply and services markets start to tighten, pushing unit costs higher, although global average capital costs for all conventional projects in 2025 in the New Policies Scenario are still 25% below 2014 levels.

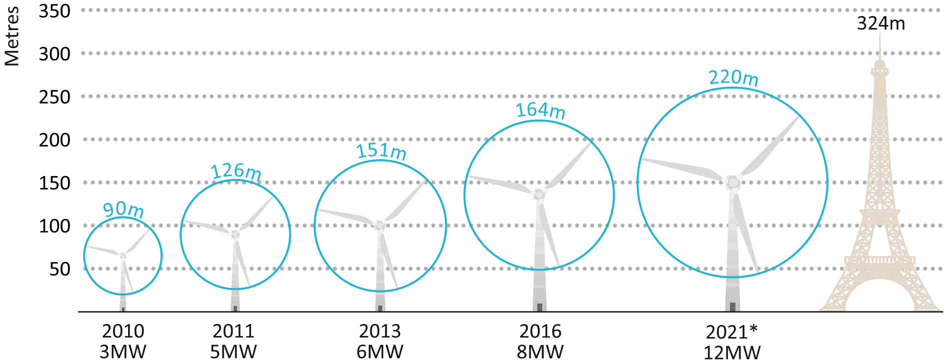
In the Sustainable Development Scenario, however, oil demand peaks around 2020 and prices remain at much lower levels. The slack in the supply and services markets is maintained (and so the increase in unit costs is therefore marginal): there is less need to develop more complex projects, and in an environment where demand has started to decline, the industry is able to proceed only with a smaller number of the most promising offshore projects. Natural gas investment follows a slightly different pathway, and more large-scale new offshore projects need to proceed to meet demand. Yet by 2025 the costs of conventional projects in the Sustainable Development Scenario are about 40% below 2014 costs, with offshore projects remaining slightly below the global average.

Electricity

Concerted efforts are underway to drive down each major cost element of offshore power generation technologies. Offshore wind technologies are in a particularly dynamic phase of development. One key trend in offshore wind is the increasing physical size of turbines, in terms of height and swept area, which raises their maximum output. The height of commercially available turbines has increased from just over 100 m in 2010 (3 MW turbine) to more than 200 m in 2016 (8 MW turbine), which increased the swept area by 230%. A 12 MW turbine now under development is expected to reach 260 m, approaching the height of the Eiffel Tower (Figure 5). An even-larger 15 MW turbine is targeted by the industry by 2030. The growing turbine size has an impact on all cost aspects for offshore wind, putting upward pressure on capital costs due to more challenging construction and larger subsea structures, while reducing operation and maintenance and increasing performance, ultimately leading 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 (IRENA, 2018). The increasing ability to install offshore wind in deeper waters has also enabled 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, aiming to tap additional potential in deeper waters, open up new markets and unlock the benefits of standardisation (Box 3). With technology advances for both fixed-bottom and floating installations, offshore wind is looking to gain ground and become cost competitive with other generation options.

Figure 5 ▻ **Evolution of the largest commercially available wind turbines**



With fewer restrictions on size and height than their onshore counterparts, offshore turbines are becoming giants – a key factor behind anticipated lower generation costs

* Announced expected year of commercial deployment.

Note: Illustration is drawn to scale. Figures in blue indicate the diameter of the swept area.

Thus far, the average capital costs per unit of new offshore wind capacity (projects actually entering into operation) have not changed appreciably since 2010, rising by a few percentage points to $4 487 per kilowatt (kW) in 2016 (IRENA, 2018). To date, there exists a wide range of values depending on project type, the maturity of local markets and variations in site conditions: estimated capital costs of new projects ranged from approximately $2 900/kW for the Lingang phase 1 project in China to $7 500/kW for the Block Island Wind Farm in the United States (US DOE, 2017). However, as the offshore wind industry continues to mature, turbine unit costs are expected to decline and there are many opportunities to innovate throughout the construction and installation process, leading to substantial capital cost reductions (IRENA, 2016). The key uncertainty for the future is the pace at which these cost declines might materialise. Suggested learning rates (defined as the reduction in costs for each doubling of cumulative capacity) have ranged from 8% to 19% for offshore wind turbines, more than 20% for installation costs and up to 40% for grid infrastructure; rates have been estimated in the single-digit percentages for overall offshore wind farm costs (Rubin et al., 2015).[6] In our projections, we assume a

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[6] The uncertainty is not limited to offshore wind: estimated learning rates for onshore wind range from 8% to 23% in global and OECD studies, and 4% to 10% in European studies.

learning rate of 11% for offshore wind, driven by local and global factors.[7] Based on the deployment in the New Policies Scenario, this leads projected capital costs to decline from around $4 500/kW in 2016 to about $3 550/kW in 2025 and $3 000/kW in 2040 (Figure 6). However, if these cost reductions can be strongly accelerated – for example, achieving a 20% reduction for each doubling in cumulative capacity – average capital costs would drop below $3 000/kW in 2025 and near $2 000/kW in 2040 (and any consequent acceleration in deployment would bring these gains forward).

Box 3 ▷ Floating offshore wind — how could this change the game?

One of the most advanced innovations for offshore wind is floating structures, based on concepts that are 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 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 wind turbine technology by 2030.

The leading countries in the development of floating offshore wind are France, Germany, Japan, Norway, Portugal, United Kingdom and United States. 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 that currently tend to rely on relatively expensive (and highly polluting) diesel-based generation. They also have the potential to be a game-changer for countries with deep offshore coastal areas, like Japan.

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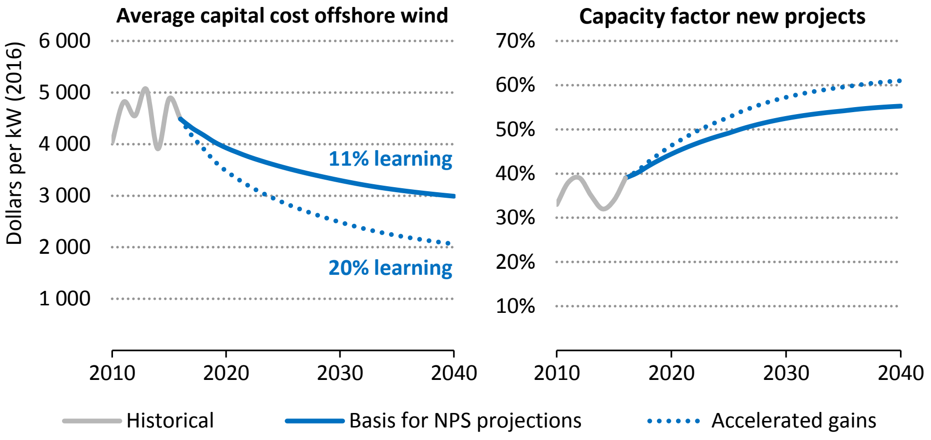
[7] In our World Energy Model, learning rates are applied to the capital cost of power generation technologies. The overall LCOE reductions are enhanced where performance improvements are assumed over time, as is the case for offshore wind, as well as for onshore wind and solar PV. For additional information, model documentation is available at www.iea.org/weo/weomodel/.

Figure 6 ▻ **Historical and projected global average capital costs for offshore wind** (left) **and global average annual capacity factors for new projects** (right)



The case for offshore wind is being transformed by falling capital costs and higher capacity factors, although the pace of future improvement remains uncertain

Notes: Capital costs include grid development costs. Capital costs refer to the year of commissioning.

Since the first offshore projects were developed in the late 1990s, the performance of offshore wind has improved dramatically; 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. As turbines continue to increase in size, the global average capacity factor for new offshore wind projects is assumed to reach 55% in the long term (the right-hand side of Figure 6). This performance gain has a significant impact on the levelised cost – for example, increasing the capacity factor by ten percentage points to 50% reduces the LCOE by about one-fifth. Floating offshore structures could be a way to unlock even higher performance. Greater emphasis on floating turbines further from shore or turbine design advances could accelerate performance gains, supporting an accelerated gains case where average capacity factors for new projects could surpass 60%.

Higher capacity factors not only help reduce the LCOE, 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 PV. This can be an important advantage for offshore wind, and 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. However, the concentration of offshore wind resources in specific areas can also affect its integration into the existing grid infrastructure. The cost of interconnection for offshore wind farms can be significant and the grid network can struggle to support large-scale deployment of offshore wind if it grows at a rapid pace. For example, the offshore wind auctions in Germany for capacity in 2021 restricted new connections only to the Baltic Sea region as the grid in parts of the North Sea needs to be expanded first and is expected to be ready only in 2023 to accommodate new offshore wind developments.

Other key considerations related to the costs of offshore wind power are operation and maintenance (O&M) costs, the economic lifetime of projects and the financing costs. O&M is a significant cost element for offshore wind, with annual costs ranging from $109-140/kW, equivalent to about 3% of capital costs. These are significantly higher than the equivalent costs for onshore wind projects, due to the harsh operating conditions and difficulty in servicing turbines in those conditions (IRENA, 2018), although this effect is offset in part by higher average turbine size (which reduces the number of turbines to maintain for a given project size).

Challenging offshore conditions could also affect the expected lifetime of the turbines, although experience is limited to date, as the vast majority of offshore wind capacity is under a decade old. In the *World Energy Outlook* (*WEO*), the economic lifetime of offshore wind is assumed to be 20 years (applicable for the LCOE calculation), the same as onshore wind, while the technical lifetime for both is most likely in the range from 20 to 30 years.[8]

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, a standard weighted average cost of capital (WACC) applies: this is assumed to be 8% in the *WEO 2017* in advanced economies (IEA, 2017a). At this rate, financing costs made up 45% of the total LCOE for offshore wind in 2016. 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. Lower risk enables project developers to rely more heavily on debt financing, lowering the WACC of a project. For example, lowering the WACC from 8% to 5% would reduce the overall LCOE of offshore wind in 2016 by about 20%. Low cost financing may also be available to projects without policy support in cases where market, technology and volume risks are perceived as low.

The global average LCOE from offshore wind projects has declined slightly from about $200 per megawatt-hour (MWh) in 2010 to an estimated $187/MWh in 2016, fluctuating from year-to-year (Figure 7).[9] Over this period, a wide range of project-level costs have been reported, including less than $100/MWh for one project completed in 2011, to projects more than three-times that level as recently as 2015. Both of these data points

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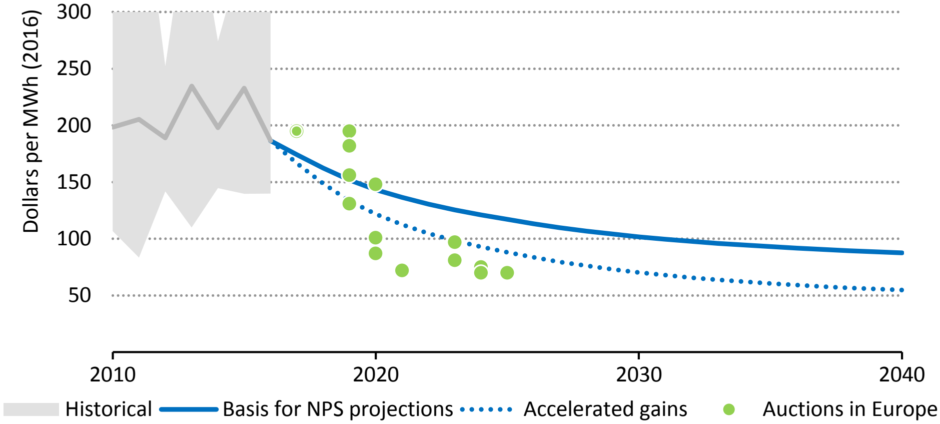
[8] The same consideration applies to conventional thermal power plants; for example, the economic lifetime of coal-fired power plants is 30 years in LCOE calculations, while more than one-quarter of coal-fired capacity in operation is over 30 years old and 5% is more than 50 years old.

[9] Based on capital costs of $4 487/kW and 39% capacity factor (IRENA, 2018), O&M costs of $123/kW per year, a 20-year economic lifetime and an 8% WACC. The estimated LCOE is higher than the IRENA estimate, which applies a 25-year lifetime and a 7.5% WACC in the absence of project-specific financial parameters, which may benefit from supportive policy frameworks in place today.

highlight the site-specific nature of offshore wind costs, dependent on many factors along the supply chain. To achieve systematic cost reductions requires moving beyond this issue to standardise the components and services provided, as well as capturing economies of scale.

Looking forward, the global average LCOE of offshore wind is projected to decline by more than one-third to 2025 and more than half by 2040, based on projected deployment in the New Policies Scenario. With accelerated gains (20% learning and higher capacity factors), the global average LCOE would reach half of today's level by 2025 and 70% below current costs in 2040. Adjusted strike prices from recent European offshore wind auctions point to an even more aggressive pace of cost reductions – with projects approaching $70/MWh by 2025 (Figure 7). If they prove to be representative of 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. However, analysis of potential reductions of individual cost components suggest that overall declines may be more limited – for example, dropping to $120/MWh by 2025 (IRENA, 2017). In the case where these project costs are not immediately replicable, they still represent a major vote of confidence in the future of offshore wind and reflect the growing optimism of the benefits of ever-larger turbines coming to the market.

Figure 7 ▹ **Historical and projected global average LCOE of offshore wind and adjusted strike prices from recent auctions in Europe**



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

Notes: 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 WACC 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.

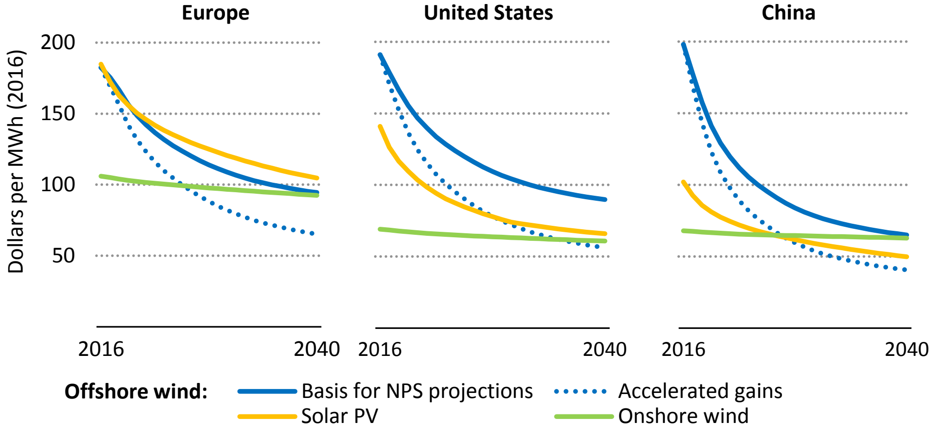
Sources: NREL (2017); IEA analysis.

An analysis of recently commissioned projects shows that 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. Over the outlook period, offshore wind looks to close these gaps.

In Europe, offshore wind costs are projected to fall below those for solar PV based on deployment in the New Policies Scenario and reach parity with onshore wind (Figure 8). Hence, offshore wind contributes more than one-quarter of the overall growth in renewables-based generation in Europe to 2040 in this scenario, outpaced only by onshore wind power.

In the United States, offshore wind remains at something of a cost disadvantage in this scenario: even if costs for European projects were translated directly to the US context, offshore wind would remain significantly 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. In China, offshore wind costs are projected eventually to reach parity with onshore wind projects, though onshore wind has the advantage of the planned development of ultra-high voltage transmission lines connecting the best onshore resources in the north, northeast and northwest with the largest populations in central and east China (IEA 2017a). Solar PV costs also continue to outrun offshore wind costs in China, making it the cheapest source of new electricity by 2030.

Figure 8 ▷ Projected LCOEs of offshore wind, onshore wind and solar PV by region in the New Policies Scenario



Although relatively expensive to date, falling costs for offshore wind are set to change its competitiveness among renewables, as well as with fossil fuels and nuclear power

Note: 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.

If offshore wind were to achieve an accelerated pace of cost reductions (as described above), while other technologies remain on the pathway used as a basis for our projections, 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. In such a case, offshore wind could grow substantially more in Europe, perhaps making up as much as half of overall renewables growth; that would mean an additional 120 GW added to 2040, beyond the 94 GW reached in the New Policies Scenario (see next section). In the United States, although faster cost reductions would surely energise the industry, the impact would likely be more limited as 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, perhaps shifting the priorities for development. In the New Policies Scenario, offshore wind represents just 2.5% of total renewable capacity additions to 2040. If this percentage reached 10%, then that would mean nearly an additional 120 GW of offshore wind over the next two decades. With such low costs, offshore wind would pose an opportunity to displace output from existing fossil-fuelled power plants, which would open a much larger market. 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. 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, these low costs were made possible due to very favourable site-specific conditions. 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).[10] Additional targeted research, development and deployment support could unlock technological innovations and drive down these costs.

Offshore energy production by scenario

Offshore energy continues to play a major role in meeting the world's energy needs to 2040 in both the New Policies and Sustainable Development scenarios. However, as Figure 9 illustrates, the composition of this contribution varies substantially in the two scenarios. All elements of the offshore picture exhibit growth relative to today in the New Policies Scenario, but the more stringent emphasis on low-carbon options constrains the outlook for offshore oil in the Sustainable Development Scenario and provides a major extra boost to the offshore wind sector.

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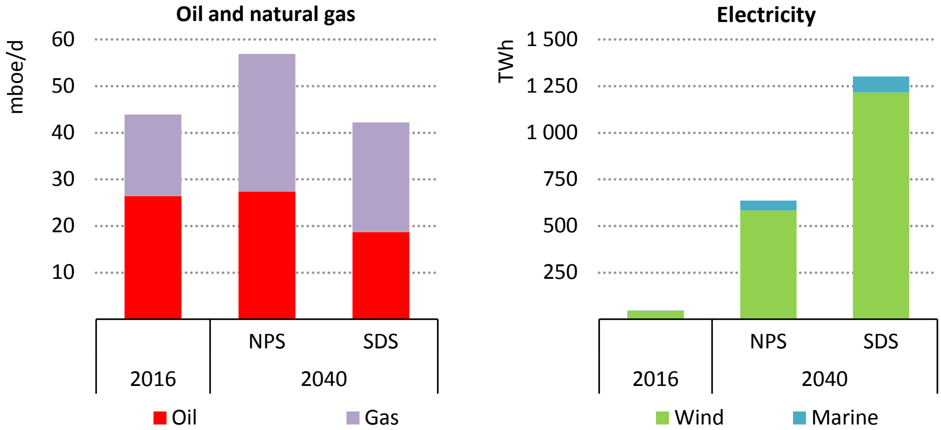
[10] Estimated LCOE for a 100 MW plant.

Figure 9 ▷ **Global offshore energy production by scenario**



Offshore energy production remains robust in both scenarios, although the fortunes of oil, gas and wind power vary depending on the policies in place

Note: mboe/d = million barrels of oil equivalent per day.

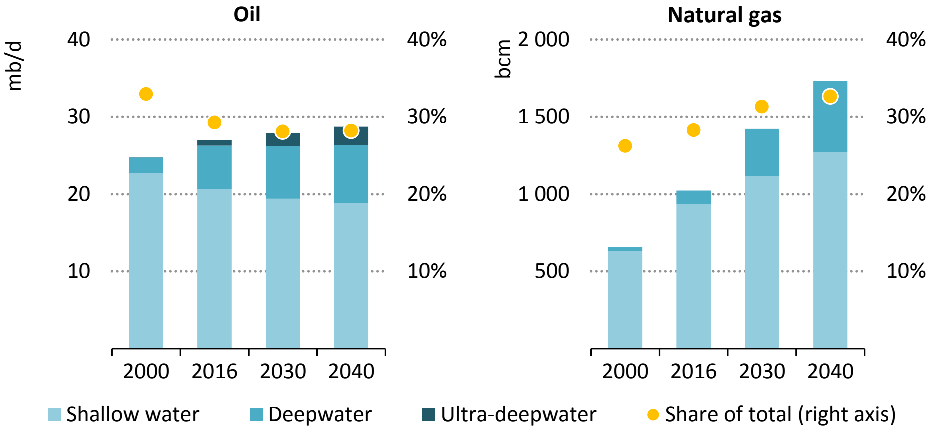
New Policies Scenario

In the New Policies Scenario, total offshore *oil* production increases only slightly from its current level of 27 mb/d, but there are different trajectories across various water depths (Figure 10 shows the overall trend by water depth for oil and natural gas). Shallow water production continues to decline moderately from today's level of around 20 mb/d, but this is offset by an increase in deepwater output, which rises from less than 7 mb/d today to almost 10 mb/d in 2040. In the context of a growing oil market, a flat trend for offshore oil means that its share of global oil production declines slightly to about 28% in 2040.

Around 40% of today's shallow water oil production comes from mature regions such as Europe (Norway and United Kingdom), North America (United States and Mexico) and the Asia Pacific (China, India, Indonesia and Malaysia): all of these regions are projected to experience declining production to 2040. European offshore oil production in 2016 stood at 3.2 mb/d (Norway and United Kingdom accounting for 2 mb/d and 1 mb/d respectively), of which 2.9 mb/d was from shallow waters. Total European offshore oil production drops by more than half by 2040. Among the other shallow water producers, output in the Middle East (mainly Iran, Qatar and Saudi Arabia) increases from 8.4 mb/d today to 9.6 mb/d in 2040 and production in Eurasia (the Russian Federation [hereafter, "Russia"] and the Caspian countries, mainly Kazakhstan) rises from 1.5 mb/d to 2.1 mb/d over the same period.

Today's deepwater oil production is much more concentrated, with four countries (Angola, Brazil, Nigeria and United States) accounting for nearly 90% of the 6.4 mb/d produced globally in 2016. Of these, Brazil is by a distance the largest source of anticipated deepwater growth to 2040, more than doubling its current output of 2.2 mb/d. The huge investments made by Petrobras, Brazil's leading domestic oil and gas company, in recent years bring increasing returns, as highly productive wells are connected to floating production, storage and offloading vessels (FPSOs). The removal of the mandatory minimum 30% operating stake in new pre-salt developments for Petrobras and other regulatory changes (e.g. on some very tight local content requirements), have spurred interest from other operators as well. The Libra field – the largest pre-salt discovery so far – began producing in late 2017 and field development is expected to continue well into the 2020s. Our projections imply that Brazil remains an important focal point for global spending on deepwater production, particularly in the period to 2025.

Figure 10 ▹ **Global offshore oil and natural gas production by water depth in the New Policies Scenario**



As more accessible shallow water plays deplete, global demand trends underpin a steady shift towards output from deeper waters in the New Policies Scenario

Mexico is another major source of growth in deepwater activity. The liberalisation of the Mexican oil sector in 2013 was followed by successful bidding rounds that have raised expectations for future growth. Deepwater production is expected to start around 2025 and holds the potential to reverse the long-term decline in Mexican output (shallow water production currently accounts for around 70% of Mexico's total output, but the main producing complexes, especially Cantarell, are already relatively mature). Deepwater is a new frontier for Mexico where Petróleos Mexicanos (Pemex), the country's leading oil and gas company, has less experience and where other players are anticipated, alone or in partnership with Pemex (as with the Trion project), to play a prominent role: the projected 1 mb/d of deepwater output in 2040 makes up almost half of Mexico's projected offshore oil output.

In the United States, deepwater production continues to be concentrated in the Gulf of Mexico. Activity in this area has remained relatively strong through the price downturn since 2014 (as evidenced by the approval of the Appomattox project in 2015 and Mad Dog

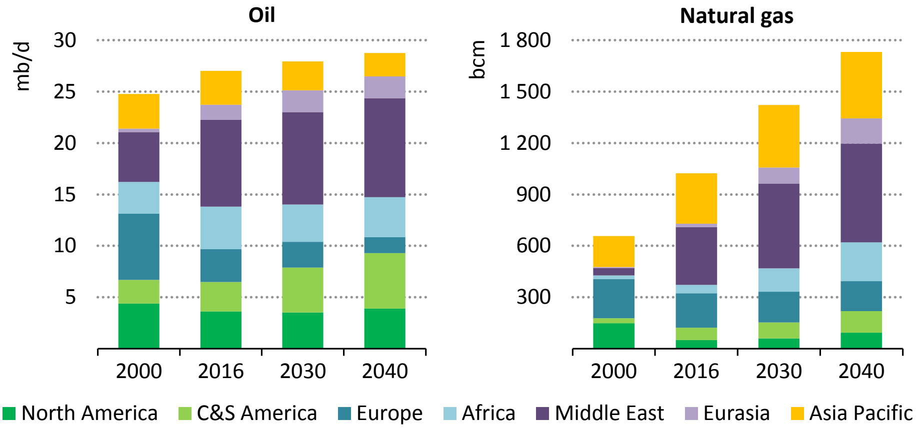
Phase II in 2017), although a major lease sale in March 2018 showed relatively subdued interest from companies in new acreage. In January 2018, the US administration released a plan to allow new offshore oil and gas drilling in nearly all US coastal waters, giving energy companies access to leases off California for the first time in decades and opening more than a billion acres in the Arctic and along the eastern seaboard. This initiative provoked opposition from a number of coastal states and the extent of commercial interest in these new opportunities remains to be seen: the availability of this additional acreage is not included in our current projections for US offshore production. Projected US deepwater output remains just above 1 mb/d through to 2040.

Among the other major current deepwater players, activity levels in Angola and Nigeria have declined since 2014, with companies reluctant to invest in light of reduced cash flow, some uncertainty over contractual requirements and increased instability in Nigeria. Deepwater production from these sources struggles to remain at current levels. However, there are some new deepwater producers in the New Policies Scenario, notably Guyana and Suriname. In Guyana, the first phase of development of the Liza field is due to start from 2020, with planned peak production of around 100 thousand barrels per day (kb/d) expected a few years after. This has led to a high degree of interest in exploring neighbouring areas, including in Suriname.

Offshore *natural gas* production rises to almost 1 700 bcm in 2040, by which time it represents just over 30% of total gas production. Deepwater and shallow water production accounts for about half of the increase each as shallow water gas production increases from 950 bcm in 2016 to 1 250 bcm in 2040 and deepwater production from less than 100 bcm in 2016 to over 450 bcm in 2040. The increases are spread quite widely, but the largest increments come from two regions: the Middle East and Africa. In the Middle East, this is largely due to large shallow water developments of the South Pars (for Iran) / North field (for Qatar), the world's largest gas field. The removal of some international sanctions has lifted the prospects for investment in Iran, and Qatar has recently lifted the development moratorium on its share of the field. Offshore gas production in the Middle East rises from around 330 bcm in 2016 to over 550 bcm by 2040. In Africa, production rises significantly in Tanzania and Mozambique, as the large new deepwater gas discoveries are developed. The first element, which received the go-ahead in 2017, is the Coral floating LNG project in Mozambique; another floating project is planned, and, in our projections, this is followed by the construction of large onshore LNG trains, as well as some (limited) supply of gas to the East African market.

Brazil and Australia are two other countries that experience significant growth in offshore gas production. In Brazil, the deepwater pre-salt fields produce large volumes of associated gas and total offshore gas production in Brazil increases from around 20 bcm today to 60 bcm by 2040, the majority from deepwater. Australia already has significant offshore gas production in the northwest; total offshore gas production is projected to rise from 60 bcm in 2016 to 130 bcm in 2040 in the New Policies Scenario. East Mediterranean offshore gas production also experiences significant growth. In Europe, offshore gas production amounted to 200 bcm in 2016, the majority in shallow waters (Norwegian gas output was around 120 bcm and UK production around 40 bcm). Production in Norway remains at high levels over the next few years in our projections, helped by expansions on the super-giant Troll field in the North Sea and by the coming online of the new Aasta Hansteen development in 2018. However, Norway faces the prospect of declining export availability over the longer term: after 2020, production is expected gradually to decline from around 120 bcm to 100 bcm towards 2040, although the Barents Sea holds exploration promise and could potentially affect the longer-term production outlook. However, the outlook for elsewhere in Europe is less upbeat: UK production is cut in half by 2040.

Figure 11 ▻ Offshore oil and natural gas production by region in the New Policies Scenario



The Middle East is a mainstay of offshore hydrocarbons output in the New Policies Scenario; Central & South America (for oil) and Africa (for gas) are other key sources of growth

Note: C&S America = Central and South America.

Turning to offshore *electricity* production, 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 there are a growing number of countries that have announced capacity targets and supportive policies. Targets and support schemes for offshore wind and marine power, however, are not as widespread as those for solar PV and onshore wind.

The most ambitious capacity targets are in the United Kingdom and Germany. The United Kingdom aims for 10 GW of installed offshore wind capacity by 2020, while Germany targets 6.5 GW by 2020 and 15 GW by 2030. Other key countries with firm targets in the European Union include the Netherlands, which has an offshore wind target of 4.5 GW by 2023 and has signalled its intent to construct 1 GW a year thereafter to 2030, and France, which has a target of 3 GW by 2023 and an additional 6 GW by 2030.

Outside of Europe, most of the policy action thus far has been concentrated in Asia – which has seen strong research and development activities underway – and in the United States. China is the biggest market for offshore wind outside of Europe 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. Japan has long considered offshore wind as part of its renewable energy strategy; however, this has not yet translated into an official target for capacity deployment.

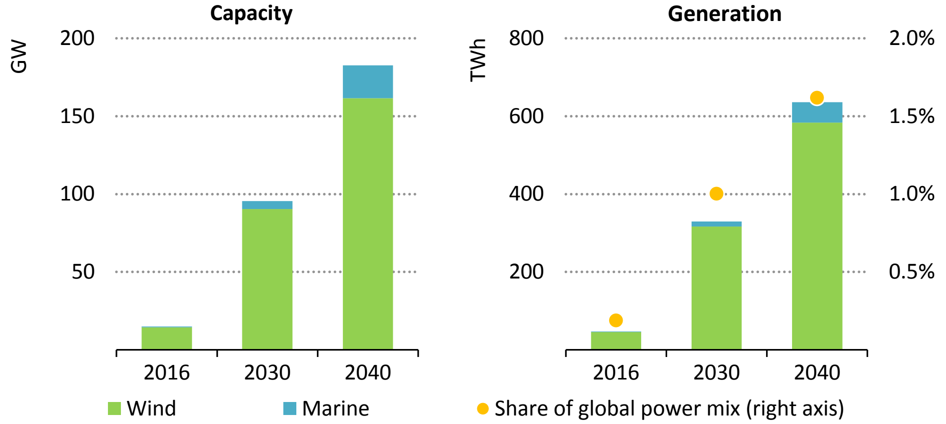
The United States has large offshore wind potential but the only offshore wind project currently in operation is the 30 MW Block Island facility off Rhode Island, after the cancellation of the 468 MW Cape Wind project off the coast of Massachusetts due to permitting difficulties and financing and legal obstacles. Development of offshore wind has been slow to take off due to various factors, including delays on leasing and regulations, although there are signs that the cost reductions seen in recent auctions in Europe may spark 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. Annex B provides more details on the targets and key features of offshore wind policies in four countries: China, Germany, United Kingdom and United States.

A notable recent policy trend for renewables in general, including offshore wind, is the increasing prevalence of auctions to determine the level of support instead of administratively set subsidies. Auctions are well suited to offshore wind as they are better equipped to offer market support mechanisms needed to drive competition and to support successful project delivery than mechanisms offering direct financial support, e.g. feed-in tariffs. This is especially so as offshore wind farms are significantly larger in scale, more complex to develop and require longer lead times than distributed renewables like solar PV and most other utility-scale plants. Given the untapped nature of offshore locations and difficulties involved in connecting the offshore installations to grids, active involvement of governments and grid operators is typically essential. The auction mechanism has evolved in certain countries to cover site location and development in addition to setting the level of support. For example, under Germany's new framework that will apply to projects coming online from 2026, the government will identify specific site locations and undertake site investigations and grid planning before the auction process. Such centralised approaches reduce project uncertainty and can sharply reduce financing costs. This approach is also being used in Denmark and the Netherlands.

In the New Policies Scenario, it is assumed that countries reach the targets set by 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 wind 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 countries could well increase their ambition in the future, leading to higher deployment (and further cost reductions reflecting learning effects).

Overall, installed offshore wind capacity grows to around 160 GW in the New Policies Scenario, generating 583 TWh by 2040. Marine technologies see increased growth after 2030 but from a very low level, reaching 21 GW of capacity and 53 TWh of generation in 2040. 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 12).

Figure 12 ▻ **Global offshore electricity capacity and generation in the New Policies Scenario**

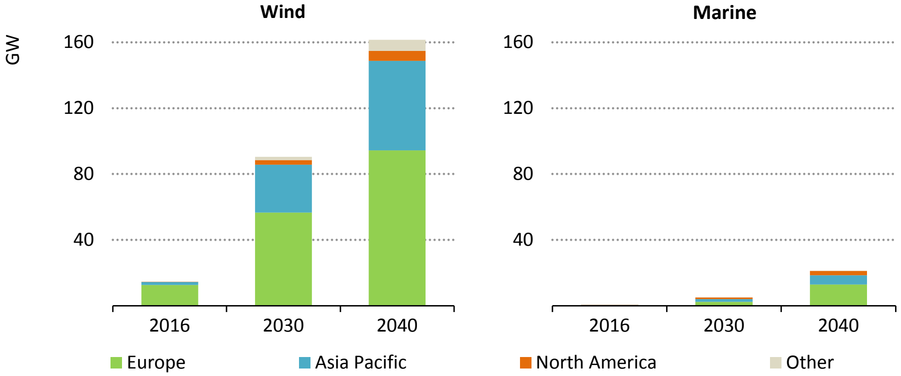


Supportive policies, especially auctions, are the key mechanism to encourage new offshore electricity investment in the New Policies Scenario

In the New Policies Scenario, offshore wind capacity growth is dominated by Europe, which accounts for close to 60% of total global additions with 94 GW by 2040 (Figure 13). With relatively shallow waters suitable for development and easier access to existing transmission grids than most regions, Europe is well placed to develop offshore wind. Most of the remaining capacity additions are from northeast Asia, primarily China and to a lesser extent, Korea, Chinese Taipei and Japan. Despite being relatively new to offshore wind deployment, China has demonstrated its ability to ramp up renewables deployment quickly, having done so already for onshore wind and solar PV installations. China is thus projected to surpass its target of 5 GW in installed capacity by 2020 in the 13th Five-Year Plan and adds almost 40 GW in capacity additions through to 2040.

The United States has long been interested in developing offshore wind, particularly along the east coast. However, the first offshore wind installation only came into operation in 2016 (Block Island), and it will take some time for the US offshore wind industry to ramp up. In the absence of the Clean Power Plan, the United States is projected to reach only around 4 GW of capacity by 2040 in the New Policies Scenario, driven by state level actions and mandates.

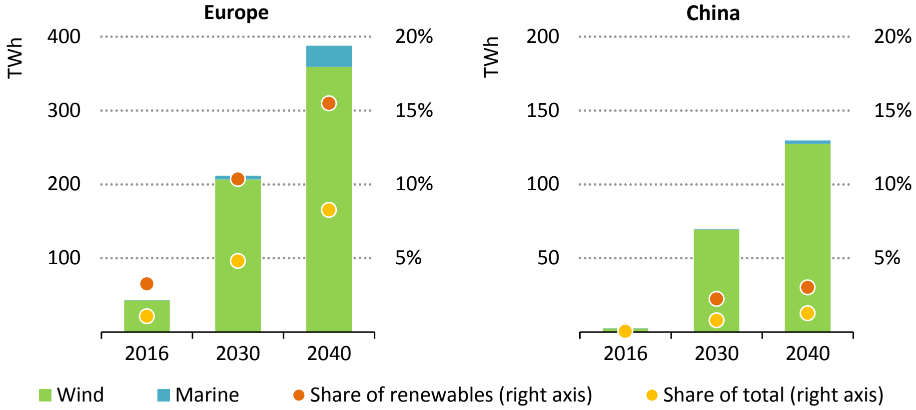
Figure 13 ⊳ **Installed offshore capacity by region in the New Policies Scenario**



Europe and China dominate capacity growth for offshore wind in the New Policies Scenario, reflecting their more ambitious policies and targets

Despite its marginal contribution to the global power mix, offshore power generation makes a significant contribution to electricity generation in Europe, with its projected share in total generation growing from around 1% in 2016 to more than 8% in 2040 (Figure 14). Considering only the European Union (in its 2018 composition), the share of offshore power in total generation in 2040 is about 10%. In the second-largest market for offshore power, China, the contribution of offshore power generation in the total mix is only slightly above 1% in 2040.

Figure 14 ⊳ **Offshore electricity generation in Europe and China in the New Policies Scenario**



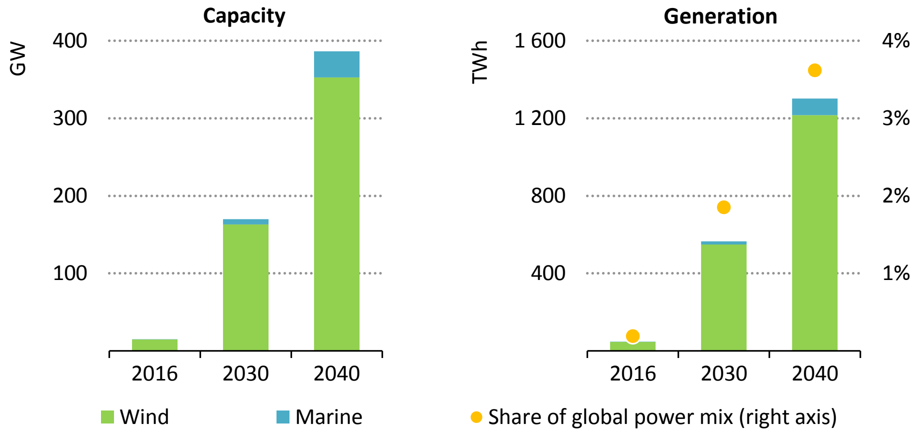
The share of offshore wind in Europe's electricity mix reaches 8% by 2040 (10% in the European Union), making Europe the global leader for this technology

Sustainable Development Scenario

In the Sustainable Development Scenario, we assume that supportive conditions for deployment of low-carbon technologies are in place, including via higher and more widespread pricing of carbon. This drives greater offshore wind deployment, which in turn drives down costs further and faster. The same effect applies to solar PV and onshore wind. The impact on the competitiveness of offshore wind versus other renewable sources varies from country-to-country. However, the prospects for offshore electricity generation in practice are not only a question of relative costs, but also depend on potential constraints on large-scale onshore developments, including siting issues and social acceptance.

Offshore **electricity** production in the Sustainable Development Scenario gets a major boost as 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 (Figure 15). Marine power also grows, albeit to a smaller extent, topping 30 GW by 2040 and producing 85 TWh of electricity. By 2040, offshore electricity generation meets 3.5% of the world's power generation needs.

Figure 15 ▹ Global offshore electricity capacity and generation in the Sustainable Development Scenario

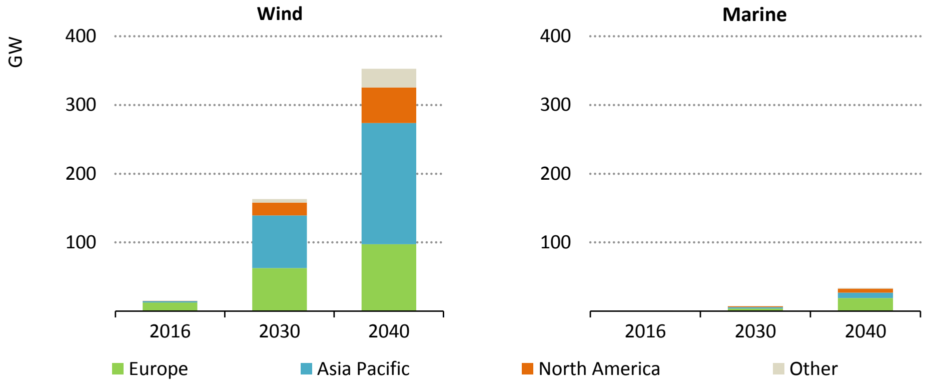


Offshore electricity generation grows twice as fast in the Sustainable Development Scenario, accounting for nearly 4% of global generation by 2040

Europe, the leader in offshore wind deployment in the New Policies Scenario, sees only a relatively minor upswing in offshore wind investment in the Sustainable Development Scenario. This is because the lion's share of power sector investment in Europe already goes to renewable technologies in the New Policies Scenario: overall, the Sustainable Development Scenario sees around 710 GW of total capacity from solar PV and wind (both onshore and offshore), compared with about 600 GW under the New Policies Scenario. In addition, we assume in the Sustainable Development Scenario that regulatory barriers and public acceptance issues for all renewables subside, which favours the development of a portfolio of low-carbon generation options led by (lower cost) solar PV and onshore wind. However, there are clearly circumstances in which offshore wind could grow more strongly. If some restrictions on onshore wind and solar PV remain, for example because of public opposition to new onshore sites, offshore wind would be well placed to offer development opportunities. Alternatively, offshore wind could also pick up a share of the upside in scenarios that see even more 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 (Philibert, forthcoming).

Offshore wind in the Asia Pacific region grows very strongly, alongside rapid growth in onshore wind and solar PV (Figure 16). In total, countries in Asia Pacific install almost 180 GW of offshore wind by 2040, compared with less than 60 GW in the New Policies Scenario. China becomes the global leader in offshore wind capacity additions with more than 100 GW of capacity additions, overtaking Europe, while India, Japan and Korea each add substantial amounts of capacity. Offshore wind capacity increases significantly in the United States in the Sustainable Development Scenario, 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 Russia becoming important markets for offshore wind in the Sustainable Development Scenario.

Figure 16 ⊳ **Installed offshore capacity by region in the Sustainable Development Scenario**



Technology improvements spark a virtuous circle of deployment and cost reductions in the Sustainable Development Scenario, spreading offshore electricity generation worldwide

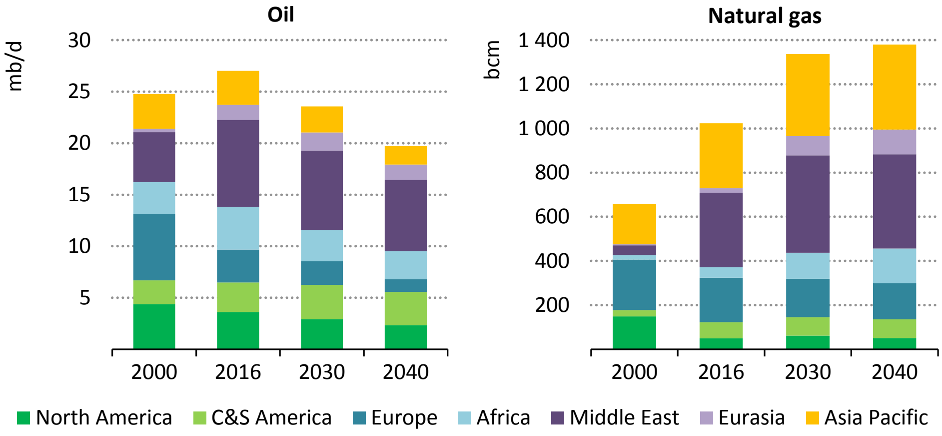
By 2040, offshore power generation accounts for more than 9% of the total power mix in Europe (12% in the European Union) in the Sustainable Development Scenario. In China, offshore power generation reaches a share of almost 4% in 2040. In terms of shares, both

Japan and Korea surpass China with offshore generation reaching a penetration of more than 6%. Australia, Canada, Mexico and the United States see shares of around 3%.

In the Sustainable Development Scenario, offshore **oil** production declines to 20 mb/d by 2040; this is a result of shallow water oil production declining by more than one-third while deepwater production stays at around current levels (Figure 17). Limited shallow water exploration and unfavourable cost competitiveness (in a lower price environment) are the two key reasons for the production trajectory in the Sustainable Development Scenario. Regions that have large remaining low cost reserves in shallow water areas, such as Eurasia and the Middle East, are better able to sustain production levels throughout the Sustainable Development Scenario (the Middle East remains the largest shallow water producing region, but still sees production fall by about 15% between 2016 and 2040). However, mature producing regions such as Europe, North America and the Asia Pacific see combined production fall by almost 60%, compared with a 40% drop in the New Policies Scenario. Production in Africa, which in the New Policies Scenario drops only marginally, shrinks by over 30% between 2016 and 2040.

Growth in Brazil's deepwater output in the Sustainable Development Scenario resembles the growth in the New Policies Scenario until 2025 (as existing or currently planned investments ramp up), but then production plateaus and falls back slightly. In 2040, Brazilian deepwater production stands at 2.8 mb/d in the Sustainable Development Scenario, 0.6 mb/d higher than 2016, but about half of the level in 2040 that is projected in the New Policies Scenario. Declines in deepwater production in the United States, Angola and Nigeria and are more severe while Mexico's output grows at a slightly more modest pace.

Figure 17 ▻ **Offshore oil and natural gas production by region in the Sustainable Development Scenario**



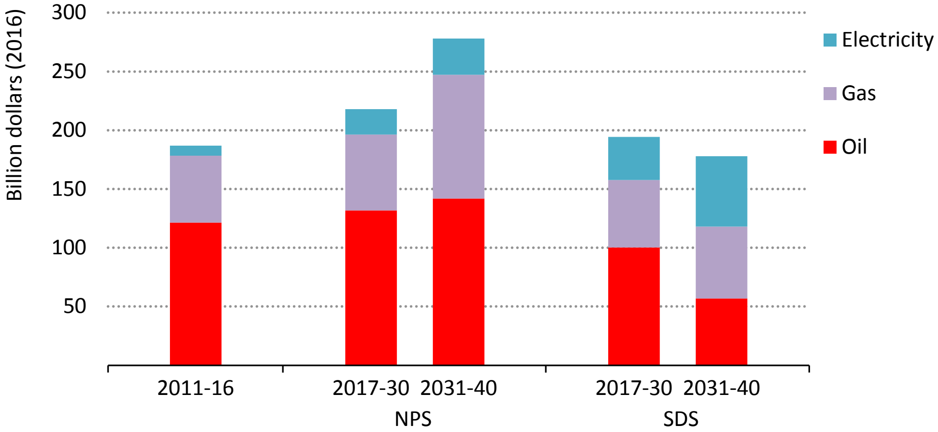
The prospects for offshore gas remain relatively robust in a Sustainable Development Scenario, but declining oil demand weighs against major new offshore oil projects

In contrast to the outlook for oil production, offshore **natural gas** production grows in the Sustainable Development Scenario (albeit less rapidly than in the New Policies Scenario). Offshore production reaches 1 380 bcm in 2040 (one-third of total production at that time). Despite lower natural gas prices and overall demand growth, the market environment in the Sustainable Development Scenario is sufficiently supportive to develop already-discovered gas resources. Offshore gas production rises to 420 bcm in the Middle East in 2040 (compared with 570 bcm in the New Policies Scenario), to 110 bcm in Eurasia (compared with 170 bcm in the New Policies Scenario) and to 160 bcm in Africa (compared with 230 bcm in the New Policies Scenario). The downside for European offshore gas production in the Sustainable Development Scenario is limited as it benefits from existing infrastructure and market proximity (and an assumption that Europe develops indigenous resources where possible, rather than relying more on imports).

Offshore investment and supply chains

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 $5.9 trillion in cumulative capital spending to 2040 in the New Policies Scenario and $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 18).

Figure 18 ▷ **Average annual global offshore energy investment by scenario**



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

Notes: The figures for new investment detailed in this report 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. spending to ensure the day-to-day functioning of the asset, nor do they include costs of abandonment or decommissioning. The investment is booked in the year in which new energy supply comes online.

In the early years of our projection period, global investment in offshore oil and gas projects is roughly similar across the two scenarios. From the mid-2020s, the difference in overall demand and activity becomes more apparent and investment levels diverge. After the mid-2020s, investment in offshore oil and gas in the New Policies Scenario continues to grow, particularly for offshore gas, while in the Sustainable Development Scenario, it peaks and starts to decline as lower volumes, at lower average costs, are developed. Despite the difference in absolute investment levels, the share of offshore in total oil and gas investment remains at around one-third in both scenarios.

In general, offshore investment in power generation remains significantly lower than total offshore oil and gas upstream investment, although the gap narrows towards the end of the projection period in the Sustainable Development Scenario. Annual investment in offshore electricity generation increases to more than \$25 billion by the 2030s in the New Policies Scenario and to more than \$50 billion in 2040 in the Sustainable Development Scenario.

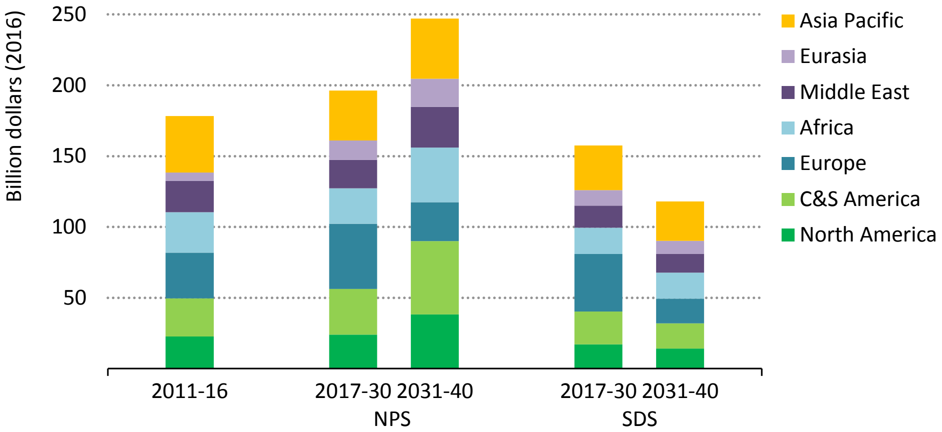
By the 2030s, overall capital investment in offshore power generation in the Sustainable Development Scenario reaches rough parity with oil and gas (when compared individually). In some regions, this gap narrows much more quickly, notably in Europe. Overall, these patterns of investment, especially the way that investment in renewables rises to fill a part of the gap left by falling oil and gas investment in the Sustainable Development Scenario, can offer a reassuring perspective for companies engaged in the offshore energy sector.

Investment in offshore oil and gas

Investment patterns naturally correlate with the overall outlook for production, while also reflecting the cost differentials between regions (Figure 19). One of the key locations for offshore oil and natural gas investment in the New Policies Scenario is Brazil, where annual capital spending reaches \$60 billion by 2040 (more than \$50 billion of which is for oil). In the Gulf of Mexico, combined investments on both the US and Mexican sides rise by the mid-2020s to around \$20 billion per year and continue to rise to above \$30 billion by 2040; the increase reflects the shift in investment from shallow to deeper waters, especially in Mexico. After falling back during the period to 2025 (when lower prices continue to constrain investment), investment picks up in Africa, due to some rebound in Nigeria and Angola and to the major natural gas projects coming online in East Africa. By way of contrast, offshore oil investment in Europe tails off considerably in the latter part of the projection period.

In the Sustainable Development Scenario, oil and gas activity and investment are lower and, especially after 2030, the outlook diverges markedly from the New Policies Scenario. Investment in gas is relatively robust (although still well below the levels reached in the New Policies Scenario), but by the 2030s all regions see offshore oil investment at about half of the levels projected in the New Policies Scenario, in some cases even lower. In the North Sea, annual offshore oil investment falls below \$5 billion by 2040. The continued need for upstream oil spending in this scenario is motivated entirely by the need to compensate for declining output at existing fields. Even in a scenario in which demand falls by 1.7% per year in the 2030s, there is still a need for upstream investment to compensate for falling production from existing fields (observed declines in post-peak fields average more than 6%, with decline rates for offshore fields typically higher).

Figure 19 ⊳ **Average annual offshore oil and natural gas upstream investment by region and scenario**



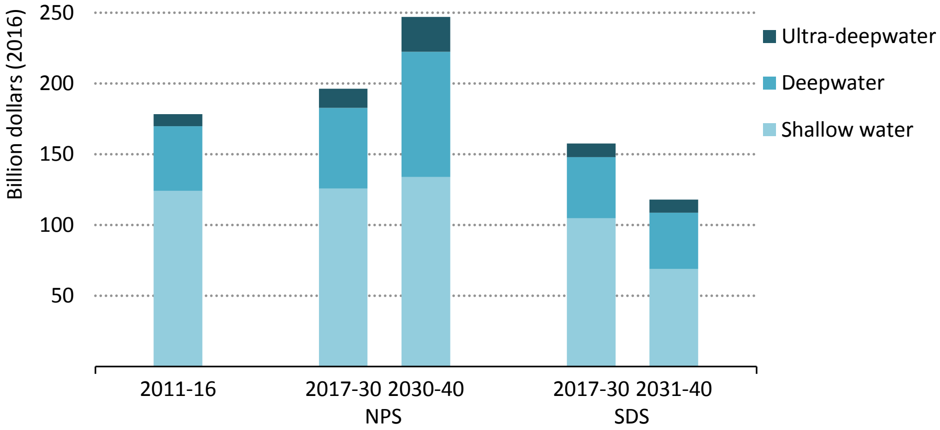
Offshore oil and gas investment in the Americas nearly doubles to 2040 in the New Policies Scenario, largely because of rising output in Brazil and Mexico

Looking at the profile of upstream investment, there is a notable shift from shallow water to deepwater plays in the New Policies Scenario (Figure 20). Mexico provides a good example of this dynamic: Mexico is a longstanding shallow water producer, but the main sources of future growth are anticipated to come from deepwater opportunities offered in the country's current licensing rounds, notably the Perdido basin in the northern Gulf of Mexico and to the south in the Bay of Campeche. The steady rise in oil prices in the New Policies Scenario and the assumption of continued technology innovation brings such resource areas firmly into play. In the Sustainable Development Scenario, the market and price environment weighs against complex projects with long-lead times.

Our projections also provide some indications as to the types of offshore facilities that might be required. Overall, there are three broad categories of installations in offshore oil and gas developments: fixed, floating and subsea tie backs. Fixed installations sit permanently on the seabed and are typically used at water depths of less than 125 m. They are made of steel or concrete with sizes ranging from small steel wellhead platforms to large concrete structures. Floating facilities include FPSOs, semi-submersible platforms, spar platforms and tension leg platforms. These are primarily used in deepwater developments as they are not fixed but rather anchored to the seabed. Subsea tie backs are offshore production facilities that are completely submerged and located at the seabed.

From the seabed they are tied back to a fixed or floating offshore production facility, or to an onshore facility for processing.

Figure 20 ▻ **Annual average offshore oil and natural gas upstream investment by water depth and scenario**

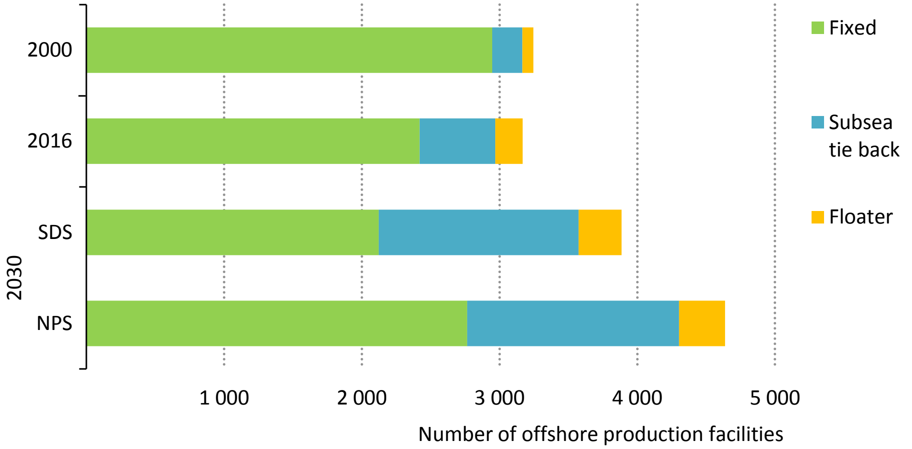


Growth in offshore oil & gas spending in the New Policies Scenario comes from deepwater; declines in the Sustainable Development Scenario are largely from shallow water

Historically most offshore oil and gas developments have been in shallow water with fixed steel platforms (Figure 21). In 2000, there were close to 3 000 fixed platforms worldwide with the number of subsea tie backs and floating production facilities marginal in comparison. By 2016, the number of fixed platforms had fallen slightly (although the level of production from each platform was on average higher) while the number of subsea tie backs and floating facilities had more than doubled. The increase in floating facilities between 2000 and 2016 accompanied a more than tripling of deepwater oil and gas production.

In the outlook, a rapid increase in subsea tie backs and floating facilities is expected to continue as deepwater production ramps up and smaller new fields are tied in to existing infrastructure. This happens in both scenarios, although the number of facilities added in the Sustainable Development Scenario is lower. The outlook for fixed facilities also shows growth, but this is more subdued because of the relative maturity of many shallow water basins. In addition, there are increasing numbers of old facilities that will require decommissioning (Box 4).

Figure 21 ▷ Type of global offshore oil and natural gas production facilities deployed in selected years by scenario



Offshore oil and gas production growth comes primarily from floating facilities and from subsea tie backs, rather than from fixed installations

Sources: Historical data from Rystad AS; projections from IEA.

Box 4 ▷ The decommissioning challenge

Decommissioning of offshore platforms is set to be an increasingly important issue over the period to 2040. We estimate that between 2 500-3 000 offshore projects are likely to require decommissioning, intensifying a debate over costs and optimal approaches (Figure 22). 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. The types of structures requiring decommissioning are also set to evolve: to date, most activities have involved steel platforms in shallow water, but looking ahead there will be a rising need to decommission more complex deepwater structures and subsea tie backs.

The North Sea provides a good example of the challenges: it has more than 500 platforms and roughly ten-times as many wells in place, as well as subsea assets and other infrastructure, including pipelines. Decommissioning has started, but the overwhelming bulk of the work lies ahead. Alongside plugging and abandoning the wells (typically the largest element of the overall cost), an intergovernmental convention from 1998 requires that all topsides (the part of the structure above sea level) as well as sub-structures/jackets are to be removed, re-used, recycled or disposed of on land.[11] Estimates of the total decommissioning cost for the North Sea vary, but all are

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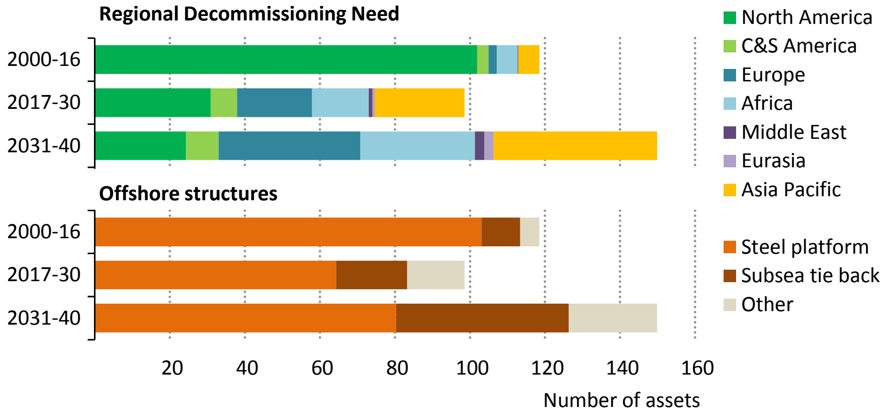
[11] The Convention for the Protection of the Marine Environment of the North-East Atlantic ("OSPAR Convention").

substantial, typically around $100 billion for the period to 2050 (WEC, 2017).

As in the North Sea case, regulations typically allow for the possibility of re-using or re-purposing offshore infrastructure, which has sparked a debate about potential alternative uses. One option that has been tried in the United States and Southeast Asia is the "Rigs-to-Reefs" approach, which leaves some of the rig behind to become an artificial habitat for marine life. Not all platforms are suitable, but where applicable, it is much less costly than full removal. More than 500 platforms in the Gulf of Mexico, for example, have already been converted to permanent artificial reefs.

The issue of decommissioning offshore wind farms is less pressing than for oil and gas infrastructure, but initial experiences are starting to provide a clearer picture of costs and approaches. In 2016, Vattenfall decommissioned its 15-year old 10 MW Yttre Stengrund site in the Swedish Baltic Sea, while Ørsted (previously known as DONG Energy) decommissioned its 5 MW Vindeby offshore project after 25 years of operation (Ørsted, 2017). Projects that started operation in the early 2000s can be expected to begin decommissioning in the 2020s as they approach their design life of 25 years, as the availability of advanced technologies and better quality sites make it inefficient to continue operating some of them. For example, Vattenfall chose to decommission the Yttre Stengrund site early as the unavailability of spare parts for the early model technologies and the huge cost to upgrade equipment made it more economical to dismantle the wind installation and invest in other locations (Vattenfall Press Office, 2016).

Figure 22 ▻ **Estimated annual average decommissioning needs for oil and gas projects by region**



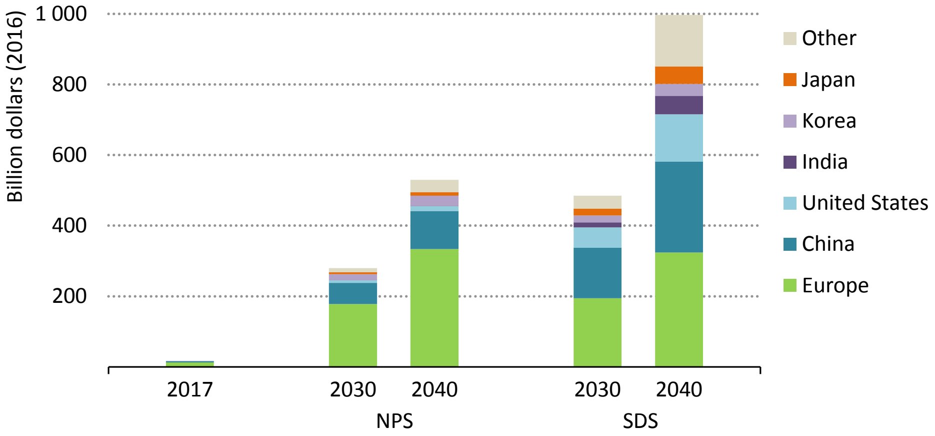
Decommissioning activity is set to take off outside North America and will require dismantling more complex structures in deeper water

Sources: Rystad AS; IEA analysis.

Investment in offshore electricity

A cumulative $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 $22 billion per year but in practice increasing at a compound average annual growth rate (CAAGR) of almost 2% per year from today (Figure 23). The cumulative figure almost doubles to just below one trillion dollars in the Sustainable Development Scenario, rising at a CAAGR of 3.5% per year from today. Europe remains the biggest market for offshore wind investment with a total $330 billion investment in both scenarios (representing almost two-thirds of global investment in the New Policies Scenario and just under one-third in the Sustainable Development Scenario), although, as discussed above, there is considerable potential upside to this figure – especially in the Sustainable Development Scenario. China is the next biggest market, with $110 billion in investment in the New Policies Scenario, but this figure skyrockets to $260 billion in the Sustainable Development Scenario as offshore wind deployment in China grows rapidly to meet decarbonisation and air quality goals.

Figure 23 ▻ **Offshore wind investment by region and scenario**



Cumulative investment in offshore wind reaches $500 billion in the New Policies Scenario and doubles in the Sustainable Development Scenario

Other countries that see a significant increase in offshore wind investment in the Sustainable Development Scenario include the United States, with investment rising from almost $15 billion in the New Policies Scenario to $135 billion, and India, which jumps from $20 million to $53 billion. Korea, the third-largest market for investment in the New Policies Scenario with $29 billion, sees a more modest increase to $34 billion.

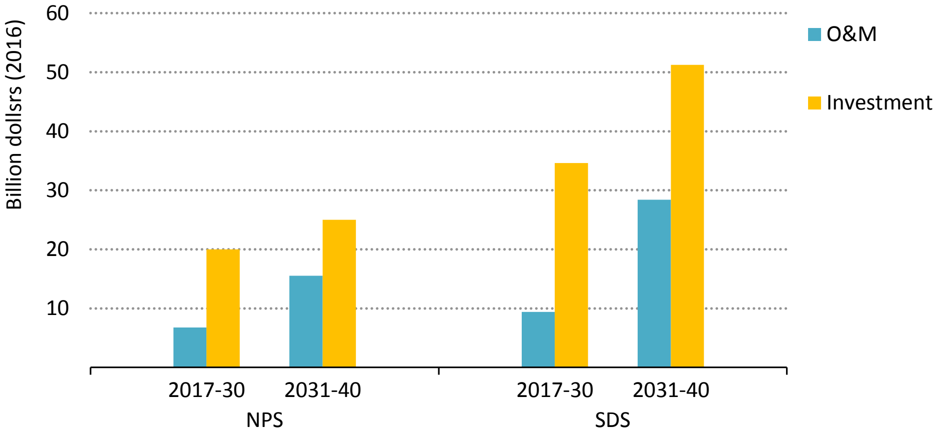
Our analysis of current costs suggests that up to half of the LCOE of a typical offshore wind farm goes towards financing costs, while about one-third is for capital costs. Turbine costs account for about 40-60% of capital costs. Using this range as the minimum and maximum of the annual average investment in both scenarios, the annual average market for offshore wind turbines is between $9-13 billion in the New Policies Scenario and between $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 $3-6.5 billion in the New Policies Scenario and $6-12.5 billion in the Sustainable Development Scenario, while the potential annual market for offshore wind installations is $2-5.5 billion in the New Policies Scenario and $4-10.5 billion in the Sustainable Development Scenario.

About 20-30% of the total LCOE goes towards operation and maintenance (O&M) costs. This is a higher O&M proportion than for onshore wind, reflecting the harsher offshore conditions and the consequent risk of equipment degrading more quickly, and the need for more specialised vessels and equipment. This is not included in our overall investment numbers (which include only capital expenditure). We estimate that the annual O&M market for offshore wind could be between $7.5-11.5 billion in the New Policies Scenario and $11.5-17.5 billion in the Sustainable Development Scenario.

Offshore wind technologies are not yet fully mature. Early development of expertise in the design, installation and O&M of offshore wind projects could provide strategic advantages as the technology matures and present opportunities to export technologies and expertise. Developing these capabilities would support the successful deployment of offshore technologies, as well as providing commercial opportunities to the countries and companies that move early.

Figure 24 ▷ **Average annual investment and O&M spending in the offshore wind sector by scenario**



Harsh offshore conditions mean that 20-30% of lifetime costs for offshore wind are for operation, maintenance and services, a higher share than for onshore projects

Factors affecting the offshore investment outlook

What will be required in order to ensure adequate investment at this scale across the variety of offshore energy operations? Rigorous cost control is a very important part of the picture as is effective regulation to ensure the highest practicable standards for operational safety and environmental performance, especially to reduce the risk of accidents and/or spills from hydrocarbon operations. Maritime spatial planning that involves the various stakeholders and actors is also essential to make informed decisions about resource developments and to achieve the appropriate balance between economic, environmental and social objectives.

Offshore projects require large upfront investments and generally pay back over extended periods, so investors require confidence in the long-term outlook and the stability and attractiveness of fiscal and regulatory conditions. However, there are some important differences in risk and reward profiles across the various types of offshore operations. In the case of oil, the output is sold into a large and liquid world market and some of the main uncertainties relate to the longer term outlook for demand and the oil price. Highly capital-intensive oil projects, with long-lead times and payback periods, may bank on the sort of world described by the New Policies Scenario, but are exposed to the possibility of eventually operating in a scenario closer to that of the Sustainable Development Scenario, in which the demand for oil is lower.

In terms of natural gas, our scenarios suggest that the long-term risks on the demand side are smaller, but here too there are significant commercial uncertainties. The risks associated with large new gas infrastructure projects (since transport of gas is much more expensive than for oil) have traditionally been managed by selling the majority of gas upfront to consumers willing to commit for the long term. However, this business model is coming under pressure; consumers are looking for more flexibility and shorter contract durations and – at least for the moment – are relying more on gas sold on spot markets. Uncertainty over the pace and direction of this change in gas markets could well affect the prospects and timing for some new offshore gas developments.

For offshore wind power, the risks and opportunities are much more directly related to policy frameworks, subsidy regimes and long-term power purchase arrangements with reliable and creditworthy offtakers. In general, offshore wind projects offer a quite distinct cash flow profile compared to oil and gas projects. They are quicker to develop and can start generating cash flow faster than hydrocarbon projects: the risk of delays and cost overruns for more standardised offshore wind projects is less severe than for many offshore oil and gas investments. The long-term cash flow is also typically more stable, albeit lower than upstream oil and gas projects that typically ramp up to a production plateau before going into decline. Where long-term revenues are guaranteed, the risk-adjusted economics of offshore wind projects may prove to be quite competitive with oil and gas projects. What is less clear, for the moment, is how offshore wind investments will look if zero-subsidy bids (of the sort seen in Germany and the Netherlands) become the norm. Much will depend on the overall evolution of electricity market designs and remuneration mechanisms, but higher exposure to wholesale price risks in new offshore projects (all else being equal) would feed through into a higher cost of capital and a different risk/return profile.

Box 5 ▻ Offshore environmental and climate risks

A crucial element for the future of offshore energy investment will be the success of regulators and industry in minimising hazards for the marine environment. Regulation of offshore oil and gas activities has tightened in many jurisdictions since the 2010 Deepwater Horizon accident and oil spill in the Gulf of Mexico. In the United States, this involved changes to system of regulation, the revision of industry best practice guidelines for various aspects of drilling safety, and a focus on enhanced spill response and well containment capabilities. Many other countries also reviewed and upgraded their offshore oil and gas safety practices post-2010. For the industry as a whole, it will be critically important to ensure that the current focus on cost-cutting and efficiencies does not put pressure on health and safety standards; likewise that other environmental issues, such as the continuing prevalence of flaring associated gas in some countries, are addressed.

The environmental risks associated with offshore wind activities are much more limited, but nonetheless require careful management. The construction of offshore wind farms, notably pile driving for the turbine foundations, causes local disruption for some marine species, while operating wind farms (which are typically off limits for fishing, another potential area of disagreement) can pose some risks to local wildlife, especially to birds, but can also provide some benefits to marine ecosystems. The growth of the offshore wind industry is making this an area of active investigation and research.

A changing climate can also affect offshore energy activities, although the extent and nature of these effects is still uncertain. The principal threat to oil and gas extraction and infrastructure is extreme weather. Hurricanes Katrina and Rita, which arrived within four weeks of each other in August and September 2005, provided a vivid demonstration of the scale of possible impacts, destroying around 115 platforms in the US Gulf of Mexico and leaving another 52 with major damage. These hurricanes resulted in the near-total shutdown of almost all of the Gulf's offshore oil and gas production. More than nine months later, more than 20% of US oil production and 13% of gas output was still shut in, in part because of damage to pipelines (although no major oil spills were attributed to either storm). Other potential challenges include the increased incidence of icebergs in some areas and the impact of sea level rise on offshore platforms and port infrastructure.

As for offshore wind, at present there is high uncertainty about how changes in wind intensity and patterns, and extreme weather, might impact the sector. The expansion of offshore wind investment outside the North Sea will expose projects to a wider range of marine settings and potential hazards, but, given the design and engineering solutions available to combat climate change impacts, it is considered unlikely that this sector will face insurmountable challenges from climate change (Hoegh-Guldberg et al, 2014).

The policy issues involved in the offshore energy sector are much broader than securing adequate investment in the projects themselves. There is the question of adequate port infrastructure and a range of other interactions with fisheries and other aspects of the overall maritime economy, as well as other environmental considerations and impacts (Box 5). There are also significant potential synergies available across offshore energy operations. To thrive, offshore energy requires integrated thinking – a topic that we take up in the next section.

Potential for offshore energy integration and synergies

Today the offshore hydrocarbon and wind power sectors are not closely interlinked. Could they benefit from working more closely together? In theory, the possibilities are broad: they span sharing infrastructure, offshore services, human capital, technology, products and knowledge, yet there are some practical challenges. In this section, we provide an overview of the potential synergies and look at the specific example of the North Sea, which has been at the centre of the international discussion about offshore integration. We conclude with a review of other regions where the offshore hydrocarbon and electricity generation sectors could work more closely together.

Synergies

This report groups the synergies into three areas, which are discussed in turn:

- The *overlapping competencies* required to construct and maintain offshore projects, creating scope for the transfer of knowledge and expertise from the oil and gas sector to help develop the offshore wind sector.
- The potential to *electrify offshore hydrocarbon operations* and improve their environmental performance by supplying them with low-carbon electricity.
- The possibility to find *new uses for existing offshore oil and gas infrastructure* once it reaches the end of its operational life.

Overlapping competencies

The production of offshore energy requires a number of specialist skills, some of which are specific to the types of operation, but many of which are common to a variety of offshore projects. Overlapping competencies include large-scale project management capabilities and the ability to work in harsh offshore conditions.[12] These elements have already brought a number of large oil and gas companies into the offshore wind sector: Statoil is operating offshore wind projects in the United Kingdom and has a project pipeline of new wind farms in Germany and the United Kingdom, while Shell entered the stage more recently after winning offshore wind auctions in the Netherlands. The Danish energy company Ørsted

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[12] Geothermal power generation is another area with potential for knowledge transfer between oil and gas operations and the renewable sector: Chevron, for example, was among the pioneers in developing geothermal projects in the Philippines and Indonesia before selling these assets in 2017.

(formerly DONG) has built up the largest portfolio (above 2 GW) of offshore wind capacity in Europe. In recent years, the company sold its oil and gas assets and now fully focuses on renewable energy, with a target of 11-12 GW of installed offshore wind capacity by 2020.

The scale of offshore wind projects can also make them quite a good match for oil and gas companies, as a large offshore wind project is comparable to a medium-size upstream oil and gas development. Because of fewer restrictions on size and scope, offshore wind projects also offer large scalability, for instance the Dogger Bank development in the United Kingdom consists of four offshore wind farms, each with a 1.2 GW capacity, which could bring total investments to almost $21 billion (GBP 15 billion). In comparison, the full field development of the Norwegian offshore field Johan Sverdrup is estimated at just below $20 billion. Another similarity is that both types of projects have a long-term time horizon, typically more than 20 years. The capital intensity means that the barriers to entry are relatively high for large-scale offshore wind projects and that there is a limited number of companies that have the capacity to develop them.

There is also 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. Other components such as the manufacture of substations (which all new offshore windfarms larger than 100 MW require) and the cables connecting one turbine to another could draw on the expertise of the oil and gas supply chain. 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 are highly transferable.

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. Integration can bring challenges: the cyclicality of oil and gas activity means that its suppliers can move in and out of emerging offshore wind markets in a way that risks discontinuities in wind power supply chain development. Nevertheless, the potential upside for offshore wind power, in terms of access to expertise, capital and supply chain efficiencies, is significant.

Electrifying offshore operations

There is a variety of activities in the offshore oil and gas sector that require electricity, notably the pumps for extraction and injection; compressors for transportation; equipment used for hydrocarbon treatment or separation; as well as other on-site needs for electricity and heat, e.g. for living quarters and metering. Most offshore oil and gas platforms typically use single-cycle gas generators to produce the needed electricity; these are relatively inefficient compared with onshore combined-cycle gas turbines, although some platforms (especially in the North Sea) already have cable connections to the mainland electricity grid.

A logical step towards offshore integration would be to supply existing oil and gas platforms with electricity from nearby offshore wind installations (if available), with shorter distances meaning lower costs for transporting the electricity compared with an onshore grid connection. The intermittency of power from offshore wind is a challenge, although there are some operational and technical measures that could reduce dependency on continual availability of power (and limit run-time for gas turbines or diesel engines): these could include battery back-up and, if costs allow, optimisation of operations such as reservoir pressure support. The benefits of electrifying the platforms in this way would be a reduction in emissions of CO_2 and air pollutants, and increased energy efficiency. Electricity from offshore wind power could also serve operations that help to improve recovery. For example, one concept being developed is to use floating wind turbines to power a water injection system in order to extend the lifetime of existing oil fields.[13] Electrification would also be a pre-requisite for many of the options for re-use or re-purposing of offshore platforms (discussed below).

New uses for offshore oil and gas infrastructure

There are several new uses of existing infrastructure (such as platforms, cables and pipelines) that could be considered once these reach the end of their operational lifetime, as alternatives to full decommissioning. An interesting near-term opportunity (if distances allow) is that some platforms could be used as bases from which to conduct operation and maintenance (O&M) for offshore wind facilities. As described, O&M is a sizeable and growing market (worth $7.5-11.5 billion per year on average in the New Policies Scenario and $11.5-17.5 billion on average in the Sustainable Development Scenario)

Looking further ahead, offshore infrastructure could fulfil a variety of potential functions as part of the low-carbon transition. None of these has yet been proven: as usual with early-stage technologies and ideas, there is a need for policy support and pilot initiatives to explore if concepts can be proven technically and commercially:

- Power-to-gas: this would provide an alternative solution for bringing offshore electricity to shore, notably at times of “surplus” power, i.e. when there is no demand for offshore generation. It would involve conversion of the electricity into hydrogen or ammonia for transportation to shore via an existing pipeline system (which would require modification) (Jepma and van Schot, 2017). The possible advantages would need to be balanced against the inconvenience and cost of running large-scale electrolysers and complementary transformation plants offshore.
- Carbon capture and storage: this would involve depleted oil and gas fields being used to store CO_2, which could be brought to the platforms using an existing pipeline infrastructure. Assuming that the platforms are already electrified, they could house compression facilities as well.

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[13] See www.dnvgl.com/winwin.

- Gas-to-electricity or gas-to-hydrogen: this would involve gas produced from a field either being converted directly to electricity (in the case of smaller fields that lack pipeline connections) or used for production of hydrogen (that would then be transported by pipeline, with the additional possibility to store the carbon directly back in the reservoirs). As with power-to-gas, the efficiency losses during conversion make the economics of such uses very challenging.

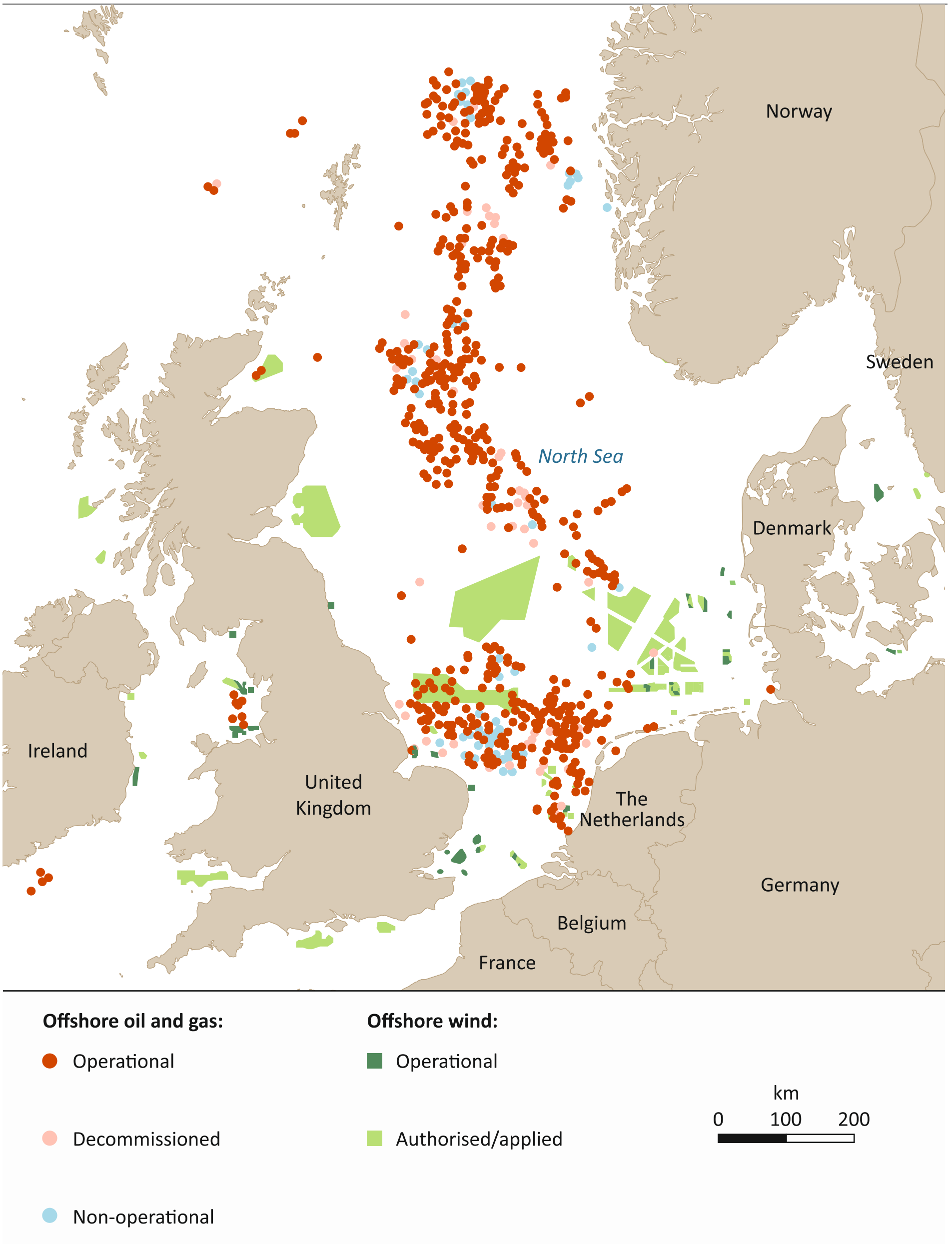
North Sea

The North Sea is at the forefront of debates about the changing nature of offshore energy and the potential synergies between different activities. Already, energy investment and production is balanced between a relatively mature oil and gas sector and a thriving renewable electricity industry. Our projections suggest a continued, albeit gradual shift, towards investment in new renewable energy projects, the vast majority in offshore wind. Near-term investment in oil and gas projects remains substantial in both our scenarios, although it tails off considerably in the Sustainable Development Scenario. However, large commitments of capital are needed under any scenario to decommission old oil and gas assets.

There are already multiple examples of oil and gas companies entering the North Sea offshore wind business, as either project developers or contractors. There are also strong incentives for governments to collaborate with each other and with a range of partners to ensure that this transition in the North Sea’s energy profile is managed cost effectively. One area of co-operation is the idea of an offshore grid for the region. The North Seas Countries' Offshore Grid Initiative (NSCOGI) was established in 2009 by ten countries (Belgium, Denmark, France, Germany, Ireland, Luxembourg, Netherlands, Norway, Sweden and United Kingdom). The NSCOGI was followed up in 2016 with a political declaration that reaffirms a commitment to deployment of offshore renewable energy, especially wind and to promote regional interconnections. This co-operation is a long-standing energy policy priority for the European Union, although it faces barriers to implementation from the diversity of regulatory frameworks and renewable energy support schemes, as well as financing challenges. The co-operative arrangement has facilitated action between industry players to develop offshore hubs for wind power that can underpin future capacity expansion and further reduce grid connection costs.

The North Sea has more than 300 oil and gas fields; its infrastructure counts more than 5 000 wells, 500 platforms and 10 000 km of pipelines (OSPAR, 2010). Incorporating ideas about alternative uses of offshore oil and gas infrastructure is also an important part of a cost-effective approach, given that in the majority of cases, the government covers some decommissioning costs, either directly (as a shareholder) or indirectly as the costs are tax-deductible. This is a particular issue for the United Kingdom, Norway and the Netherlands, which will account for the lion’s share of decommissioning activity in the North Sea.

Figure 25 ▹ **Offshore hydrocarbon and wind installations in the North Sea**



This map is without prejudice to the status of or sovereignty over any territory, to the delimitation of international frontiers and boundaries, and to the name of any territory, city or area.

A relatively mature oil & gas sector and a thriving renewable electricity industry are making the North Sea a test bed for offshore energy collaboration

Sources: OSPAR (2018); 4C Offshore (2018).

Other regions with potential for offshore synergies

Our assessment of offshore regions with potential for synergies between the oil and gas sector and the wind power sector is based on a number of criteria: offshore wind resources, with a supportive regulatory framework and relatively proximate centres of electricity demand, and a well-developed oil and gas supply chain that is capable of providing support to offshore wind development. The analysis was informed by our projections of future output, but could also be facilitated by governments, for example by obliging operators to assess the scope for integration with offshore renewables in their field development plans. In the next section, we rate selected countries and regions as having high, medium or limited potential for future synergies between different types of offshore energy activity.

High potential

China has a long coastline with excellent wind resources and proximity to the huge electricity demand centres (most of China's economic activity and energy demand are concentrated in the coastal eastern provinces, home to more than one-third of its population). The policy framework for renewables in general is supportive and the focus on offshore wind is increasing. The electricity market in China is the largest in the world and the offshore oil and gas industry is also well developed; in tandem with the country's industrial capabilities, China looks to have the ingredients necessary to foster a strong offshore wind supply chain.

Australia has strong potential for offshore wind with ample coastline and good access to quality wind resources. There is no lack of demand, as Australia's largest cities and demand centres for electricity are close to some of the country's best offshore wind resources; however offshore wind faces strong competition from onshore wind and solar power. The country has a significant offshore oil and gas sector that could support offshore wind developments. There is no specific target for offshore wind deployment, but there are plans to develop Australia's first offshore wind farm (2 GW) in Victoria's Gippsland Basin. There is some oil and gas infrastructure in Gippsland Basin (with more than 20 oil and gas platforms), which could offer some synergies, although most of the offshore oil and gas developments are concentrated in the more remote northwest of the country.

Brazil has a long coastline with areas in the northeast and the south offering very good wind resources. Brazil is one of the largest markets for onshore wind and moving into offshore wind would be a natural step, although thus far there is no specific framework for offshore wind in place. Several large demand centres are located along the coast. The Brazilian oil and gas sector is undergoing rapid development and is a leader in offshore development, especially for deepwater, and its offshore oil and gas supply chain is very well developed. Further down the South American east coast, Uruguay and Argentina also have areas with strong wind resources.

The *United States* has significant offshore wind resources along the east coast and in the Pacific Northwest, in relatively close proximity to major cities and demand centres. At state level, there are some targets for offshore wind. In addition, the US oil and gas industry is the largest and among the most innovative in the world. However, there is only limited potential for overlap between the various offshore sectors in the US Gulf of Mexico, where most offshore oil and gas production is located: there are few viable prospects for offshore wind developments in this area, not least because onshore wind in the southern United States is very competitive.

Medium potential

Canada has vast wind resources along its east and west coasts, as well as in the Hudson Bay in the northeast region. Currently there are no specific targets for offshore wind at the national level, while at provincial level the position on offshore wind varies from Ontario, which has since 2011 imposed a moratorium on projects while it studies the potential impacts, to Nova Scotia, where there are plans to build 1 GW of offshore wind on the Atlantic coast. Another challenge is that electricity demand is quite dispersed and not many large cities are located close to offshore wind resources, unless projects are built on the Great Lakes. Canada has an Atlantic offshore oil and gas industry, albeit not at the scale of the United States or Mexico.

Mexico's offshore wind resources are limited to some pockets in the northern part of the Gulf of Mexico and the southern part of the Pacific Ocean coast. The policy framework for deployment of renewables in general is strong, but the policy and commercial focus has been on ample solar PV and onshore wind investment opportunities. Demand centres are generally not located close to the areas with offshore wind potential. Mexico has a large, mature offshore upstream oil and gas sector, which is being revitalised by the Energy Reform announced in 2013 and the arrival of new players alongside Pemex, the national oil company.

India's offshore wind potential is concentrated mostly around the southern coastal areas and off the west coast around Gujarat. India is making a major push to increase the share of renewables in its power mix with a strong focus on solar PV, followed by onshore wind. India has signalled that it plans to auction 5 GW of offshore wind capacity by 2022, its first foray into this area and an important indicator of investor sentiment. Electricity demand is expected to grow rapidly, but affordability is a major concern and the costs of offshore electricity may be too high to allow for rapid expansion. India has relatively substantial offshore oil and gas production and significant unexplored potential.

In *Southeast Asia*, several countries have good conditions for offshore wind, notably Vietnam and Indonesia. The overall policy framework for renewables is being strengthened in many parts of the region, although often without specific policies for offshore wind. Electricity demand is strong and growing; though demand centres are not located close to the most prospective offshore wind sites. Offshore wind (especially if costs for floating turbines come down) could provide a valuable way for some island communities to reduce reliance on relatively expensive oil-based power. Malaysia and Indonesia have long experience with offshore oil and gas operations.

Japan, Korea and *Chinese Taipei* all have strong potential for offshore power, with good wind conditions and well-functioning electricity grids. Policy support for renewables is growing and Chinese Taipei has offshore wind targets in place. Although lacking an offshore oil and gas industry, strong manufacturing and technological capabilities are likely to be supportive of offshore wind development. In Japan, the vast majority of its offshore is deepwater and would require floating turbines: this market could be a catalyst for floating wind power technology.

Limited potential

The opportunity to develop offshore wind in *East and West Africa* is relatively limited. Renewable policies are emerging but these are typically aimed at supporting solar power, a resource that these regions have in abundance. The electricity markets in these regions are still relatively small, although with huge potential for growth. West Africa is an established oil and gas producing region. East Africa is set to emerge as a major natural gas producer.

The *Middle East* is the largest offshore oil and gas producing region in the world, but the scope to develop offshore wind resources is quite small. Policy efforts for renewables are naturally inclined towards solar power. Electricity markets are large, but prices in most countries are subsidised (even though reforms are underway in many areas).

Russia has large coastal areas with significant wind potential, but these are typically far from demand centres and policy support for renewables generally is weak. Although the majority of Russian oil and gas activity is onshore, there is also an important offshore industry.

Annex A. Resource Estimates

Table A.1 ▻ Oil resources and reserves (bbl)

	Technically recoverable reserves	Cumulative production	Remaining TRR	Remaining share of TRR (%)	Proven reserves
Conventional oil	4 126	1 363	2 763	67%	1 294
Conventional	2 247	885	1 362	61%	825
Shallow offshore	795	299	496	62%	223
Deep offshore	224	26	198	88%	31
Ultra-deep offshore	78	2	77	98%	6
Other	782	151	630	81%	209
Unconventional oil	3 411	27	3 384	99%	400
World total	**7 537**	**1 390**	**6 146**	**82%**	**1 695**

Notes: bbl = billion barrels; TRR = technically recoverable reserves.

Source: IEA (2017a).

Table A.2 ▻ Natural gas resources and reserves (tcm)

	Technically recoverable reserves	Cumulative production	Remaining TRR	Remaining share of TRR (%)	Proven reserves
Conventional gas	544	113	432	79%	204
Conventional	234	86	148	63%	110
Shallow offshore	179	22	156	88%	69
Deep offshore	79	4	74	95%	22
Ultra-deep offshore	53	0.2	53	99.6%	4
Unconventional gas	375	10	365	97%	12
World total	**919**	**122**	**796**	**87%**	**216**

Notes: tcm = trillion cubic metres; TRR = technically recoverable reserves.

Source: IEA (2017a).

Table A.3 ▻ Wind resources in selected countries and regions

	European Union	United States	China
Assessed technical potential	2 700 GW	2 085 GW	200 GW / 500 GW
Distance from shore	From 5 nm from shore to limit of economic exclusive zones	Up to 200 nm from shore	Not stated
Water depth	1 000 m (70 m for Baltic Sea)	1 000 m (60 m for Great Lakes)	5-25 m / 5-50 m
Height of turbine	100 m	100 m	50 m / 70 m
Wind speed	> 8 m/s	> 7 m/s	Not stated
Exclusions	Areas with conflicting uses or environmental concerns	Areas with conflicting uses or environmental concerns	Not stated

Notes: GW = gigawatt; nm = nautical miles; m = metres; m/s = metres per second.

Sources: WindEurope (2017); NREL (2016) and Li, et al. (2012).

Annex B. Policies for offshore wind in selected countries

	Germany	United Kingdom	United States	China
Target	Target of 35% of electricity from renewables by 2020; Renewable Energy Act (EEG); Offshore Wind Act ("WindSeeG"). (6.5 GW by 2020; 15 GW by 2030.)	Target of 30% of electricity from renewables by 2020; Levy Control Framework/Contract for Differences scheme (energy technology funding for 10 GW by 2020).	State RPS: Massachusetts bill to procure 1.6 GW of offshore wind by 2027; New York commitment to 2.4 GW of offshore wind by 2030 RPS.	5 GW by 2020.
Targeted annual deployment (2020-30)	500-840 MW	~1 000 MW	No firm targets.	No firm targets
Site development (allocation)	Centralised model (site-specific) (EEG 2017)	Decentralised model (zoning).	Not yet determined for large-scale commercial projects.	Decentralised model (open-door).
Grid connection	Shallow-charging model	Hybrid deep/shallow-charging model.	Not yet determined for large-scale commercial projects; deep-charging model.	Deep-charging model.
Key incentive mechanisms	EEG 2017 (subsidy level determined by auction; duration of 15 years).	Renewable obligation certificates (1.8-2.0; duration of 20 years); contracts for difference (subsidy level determined by auction; duration of 15 years).	Not yet determined for large-scale commercial projects.	Feed-in tariff (near shore: 0.85 CNY/kwh; intertidal: 0.75 CNY/kWh; duration of 20 years).

Notes: RPS = renewable portfolio standards; CNY = China yuan renminbi. 1) Centralised model = government bears the majority of the upfront financial risk and undertakes the site identification, surveying, consent and grid permitting prior to auctioning the site. 2) Decentralised model = developer takes the lead in undertaking site surveys, acquiring consent and grid permits, and designing and constructing the electrical infrastructure. 3) Open-door = developers take the lead in identifying suitable sites and securing agreements for lease with the government. 4) Zoning = government designates large offshore zones for prospective developers to acquire through a competitive process. 5) Site specific = government identifies specific project sites for offshore wind development. 6) Deep-charging model = developer is responsible for constructing and operating all offshore transmission assets, often including onshore reinforcements (i.e. onshore substation and cable routing). 7) Shallow-charging model = developer is responsible for intra-array cabling and offshore substation. The transmission system operator (TSO) provides infrastructure to export electricity to shore. 8) Hybrid deep/shallow model = variants of the other models. This can entail a developer constructing the offshore assets but transferring ownership and operation to a TSO or a third-party. Sources: BWMi (2017); IEA RETD TCP (2017); NREL (2017); IEA analysis.

Annex C. Tables for Scenario Projections

New Policies Scenario

	Production							Shares (%)		CAAGR (%)
	2000	2015	2016e	2025	2030	2035	2040	2016e	2040	2016e-40
Oil Production (mb/d)										
World	**75**	**92**	**92**	**98**	**99**	**100**	**102**	**100**	**100**	**0.4**
Onshore	50	65	65	70	71	72	73	71	72	0.5
Offshore	25	27	27	28	28	28	29	29	28	0.3
Shallow water	*23*	*21*	*21*	*20*	*19*	*19*	*19*	*22*	*18*	*-0.4*
Deep water	*2*	*6*	*6*	*8*	*9*	*9*	*10*	*7*	*10*	*1.8*
Natural Gas Production (bcm)										
World	**2506**	**3 592**	**3 621**	**4 174**	**4 546**	**4 950**	**5 306**	**100**	**100**	**1.6**
Onshore	1848	2 596	2 597	2 945	3 123	3 352	3 574	72	67	1.3
Offshore	658	996	1 024	1 229	1 423	1 598	1 732	28	33	2.2
Shallow water	*633*	*913*	*934*	*1 009*	*1 118*	*1 209*	*1 271*	*26*	*24*	*1.3*
Deep water	*25*	*83*	*90*	*220*	*304*	*389*	*461*	*2*	*9*	*7.0*

								Shares (%)		CAAGR (%)
	2000	2015	2016e	2025	2030	2035	2040	2016e	2040	2016e-40
Installed Electrical Capacity (GW)										
World		**6 414**	**6 677**	**8 647**	**9 725**	**10 857**	**11 960**	**100**	**100**	**2.5**
Coal		1 963	2 020	2 228	2 296	2 360	2 434	30	20	0.8
Gas		1 621	1 650	2 087	2 325	2 571	2 800	25	23	2.2
Oil		439	443	334	287	259	233	7	2	-2.6
Nuclear		404	413	448	468	492	516	6	4	0.9
All Renewables		1 986	2 151	3 550	4 349	5 175	5 978	32	50	4.4
Offshore wind		*12*	*14*	*58*	*90*	*127*	*162*	*0*	*1*	*10.6*
Marine		*1*	*1*	*2*	*5*	*11*	*21*	*0*	*0*	*16.5*
Electricity Generation (TWh)										
World	**15 477**	**24 239**	**24 770**	**29 657**	**32 864**	**36 097**	**39 290**	**100**	**100**	**1.9**
Coal	6 005	9 532	9 282	9 675	9 880	9 968	10 086	37	26	0.3
Gas	2 753	5 519	5 850	6 730	7 581	8 443	9 181	24	23	1.9
Oil	1 259	1 022	1 006	719	621	549	491	4	1	-2.9
Nuclear	2 591	2 571	2 611	3 217	3 440	3 642	3 844	11	10	1.6
All Renewables	2 869	5 595	6 021	9 316	11 343	13 495	15 688	24	40	4.1
Offshore wind	*0*	*39*	*45*	*200*	*317*	*454*	*583*	*0*	*2*	*11.2*
Marine	*1*	*1*	*1*	*4*	*12*	*28*	*53*	*0*	*0*	*17.0*

Notes: Rounding may lead to minor differences between totals and the sum of their individual components. Nil values are marked “-“.

Sustainable Development Scenario

	Production							Shares (%)		CAAGR (%)
	2000	**2015**	**2016e**	**2025**	**2030**	**2035**	**2040**	**2016e**	**2040**	**2016e-40**
				Oil Production (mb/d)						
World	**75**	**92**	**92**	**90**	**85**	**77**	**71**	**100**	**100**	**-1.1**
Onshore	50	65	65	64	61	56	51	71	72	-1.0
Offshore	25	27	27	26	24	21	20	29	28	-1.3
Shallow water	*23*	*21*	*21*	*19*	*17*	*15*	*13*	*22*	*19*	*-1.8*
Deep water	*2*	*6*	*6*	*7*	*7*	*6*	*6*	*7*	*9*	*-0.1*
				Natural Gas Production (bcm)						
World	**2506**	**3 592**	**3 621**	**4 127**	**4 271**	**4 253**	**4 214**	**100**	**100**	**0.6**
Onshore	1848	2 596	2 597	2 908	2 934	2 882	2 834	72	67	0.4
Offshore	658	996	1 024	1 219	1 337	1 371	1 380	28	33	1.3
Shallow water	*633*	*913*	*934*	*999*	*1 048*	*1 043*	*1 024*	*26*	*24*	*0.4*
Deep water	*25*	*83*	*90*	*220*	*288*	*328*	*357*	*2*	*8*	*5.9*

								Shares (%)		CAAGR (%)
	2000	**2015**	**2016e**	**2025**	**2030**	**2035**	**2040**	**2016e**	**2040**	**2016e-40**
				Installed Electrical Capacity (GW)						
World		**6 414**	**6 678**	**8 899**	**10 238**	**11 693**	**13 100**	**100**	**100**	**2.8**
Coal		1 963	2 020	1 991	1 686	1 370	1 150	30	9	-2.3
Gas		1 621	1 650	1 938	2 032	2 160	2 297	25	18	1.4
Oil		439	443	323	274	245	210	7	2	-3.1
Nuclear		404	413	491	586	661	720	6	6	2.3
All Renewables		1 986	2 151	4 157	5 661	7 258	8 724	32	67	6.0
Offshore wind		*12*	*14*	*83*	*163*	*257*	*353*	*0*	*3*	*14.2*
Marine		*1*	*1*	*2*	*7*	*18*	*34*	*0*	*0*	*18.8*
				Electricity Generation (TWh)						
World	**15 477**	**24 240**	**24 770**	**28 226**	**30 547**	**33 128**	**35 981**	**100**	**100**	**1.6**
Coal	6 005	9 532	9 282	6 575	4 472	3 055	2 195	38	6	-5.8
Gas	2 753	5 519	5 850	6 903	6 950	6 283	5 585	24	16	-0.2
Oil	1 259	1 022	1 006	593	412	272	192	4	1	-6.7
Nuclear	2 591	2 571	2 611	3 531	4 295	4 903	5 345	11	15	3.0
All Renewables	2 869	5 595	6 021	10 625	14 417	18 616	22 664	24	63	5.7
Offshore wind	*0*	*39*	*45*	*274*	*549*	*877*	*1 217*	*0*	*3*	*14.7*
Marine	*1*	*1*	*1*	*5*	*17*	*44*	*85*	*0*	*0*	*19.4*

Notes: Rounding may lead to minor differences between totals and the sum of their individual components. Nil values are marked “-“.

New Policies Scenario

	Investment		Average Annual		Cumulative
	2000	2016e	2017-30	2031-40	2017-40
Regional Energy Investment (billion $2016)					
World					
Oil and gas	166	434	570	743	15 417
Renewables	59	297	292	351	7 596
Offshore energy	**76**	**145**	**218**	**278**	**5 831**
Oil and gas	76	134	196	247	5 219
Electricity	-	10	22	31	611
Oil and gas share	*100%*	*93%*	*90%*	*89%*	*90%*
Electricity share	-	*7%*	*10%*	*11%*	*10%*
North America					
Oil and gas	36	112	164	212	4 411
Renewables	2	60	40	42	988
Offshore energy	**14**	**10**	**25**	**40**	**749**
Oil and gas	14	9	24	38	717
Electricity	-	0	1	2	31
Oil and gas share	*100%*	*99%*	*95%*	*96%*	*96%*
Electricity share	-	*1%*	*5%*	*4%*	*4%*
Central and South America					
Oil and gas	21	42	55	88	1 648
Renewables	10	27	16	19	414
Offshore energy	**9**	**22**	**32**	**52**	**976**
Oil and gas	9	22	32	52	969
Electricity	-	-	0	1	7
Oil and gas share	*100%*	*100%*	*100%*	*99%*	*99%*
Electricity share	-	-	*0%*	*1%*	*1%*
Europe					
Oil and gas	32	43	53	39	1 125
Renewables	24	57	54	66	1 425
Offshore energy	**28**	**44**	**60**	**47**	**1 302**
Oil and gas	28	37	46	27	920
Electricity	-	7	14	19	382
Oil and gas share	*100%*	*84%*	*77%*	*59%*	*71%*
Electricity share	-	*16%*	*23%*	*41%*	*29%*

Notes: Rounding may lead to minor differences between totals and the sum of their individual components. Nil values are marked “-“.

Sustainable Development Scenario

	Investment		Average Annual		Cumulative
	2000	2016e	2017-30	2031-40	2017-40
Regional Energy Investment (billion $2016)					
World					
Oil and gas	166	434	452	352	9 852
Renewables	59	297	447	583	12 094
Offshore energy	**76**	**145**	**194**	**178**	**4 500**
Oil and gas	76	134	158	118	3 385
Electricity	-	10	37	60	1 115
Oil and gas share	*100%*	*93%*	*81%*	*66%*	*75%*
Electricity share	-	*7%*	*19%*	*34%*	*25%*
North America					
Oil and gas	36	112	132	89	2 736
Renewables	2	60	74	98	2 019
Offshore energy	**14**	**10**	**22**	**25**	**559**
Oil and gas	14	9	17	14	381
Electricity	-	0	5	11	178
Oil and gas share	*100%*	*99%*	*77%*	*57%*	*68%*
Electricity share	-	*1%*	*23%*	*43%*	*32%*
Central and South America					
Oil and gas	21	42	40	32	879
Renewables	10	27	19	28	545
Offshore energy	**9**	**22**	**23**	**19**	**524**
Oil and gas	9	22	23	18	501
Electricity	-	-	0	2	23
Oil and gas share	*100%*	*100%*	*98%*	*91%*	*96%*
Electricity share	-	-	*2%*	*9%*	*4%*
Europe					
Oil and gas	32	43	46	23	881
Renewables	24	57	64	75	1 652
Offshore energy	**28**	**44**	**56**	**36**	**1 137**
Oil and gas	28	37	41	17	743
Electricity	-	7	15	18	395
Oil and gas share	*100%*	*84%*	*73%*	*49%*	*65%*
Electricity share	-	*16%*	*27%*	*51%*	*35%*

Notes: Rounding may lead to minor differences between totals and the sum of their individual components. Nil values are marked “-“.

New Policies Scenario

	Investment		Average Annual		Cumulative
	2000	**2016e**	**2017-30**	**2031-40**	**2017-40**
Regional Energy Investment (billion $2016)					
Africa					
Oil and gas	17	33	54	83	1 591
Renewables	1	10	17	28	513
Offshore energy	**7**	**15**	**25**	**39**	**739**
Oil and gas	7	15	25	39	736
Electricity	-	-	0	0	3
Oil and gas share	*100%*	*100%*	*100%*	*100%*	*100%*
Electricity share	-	-	*0%*	*0%*	*0%*
Middle East					
Oil and gas	20	74	81	114	2 284
Renewables	-	1	6	14	223
Offshore energy	**4**	**16**	**20**	**29**	**571**
Oil and gas	4	16	20	29	567
Electricity	-	-	0	0	4
Oil and gas share	*100%*	*100%*	*100%*	*99%*	*99%*
Electricity share	-	-	*0%*	*1%*	*1%*
Eurasia					
Oil and gas	14	57	79	103	2 138
Renewables	-	-	4	8	131
Offshore energy	**1**	**5**	**14**	**20**	**395**
Oil and gas	1	5	14	20	392
Electricity	-	-	0	0	3
Oil and gas share	*100%*	*100%*	*100%*	*99%*	*99%*
Electricity share	-	-	*0%*	*1%*	*1%*
Asia Pacific					
Oil and gas	26	72	83	105	2 220
Renewables	21	140	155	173	3 902
Offshore energy	**12**	**34**	**42**	**51**	**1 099**
Oil and gas	12	31	35	43	918
Electricity	-	3	7	9	181
Oil and gas share	*100%*	*91%*	*84%*	*83%*	*84%*
Electricity share	-	*9%*	*16%*	*17%*	*16%*

Notes: Rounding may lead to minor differences between totals and the sum of their individual components. Nil values are marked “-“.

Sustainable Development Scenario

	Investment		Average Annual		Cumulative
	2000	**2016e**	**2017-30**	**2031-40**	**2017-40**
Regional Energy Investment (billion $2016)					
Africa					
Oil and gas	17	33	40	40	962
Renewables	1	10	34	54	1 016
Offshore energy	**7**	**15**	**19**	**20**	**460**
Oil and gas	7	15	19	18	446
Electricity	-	-	0	1	14
Oil and gas share	*100%*	*100%*	*99%*	*94%*	*97%*
Electricity share	-	-	*1%*	*6%*	*3%*
Middle East					
Oil and gas	20	74	62	50	1 376
Renewables	-	1	14	49	684
Offshore energy	**4**	**16**	**16**	**14**	**360**
Oil and gas	4	16	16	13	349
Electricity	-	-	0	1	11
Oil and gas share	*100%*	*100%*	*99%*	*94%*	*97%*
Electricity share	-	-	*1%*	*6%*	*3%*
Eurasia					
Oil and gas	14	57	63	54	1 425
Renewables	-	-	8	17	291
Offshore energy	**1**	**5**	**11**	**11**	**262**
Oil and gas	1	5	11	9	245
Electricity	-	-	0	1	17
Oil and gas share	*100%*	*100%*	*98%*	*87%*	*93%*
Electricity share	-	-	*2%*	*13%*	*7%*
Asia Pacific					
Oil and gas	26	72	68	64	1 594
Renewables	21	140	233	262	5 886
Offshore energy	**12**	**34**	**47**	**53**	**1 198**
Oil and gas	12	31	32	28	720
Electricity	-	3	16	26	478
Oil and gas share	*100%*	*91%*	*67%*	*52%*	*60%*
Electricity share	-	*9%*	*33%*	*48%*	*40%*

Notes: Rounding may lead to minor differences between totals and the sum of their individual components. Nil values are marked “-“.

Annex D. Abbreviations, Acronyms and Units

Abbreviations and acronyms

C&S	Central and South America
CAAGR	compound average annual growth rate
CNY	Chinese yuan (renminbi)
CO_2	carbon dioxide
DOE	Department of Energy
EU	European Union
FPSO	floating production, storage and offloading vessels
GoM	Gulf of Mexico
IEA	International Energy Agency
IRENA	International Renewable Energy Agency
JRC	Joint Research Centre
LCOE	levelised costs of electricity
LNG	liquid natural gas
ME	Middle East
NPS	New Policies Scenario
NREL	National Renewable Energy Laboratory
NSCOGI	North Seas Countries' Offshore Grid Initiative
O&M	operation and maintenance
OECD	Organisation for Economic Co-operation and Development
OES	other energy sector
OMS	operation, maintenance, and service
OSPAR	OSlo PARis (the mechanism by which 15 governments & the EU cooperate to protect the marine environment of the North-East Atlantic)
OTEC	Ocean Thermal Energy Conversion
PV	photovoltaics
RPS	renewable portfolio standards
SDS	Sustainable Development Scenario
STO	Sustainability, Technology and Outlooks
TRR	technically recoverable reserves
US	United States
WACC	weighted average cost of capital
WEC	World Economic Council
WEM	World Energy Model
WEO	*World Energy Outlook*

Units

Distance	nm	nautical miles
Energy	mboe/d	million barrels of oil equivalent per day
	MWh	megawatt-hour
	GWh	gigawatt-hour
	TWh	terawatt-hour
Gas	bcm	billion cubic metres
	tcm	trillion cubic metres
Oil	bb	billion barrels
	mb/d	million barrels per day
Power	W	watt (1 joule per second)
	kW	kilowatt (1 Watt x 10^3)
	MW	megawatt (1 Watt x 10^6)
	GW	gigawatt (1 Watt x 10^9)
	TW	terawatt (1 Watt x 10^{12})

Annex E. References

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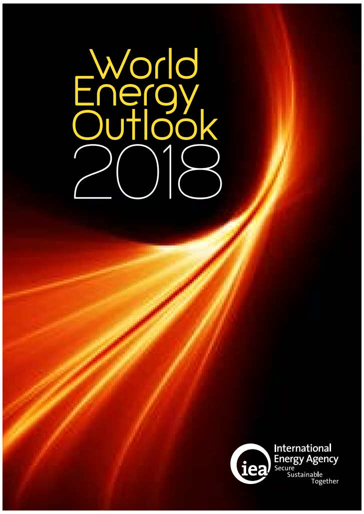

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