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Achieving a cost-competitive offshore wind power industry:

What is the most effective policy framework?

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Contents

Figures

Tables

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Abstract

The promise of carbon-free, utility-scale power generation from offshore wind farms is encouraging a number of governments to implement policy support frameworks and national targets for offshore wind power generation. However, the high capital requirements for the deployment of offshore wind have proven that it is an expensive approach to meeting national renewable energy and carbon reduction targets, relative to other power generation sources. The capital requirement for offshore wind farms will be pushed even higher as consented development zones move further from shore and into deeper waters. In this paper, we analyse the major capital cost drivers of offshore wind plants and the implications of various policy frameworks on overall cost reductions for the industry. According to the results of our analysis, this issue – whether the promotion of scalability, or of competition for subsidies, will be more effective in driving down industry-wide costs – is highly market specific. Competitive policies are likely to be most effective when the market size is sufficiently large, whereas enhancing scale is more effective in nascent markets. However, we caution that in either case, the public costs of policies directly supporting offshore wind must be reconciled with the cost of supporting other low-carbon and zero-carbon technologies that may be equally as effective in helping governments achieve renewable energy and carbon reduction targets.

Keywords: Offshore wind, cost drivers, supporting policy, grid connection

Introduction

The adoption of renewable energies on the global scale has been nothing short of remarkable over the past decade. 2014 marked the 11th consecutive year of double-digit growth for global renewable energies consumption, with the sector posting a 12 percent year-on-year gain last year alone.[1] This trend has been underpinned by transitions in the power generation sector. Government policies implemented to reduce greenhouse gas emissions from the power sector have led to greater demand for renewable energy generation. This has been followed by increased private sector competition, supply chain efficiencies, and tumbling generation costs. The cumulative effect is that power from renewable energy sources is becoming competitive with, and in some cases even cheaper than, power generated from fossil fuels.[2]

The promise of carbon-free, utility-scale power generation from offshore wind farms has recently encouraged a number of governments to implement policy support frameworks to incentivize offshore wind development. However, despite increasing political momentum in recent years, the progress of the industry has been lacklustre when compared with that of other renewable energy sources. Although installed offshore wind capacity reached nearly 9 GW globally in 2014,[3] this pales in comparison to the development of land-based wind, which surpassed 360 GW in 2014,[4] and solar photovoltaic (PV), which reached 180 GW last year.[5]

The deployment of offshore wind capacity has been stifled by its excessive capital costs. Major capital cost drivers are attributed to the R&D costs of new technologies, lack of original equipment manufacturer (OEM) competition, high construction and offshore installation costs, and lack of dedicated infrastructure, such as purpose-built manufacturing facilities and installation vessels. As a result, while the average levelized cost of energy (LCOE) of competing generation sources (such as land-based wind power generation) has fallen by 58 per cent over the past five years, and by an even sharper 72 per cent for solar PV, the capital costs for offshore wind projects have seen an escalating cost curve.[6]

As reported by the Global Wind Energy Council in 2014:

> "The broad trend in the development of Capex since the early days of offshore wind technology in the early 1990s is contrary to any expectation of conventional industrial maturation. Learning or experience curve theory would predict reducing costs with time, through the combined impact of innovation, learning effects and economies of scale. The historical reality has been dramatically different … with Capex increasing by approximately 100% in real terms, in the 4-year period from 2005 to 2008."[7]

Stated differently, the technical challenges of deploying offshore wind capacity have been outpacing the industry's learning curve. This peculiar trend invites three primary questions for our research:

1. What trends and technical hurdles are driving the capital costs of offshore wind further upwards?

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[1] (BP, 2015). Excludes hydropower.
[2] See Section 2.2.2. In Australia, for example, power generated from land-based wind is now cheaper than that generated from coal and gas, when accounting for the cost of carbon emissions.
[3] (EWEA, 2015).
[4] (GWEC, 2014, p. 7) and (BP, 2015).
[5] (REN21, 2014) and (BP, 2015).
[6] (Lazard, 2014, p. 9).
[7] (Shruti Shukla, p. 21).

2. What policy mechanisms could be most effective in encouraging and facilitating cost reductions?

3. Will the costs of these policies be justifiable in the context of other low-carbon and zero-carbon technologies?

Consideration of these questions will be of paramount importance for policy makers, as they seek to encourage the utility-scale development of offshore wind power. Despite the inherent advantages that offshore wind power generation may offer (such as scalability and proximity to major demand centres) it is still far from clear that it represents the most efficient pathway for governments needing to meet binding renewable energy and carbon reduction targets, or that prioritizing offshore wind technology over other low-carbon or zero-carbon alternatives will lead to the optimal expansion of the renewable power generation sector. Moreover, there are legitimate concerns about the high costs of supporting offshore wind through direct support mechanisms such as feed-in tariffs, and reasonable doubts exist about the potential of the industry to significantly reduce deployment costs.

In Section 1 of this paper, we offer a context for offshore wind as a power generation source in Europe, developed Asia, and the USA. We discuss what is envisaged for the role of offshore wind power in national greenhouse gas initiatives and policies, energy security, and power transmission. In Section 2, we provide an overview of the global offshore wind market structure, including installed capacity and trends in project development and investments. We then discuss the challenges facing offshore wind when competing in the power generation mix. Specifically, we compare the levelized cost of energy (LCOE) of offshore wind with competing power generation sources, and discuss the LCOE reduction targets set by national governments. This is followed in Section 3 by a breakdown of the capital cost drivers of the offshore wind industry and an analysis of the trends poised to impact capital expenditure requirements in the years to come, including a discussion of the issues associated with the connection of offshore wind to the grid. In Section 4, we review current policy mechanisms and incentives – both indirect and direct – designed to spur the offshore wind industry, together with their implications for cost reductions in the offshore wind industry, paying particular attention to the newly introduced reverse auctions for subsidies and the UK Contracts for Difference scheme. In Section 5 we present current policy approaches – both competitive and collaborative – which seek to support reduction of costs for offshore wind deployment, and consider the implications of such policy frameworks on cost drivers and policy support for offshore wind developments.

To conclude, our paper asserts that the best policies for cost reduction will be highly market specific. Although competitive policies can help curb costs when the size of the market is sufficiently large, markets lacking adequate infrastructure must assess the consequences of implementing competitive procurement policies that could reduce the overall project pipeline and stall investments in necessary infrastructure (such as specialized manufacturing facilities, ports, and purpose-built installation vessels). The costs of supporting the offshore wind industry – whether through the promotion of competition or of enhanced scale – must also be reconciled with other, potentially cheaper, policy support options that could achieve the same goals, albeit through competing low-carbon or zero-carbon technologies that impose lower costs onto ratepayers and tax payers.

1. Background: Role of the offshore wind industry

The role of offshore wind power is influenced by a multitude of country-specific factors, including nationally binding commitments to carbon reduction and renewable energy production targets, competition from other indigenous energy resources, imported energy dependency and primary energy production and demand, and transmission considerations. This section provides an overview of the basis for the role of offshore wind in three key development regions: Europe, the USA, and developed Asia. It provides a brief explanation of the national energy strategies, energy security concerns, and challenges in power infrastructure that define the role of offshore wind energy in these regions.

1.1 National renewable energy policies

The European Union (EU-28) is perhaps the most progressive developed economy in the implementation of large-scale, multi-country binding energy targets. The EU Climate Energy Package sets the groundwork for a series of goals for the EU, to be achieved by 2020:

- 20 per cent of final energy consumption to be provided by renewable energy sources (RES),
- 20 per cent reduction in greenhouse gas emissions (GHG) compared to 1990 levels,
- an increase in energy efficiency by 20 per cent.[8]

In order to achieve this mandate, individual EU countries have committed to their own national RES targets by submitting National Energy Action Plans to the EC. These individual strategies take into account different available natural resources, infrastructure, and other considerations distinctive to each energy market. Individual RES targets for the EU-28 range from 10 per cent (Malta) to 49 per cent (Sweden).[9] (See Appendix A.)

Given the strong wind resources available offshore, inexhaustible carbon-free power generated from offshore wind turbines is expected to play an increasingly prevalent role in major western European markets. This is predicated by EU member states' National Renewable Energy Targets (NREAPs), which commit each EU country to a binding target for renewable energy penetration by 2020. The scalability of the offshore wind industry offers distinctive advantages. Indeed, one average sized European offshore wind farm is capable of providing power to tens of thousands of households.[10] Given this potential, as early as 2008 the European Commission had stated that:

> " … offshore wind can and must make a substantial contribution to meeting the EU's energy policy objectives through a very significant increase – in the order of 30–40 times by 2020 and 100 times by 2030 – in installed capacity compared to today."[11]

By 2020, the EU has an indicative target of 40,000 MW (40 GW) of installed offshore wind capacity, that is implied from member states' NREAPs'. In the Netherlands, for example:

> "European and national renewable energy targets have resulted in new legislation coming into force that must procure an additional 3,500 MW of offshore wind capacity. For this purpose, subsequent licences and subsidies to build 700 MW will be tendered out annually in the years 2015–2019, with the first tender expected to start autumn 2015."[12]

It should be noted, however, that the offshore wind targets stated in members' National Renewable Energy Action Plans are merely indicative of an approach towards reaching their binding NREAP targets. These targets are not legally binding mandates for offshore wind capacity deployment. Nevertheless, as suggested in Table 1.1., these targets have been effective in signalling the market.

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[8] European Commission. http://ec.europa.eu/clima/policies/package/index_en.htm.
[9] European Commission. National Action Plans. http://ec.europa.eu/energy/node/71. Note that Norway (outside of EU-28), seeks the highest level of renewables at 67.5%.
[10] According to the Bureau of Ocean Energy Management 'one GW [1,000 MW] of power will supply between 225,000 to 300,000 average U.S. homes with power annually.' (BOEM, 2015).
[11] European Union Law. COM(2008) 768 Final. http://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:52008DC0768.
[12] (Loyens Loeff, 2015, p. 2).

Table 1.1: EU Member States' NREAP Offshore Wind Targets and Actual Installed Capacity

Unit: MWh	NREAP Target end-2012	Actual installed (end-2012)	NREAP target end-2013	Actual installed (end-2013)
United Kingdom	2,650	2,974	2,650	3,680
Denmark	856	921	856	1,270
Germany	792	280	792	520
France	667	0	667	0
Belgium	503	380	503	571
Netherlands	228	247	228	247
Sweden	97	164	97	211
Ireland	36	25	36	25
Finland	0	26	0	26
Portugal	0	2	0	2

Source: Author compiled from (EWEA, 2014), (GWEC, 2015).

Outside the European Union, various East Asian governments, including China, have also started to implement national policies and renewable energy targets that strongly support the growth of power generation from offshore wind plants. The disaster at the Fukushima nuclear reactor in 2011, for instance, as well as limited land availability and strong potential from offshore wind resources, have motivated the Japanese government to lend stronger political support to offshore wind projects and to offer feed-in tariff support mechanisms for the industry. China, Taiwan, South Korea, and India have similarly implemented carbon-free national energy plans that include targets for offshore wind capacity.

Table 1.2: Offshore Wind Targets for Countries Outside of Europe

Country	Official target for Offshore Capacity
Japan	37 GW by 2050
Taiwan	600 MW by 2020/ 3 GW by 2030
USA	No binding taget set. But federal govt pushes for 54 GW by 2050
South Korea	900 MW by 2016 and 1.5 GW by 2020
China	10 GW by 2020
India	1 GW by 2020

Source: Author compiled from GWEC (2014).

Offshore wind in the USA, by contrast, is seen as just one of several possibilities in an 'all of the above' strategy aimed at promoting energy independence and carbon reduction. The Obama administration has nevertheless indirectly supported the industry under the Climate Action Plan, which seeks to cut carbon emissions from existing power generation by 30 per cent by 2030.[13] More directly, the Federal Bureau of Ocean Energy Management (BOEM) has recently streamlined seabed leasing procedures, while in 2014 the US Department of Energy (DOE) granted three pioneering US offshore wind projects with up to $47 million each to spur demonstration projects that would seek to prove out novel cost-reduction technologies. However, a disconnect between state-level political support for offshore wind has, in one way or another, obstructed many of these pioneering projects, undermining the outlook for the industry in the USA.

[13] (EPA, 2014).

1.2 Energy transition and energy security

Growing energy security concerns and the depletion of indigenous fossil fuel resources have resulted in what is arguably a more long term and strategic view of energy policy within Europe. Given its potential scalability and proximity to high residential and industrial demand centres, it is envisaged that offshore wind energy will play a vital role in energy supply security. According to the UK Department of Energy & Climate Change, the UK faces a rapid closure of existing capacity, with nearly one-fifth of its 2011 capacity expected to be shut within the next decade.[14] In Germany, the abrupt closure of seven nuclear plants since 2011, together with the mandate to close the country's 17 remaining nuclear reactors by 2022, underscores a government target of some 6,500 MW of installed offshore wind capacity by 2020.

Given this context, public investment in renewable energy sources is generally accepted across Western Europe as a necessary step in the inevitable transition away from imported fossil fuels and carbon intensive primary energy sources, most notably natural gas and coal. According to a 2015 Ernst and Young report, current offshore wind targets have the potential to slash Europe's dependency on fossil fuels to a figure as low as 16 per cent, in the long term.[15] More immediately, the uneasy dependency on imported Russian natural gas underscores the political necessity of this transition to indigenous energy resources.

Likewise, in the developed economies of Asia, both liberal and state-run economies seek to bolster offshore wind to promote domestic, carbon-free energy production and to wean economies from imports, while also diversifying primary energy supply. Aggressive national targets and policies to cultivate offshore wind have already been implemented in a number of countries in the region. Notably, the Chinese government has set a national target of 10,000 MW (10 GW) of offshore wind capacity to be installed and grid connected by 2020 (Table 1.2). Various factors support this aggressive target: an unprecedented need for new energy generation, a need to improve air quality, and rapid urbanization to coastal areas. If realized, this target would bring China neck-and-neck with the UK as the largest offshore wind market in the world by the end of the decade. Japan, currently the world's largest importer of Liquefied Natural Gas (LNG), has also significantly ramped up targets for offshore wind capacity to diversify primary energy supply, setting a goal of at least 37 GW through 2050 (Table 1.2). Constraints in available land resources for land-based wind predicate this target, because high property values in concentrated urban areas make onshore development expensive, and it can often be met with strong public opposition.[16]

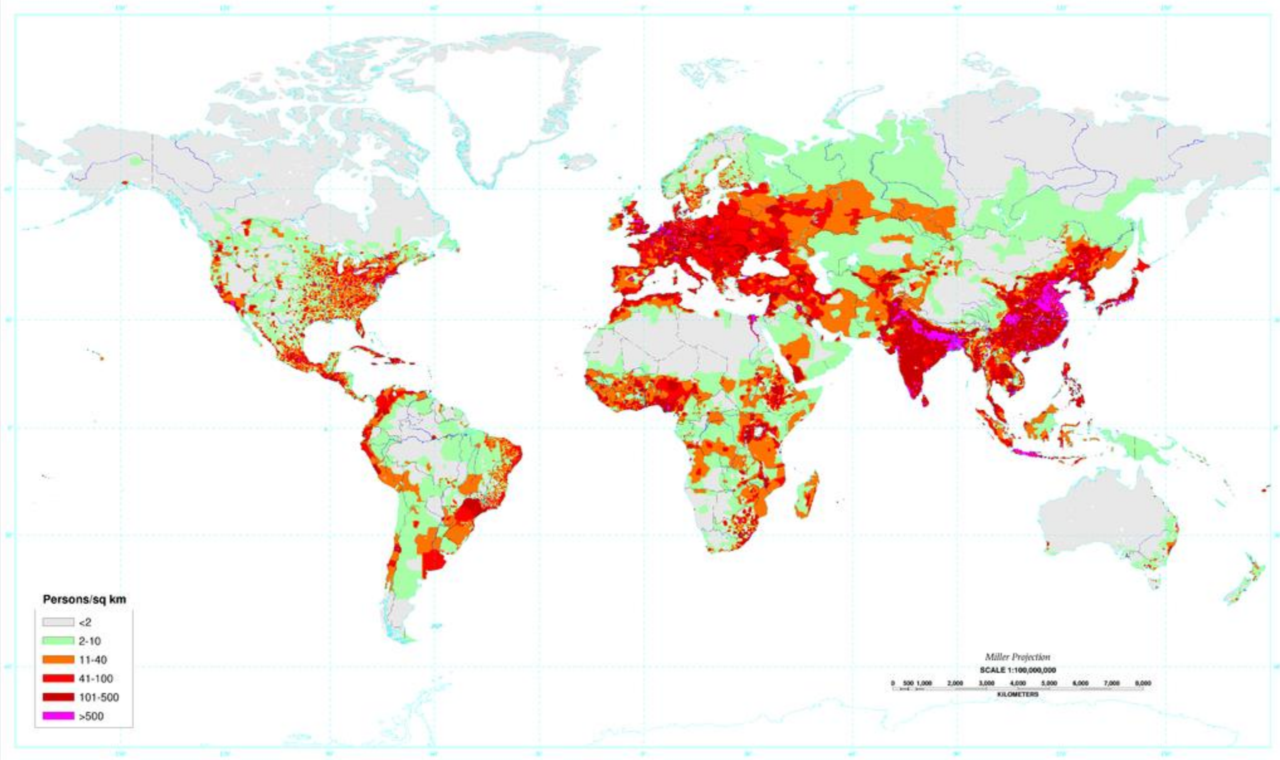
In the USA, the abundance of shale gas, together with its brand as a low-carbon 'bridge fuel', has somewhat obstructed the public and political immediacy for direct policy measures to support the offshore wind industry. The energy transition in the USA is indeed currently that of shale gas and tight oil production being achieved through hydraulic fracturing. Offshore wind support has struggled to stay on the public and political radar, particularly as the more mature renewables (such as land-based wind and solar) continue to be cost competitive with fossil fuels and are able to wean themselves from a need for public funding (see Section 2.2.3). Moreover, the proximity of the major power demand centres on the US east coast to the Marcellus and Utica shale plays paints the picture that there is already a cheap and abundant source of low-carbon primary energy supply ready to be tapped. Policy makers, particularly those in US regions benefiting directly from cheaper hydrocarbons, seem to generally accept shale gas as the transitional power generation source for decades to come, despite the fact that a bottleneck of gas pipeline capacity in the north-east actually threatens to keep power prices in that area amongst the highest in the country.

[14] (DECC, 2014, p. 4).
[15] (Ernst and Young, 2015, p. 13).
[16] (GWEC, 2015).

1.3 Electricity load centres and peak demand

The disposition of large population and industrial centres tends to be concentrated around coastlines and major port cities (Figure 1.1). In the USA, for example, some 53 per cent of the country's population lives in coastal areas, and states that have coastal boundaries account for roughly 78 per cent of the nation's power demand.[17,18] Similarly in the European Union, over 40 per cent of the population resides in coastal regions, which are also key areas for industry.[19,20] Over half of China's 1.3 billion population already lives along the coastline, and rapid urbanization is expected to accelerate this trend. Given these dynamics, it follows that energy demand and costs in these coastal regions also tend to be higher and the stress on the power transmission systems greater, while land-based renewable energy generation sources (such as land-based wind) are often limited by availability of land.

Figure 1.1: World Population Distribution



Source: (SEDAC, 2015).

It is important to note in this context that offshore wind resources blow stronger and more uniformly over the sea than overland wind resources.[21] In the USA, for example, offshore wind speeds average 7 metres/second (m/s) against 5 m/s for overland wind.[22] Because slightly higher wind speeds can produce significantly more electricity, offshore wind resources have the potential to supply immense

[17] Bureau of Ocean and Energy Management (BOEM) website. (BOEM, 2015).
[18] US Energy Information Agency. www.eia.gov/electricity/data.
[19] European Union statistics (Eurostat, 2015).
[20] 'Fishing, shipbuilding, maritime transport, ports and offshore energy-related activities (such as the extraction of fossil fuels and electricity generation) are major coastal and maritime economic activities' (Eurostat, 2015).
[21] (BOEM, 2015).
[22] See NREL U.S. Land Based and Offshore Annual Average Wind Speed Map. (National Renewable Energy Laboratory/Energy.Gov, 2015).

quantities of renewable power to major coastal cities and demand centres.[23] Offshore wind resources are also correlated with times of peak energy demand.[24] This means that 'a vast reservoir of peak-coincident [offshore] wind sits near a large population centre'.[25] This characteristic has at least two major implications. First, it allows power generated from offshore wind farms the potential to alleviate bottlenecks of power and ease transmission congestion from land-based generation plants.[26,27] Secondly, and perhaps more importantly, the correlation in peak offshore wind with peak demand in major power consumption centres implies that offshore wind plants are generating power when and where it has the highest value. As discussed in later sections, this can provide significant upside to plant economics.

2. Offshore wind market structure

2.1 Installed global capacity by market

As of year-end 2014, there was some 8,758 MW of offshore wind capacity installed globally.[28] European markets currently account for over 91 per cent of globally installed offshore wind capacity, or 8,045 MW.[29] By the end of 2014, there were 2,488 offshore wind turbines installed and grid-connected, across 74 wind farms in European waters.[30] These offshore wind farms produced a combined 29.7 TWh of electricity in 2014, meeting approximately 1 per cent of the EU's total electricity consumption.[31]

The European Wind Energy Association (EWEA) estimates that offshore wind generation capacity in Europe will increase by a further 35 per cent to 10,900 MW in the 2015/16 timeframe, as projects currently under construction become grid-connected.[32] The UK is the predominant market leader in offshore wind, with approximately 4,500 MW of grid-connected capacity, and a target of reaching some 10,000 MW by 2020. Denmark and Germany follow in terms of capacity (see Figure 2.1), each boasting over 1 GW of installed capacity. Denmark, Germany, and the UK together represent over 80 per cent of Europe's total installed capacity.

However, a catalogue of obstacles (such as fluctuating incentive and support models in key markets such as the UK and Germany and delayed grid expansion or connection plans) has hindered the progress of offshore wind plants. As a result, the indicative EU 2020 target of 40 GW is very unlikely to be reached, with EWEA suggesting that 23.5 GW is a more realistic estimation of installed capacity by 2020.[33] Although this is a significant reduction from the cumulative EU target of 40 GW, it should be noted that even the revised trajectory entails a near tripling of currently installed capacity over the next five years. Furthermore, this rate is poised to accelerate in the 2020–30 timeframe, as the EU

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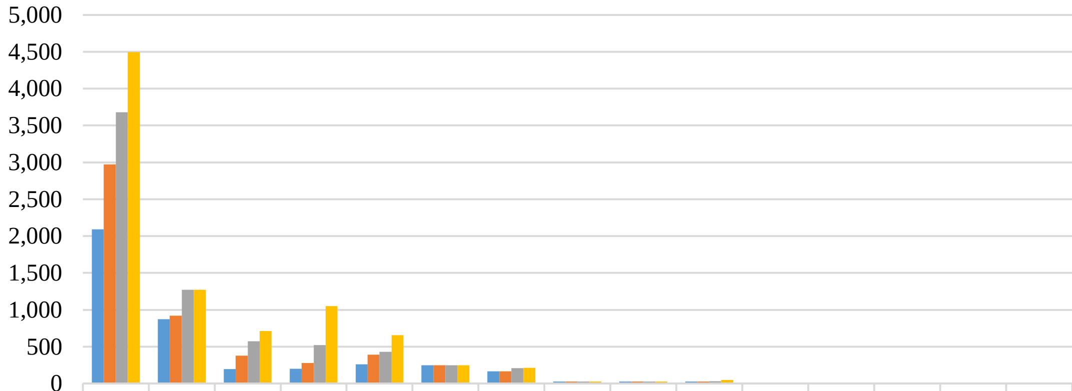
[23] According to the U.S. Bureau of Ocean Energy Management 'a turbine at a site with an average wind speed of 16 mph [7.15 m/s] would produce 50% more electricity than at a site with the same turbine and average wind speeds of 14 mph [6 m/s]'. (BOEM, 2015).
[24] Source: (Dvorak et al., 2013).
[25] (Dvorak et al., 2013).
[26] According to a 2013 Stanford University study on wind resources and correlation with peak demand hours. (Dvorak et al., 2013).
[27] Offshore transmission cables can eliminate the burden of building new terrestrial cables; this has been shown to be a limiting factor for land-based wind turbines.
[28] (GWEC, 2015).
[29] (EWEA, 2015).
[30] (EWEA, 2015).
[31] (GWEC, 2014).
[32] (EWEA, 2015).
[33] (EWEA, 2014).

seeks to secure 27 per cent of renewables in gross consumption by 2030. According to an Ernst and Young forecast, installed capacity of offshore wind could reach nearly 65 GW by 2030.[34]

Figure 2.1: Installed Offshore Wind Capacity from 2011–14 (MW)



	UK	Denmark	Belgium	Germany	PR China	Netherlands	Sweden	Finland	Ireland	Japan	Korea	Spain	Norway	Portugal	USA
2011	2093	874	195	200.3	262	247	164	26	25	25	0	0	2.3	2	0
2012	2974	921	379.5	280.3	389	247	164	26	25	25	5	0	2.3	2	0
2013	3680	1270	571.5	520.3	429	247	211	26	25	29.7	5	5	2.3	2	0.2
2014	4494	1271	712	1049	657.7	247	212	26	25	49.6	5	5	2.3	2	0.2

Source: Author compiled from (EWEA, 2015) and (GWEC, 2014).

The strong development of Europe's offshore wind markets has rendered Europe the de facto authority in the offshore wind industry. Denmark, Germany, and Spain are the global hubs for offshore wind turbine technology and manufacturing. European countries house the leading offshore wind companies, purpose built installation vessels, technology providers, fabrication and installation experience, and know-how. Outside of Europe, installed offshore wind capacity totalled just over 700 MW by the end of 2014. China accounts for the bulk of this capacity with 657 MW grid connected by the end of 2014, and is followed distantly by Japan (29.7 MW).[35] The USA, Taiwan, and South Korea, among others, have all made progress in the offshore wind industry; however, they are yet to have utility-scale offshore wind farms installed.

2.1.1 Infrastructure and supply chain development

The existing oil and gas infrastructure, in close proximity to strong wind resources in north-west Europe, has been a significant boon to the offshore wind industry. The decline of oil and gas production in the North Sea, coupled with the recent drastic drop in oil prices, has also proven advantageous to the offshore wind industrial supply chain in north-west Europe. Traditional servicers of the oil and gas industry are increasingly retrofitting facilities to accommodate offshore wind in order to diversify from oil and gas, thus securing the foundation for stronger development potential and competition in the offshore wind industry. Many of the original installation vessels for oil and gas have been borrowed by the offshore wind sector to install massive wind turbines and substructures offshore. Heavy industrial fabrication yards, typically dedicated to oil and gas, are now ramping up investments in facilities dedicated to the streamlined serial manufacture of offshore wind structures.

However, the migration of resources from oil and gas to the offshore wind industry is, in many ways, unique to the European landscape. The commercial case for diverting capital and resources away from the oil and gas sector, or from the even more economical land-based renewables such as onshore wind power (see Section 2.2.2), is far less logical in many markets outside of Western

[34] (Ernst and Young, 2015).
[35] As of 2014. Source: (EWEA, 2015).

Europe. In the USA, for example, the oil and gas infrastructure remains concentrated around the US Gulf of Mexico, disconnected from the coastal wind resources found along the US east and west coasts. Gulf Coast asset owners are reluctant to mobilize resources to offshore wind areas until there is a proven pipeline of projects to justify such a large capital investment. Indeed, without a bankable project pipeline, there is simply no strong commercial rationale for the support of such a move, or investment from the private sector. The few ‘purpose built’ facilities in the USA such as the port facilities in New Bedford, MA, have suffered from project setbacks or cancelations, often rendering them poor and unpopular investments.[36]

There is, therefore, little surprise that, outside of Europe, the offshore wind industry has been largely unable to prevail in the face of this ‘double squeeze’ conundrum. On the one hand, offshore wind must compete with the oil and gas exploration and service sectors to secure infrastructure and vessels. On the other hand, the industry must also compete with investments in assets for the more viable land-based wind industry, whose plant is typically too far inland to be of use to both offshore and onshore industries.

2.1.2 Project development and investment

Commercial scale offshore wind projects have, thus far, been developed in Europe primarily by large utilities and power producers such as Vattenfall, RWE, E.ON, Centrica, and SSE as well as a few major oil and gas producers such as Danish Oil and Natural Gas (DONG). More recently, a number of special purpose, joint venture entities have also been formed by utilities to develop projects. By 2014, 31 per cent of the equity investors in the industry were represented by major power producers (Figure 2.2a).

Figure 2.2a: Major Equity Investors (2014)

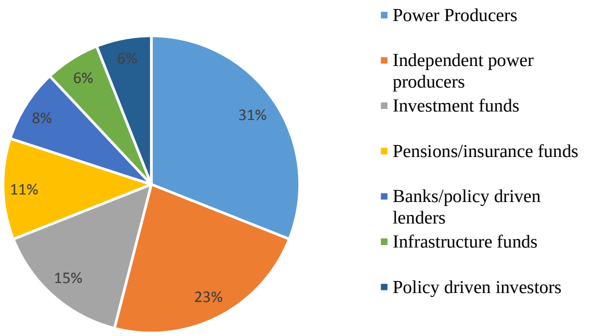
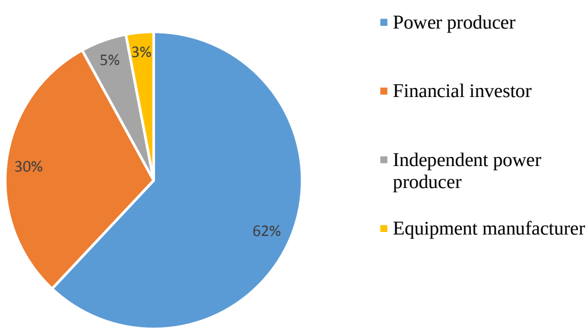


Figure 2.2b: Investments in OWF (2014)



Source: (EWEA 2015).

These large players have typically been able to leverage assets on their balance sheets to self-finance projects and obtain more favourable debt financing terms. However, the appetite and capability of the ‘utility balance sheet financing model’ for project development in Europe has been in retreat given the escalation of project costs. To a large extent, these escalations have come about because seabed leasing areas in the UK and Germany are moving further from shore and into deeper waters, due to consenting issues, and revenue guarantee models have been perceived as unreliable (see Section 3.1.3).

[36] See NPR article ‘The Future of Massachusetts’ Offshore Wind Farm is Uncertain’. 6 May 2014. Available online. www.npr.org/2015/05/06/404626479/future-of-offshore-wind-farm-in-massachusetts-uncertain.
The state of Massachusetts invested $113 million into a waterfront terminal designed to service the offshore wind industry; however, a two year lease was lost when the project lost its purchase power agreement.

Aggressive national targets for offshore wind deployment in European countries will continue to stretch thin the capabilities of major European utilities to finance these projects from their balance sheets. The general consensus is that the EU-suggested target of 40 GW by 2020 would require around €110 billion in additional capital expenditures by the end of the decade.[37] However, securing this capital will be increasingly difficult. The Boston Consulting Group (2013) succinctly states the problem:

> "Offshore wind is still a very immature industry with high risks, a view shared by potential large investors such as pension funds and insurance companies … Utilities are leading the way, but they will become capital constrained before reaching 2020 targets."[38]

Evidence of this has already been seen in the market place. According to EWEA, major power producers sold or divested some 1,580 MW of offshore wind power projects in 2014.[39] As this trend would suggest, new sources of capital, from a widening fleet of investment vehicles, will be essential to the continued development of offshore wind projects.

2.2 Offshore wind in the global energy mix

2.2.1 Competition from fossil fuels

Global power generation continues to be dominated by oil-based generation sources (diesel, fuel oils, etc.) and coal, which together account for roughly two-thirds of all global primary energy demand (Figure 2.3a). Rounded out by natural gas in the energy mix, fossil fuels continue to meet over 85 per cent of global electricity demand. To date, renewable generation sources only satisfy a fraction of global primary energy demand. Excluding hydroelectricity, power generation from renewable energy sources (wind, solar, biomass, geothermal, waste) accounted for just 2 per cent of global primary energy demand as of 2013.[40]

Figure 2.3a: Primary Energy Consumption 2013

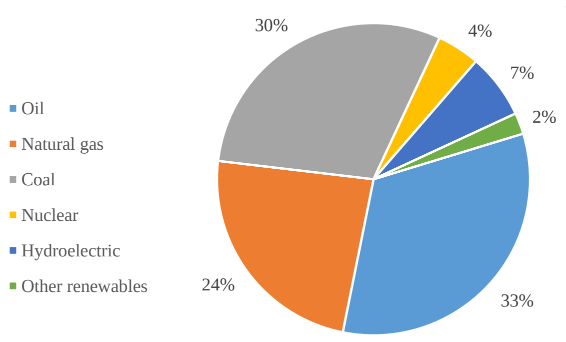
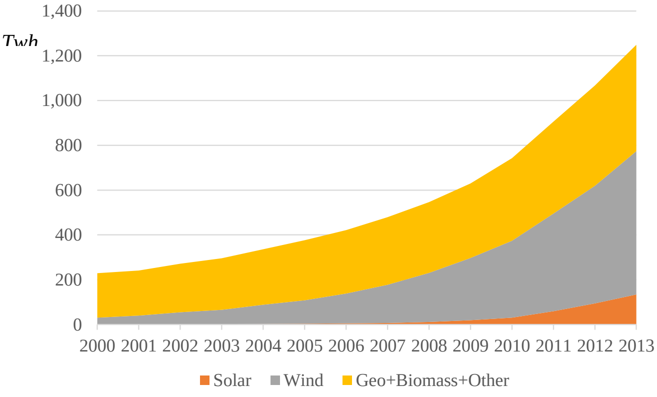


Figure 2.3b: Consumption of Renewables



Source: Author generated from *BP Statistical Review of Energy* (BP, 2014).

Despite this heavily skewed market demand, the disposition of global energy generation is experiencing rapid structural transition. Analysts posit these trends will accelerate over the next several decades: the use of oil products (such as diesel) for power generation is in long-term structural decline as they are typically too expensive relative to alternatives. Although coal, on the other hand, is cheap and global demand remains strong, the commodity faces increasing regulatory

[37] (The Boston Consulting Group, 2013).
[38] (The Boston Consulting Group, 2013).
[39] (EWEA, 2015).
[40] (BP, 2014).

pressure in developed and emerging economies that will undoubtedly add to its generation costs in the long run.

For these reasons, coal and oil are likely to be increasingly substituted in the power generation sector globally. In this process, no other fuel has gained more market share over the past several decades than natural gas. This is not only because it has been successfully branded as a low-carbon alternative to what are generally perceived as higher-cost renewable sources, but also because delivery is becoming more flexible and the commercial applications are widening,[41] driving billions of dollars of investments into the sector annually. This trend is unlikely to be significantly offset through the long term.

Even against the competition posed by natural gas, however, renewable energy sources are already proving to be the next big wave in the global energy transition. This is at least partially because the allure of natural gas isn't nearly as strong in many major energy consuming countries as it is, for example, in the USA. In Europe, both the EU and national governments, weary from historic dependence on imported Russian gas, seek to bolster home grown, indigenous resources rather than moving to incorporate more gas into the energy mix (either via imports or controversial hydraulic fracturing). In developed Asia, meanwhile, long-term gas contracts have proven pricey and politically precarious. "The bottom line..." according to market analysts, is that "...gas is seen as a liability…a political liability in Europe and an economic liability in developed Asia.[42]

This is not to say that the role of natural gas won't be predominant in the global power generation sector for years to come, particularly as new technologies unlock conventional and unconventional resources in China and elsewhere. However, in a global landscape that is increasingly driven towards true carbon-free and inexhaustible resources, the role of renewables has already begun to make remarkable inroads over the past few years, in many cases outpacing natural gas. According to Bloomberg New Energy Finance, in 2013 more renewable generation capacity was added globally on an annual basis than the combined figure for coal, natural gas, and oil (renewables added a total of 143 GW of electricity capacity, overtaking the 141 GW of fossil fuel-fired plants added).[43] In total, renewables accounted for over 56 per cent of net additions to global power capacity in 2013.[44] This trend is poised to accelerate as renewable energy sources become more cost competitive, and policies increasingly support demand for power generated from renewables. In the EU, for example, electricity generation capacity from renewables reached 380 GW in 2013, while the exiting generation capacity from fossil fuel plants combined was some 450 GW.[45] In 2014 alone, over 12 GW of wind energy capacity (onshore and offshore) was installed across the EU.[46]

Offshore Wind

In the midst of what market data suggests is a renewable energy boom, however, the role of offshore wind remains uncertain. Although Europe has demonstrated that coherent policy support and effective incentive frameworks can reshape energy markets just as efficiently as commodity markets, the impact of offshore wind in the global energy mix will depend largely on how effectively the industry can reduce its cost-curve. Often-referenced measurements of plants' economics currently suggest that offshore wind plants are far from being cost competitive with either fossil fuel generation sources (with the exception of diesel) or other renewable energy sources (See Figure 2.4). As a result, these alternative generation sources have experienced steady private capital and huge capacity gains in

[41] Natural gas is making inroads into the transportation sector with gas power vehicles, and even into lubricants markets with Gas-to-liquid plants (GTL).
[42] 'Gas Midlife Crisis? My Review of WGC PARIS 2015', Nikos Tsafos. https://www.linkedin.com/pulse/gas-midlife-crisis-my-review-wgc-paris-2015-nikos-tsafos.
[43] 'Fossil Fuels Just Lost the Race Against Renewables', Tom Randall, Bloomberg, 14 April 2015. www.bloomberg.com/news/articles/2015-04-14/fossil-fuels-just-lost-the-race-against-renewables.
[44] (REN21, 2014).
[45] (European Commission, 2015, p. 8).
[46] (European Commission, 2015, p. 8).

recent years, whereas (globally) the offshore wind industry has suffered ebbs and flows in private investment due to uncertain or insufficient policy support frameworks and high relative development costs. Indeed, since the installation of the first offshore wind farm in Denmark in 1991 (Vindeby), the development of global offshore wind capacity has been just 2 per cent that of land-based wind.[47] Even in Europe, offshore wind capacity is just 6 per cent that of land-based wind.[48] As detailed in the next section (2.2.2), measurements indicating the lifetime plant cost of offshore wind far exceed those for nearly every other generation source; this largely explains its lacklustre development on the global scale when compared to more mature renewables.

2.2.2 Levelized cost of energy (LCOE) and plant costs comparison

The Levelized Cost of Energy (LCOE) is often used to evaluate and compare the costs of electricity generation for a given plant. The formula is able to take into account plant-level effects from technology design changes, fixed costs, and other inputs. Although methodologies vary, the calculation typically incorporates four major inputs of the plant: installed capital cost (CAPEX), annual operating cost (OPEX), annual energy production, and the fixed charge rate (a coefficient that expresses the cost of financing over the plant's operational life). An example of an LCOE equation is found below:[49]

LCOE Formula 1:

$$LCOE = \frac{(ICC * FCR) + AOE}{AEPnet}$$

Where*:*

ICC = Installed Capital Costs (CAPEX)

FCR = Fixed Charge Rate

AOE = Annual Operating Expenses (OPEX)

AEPnet = Net Annual Energy Production (MWh/yr)

Put more simply, the LCOE can be seen as the present value of plant costs (in $) divided by the plant's energy production (in MWh).

LCOE Formula 2:

$$LCOE = \frac{\text{present value of total costs (\$)}}{\text{lifetime energy production (MWh)}}$$

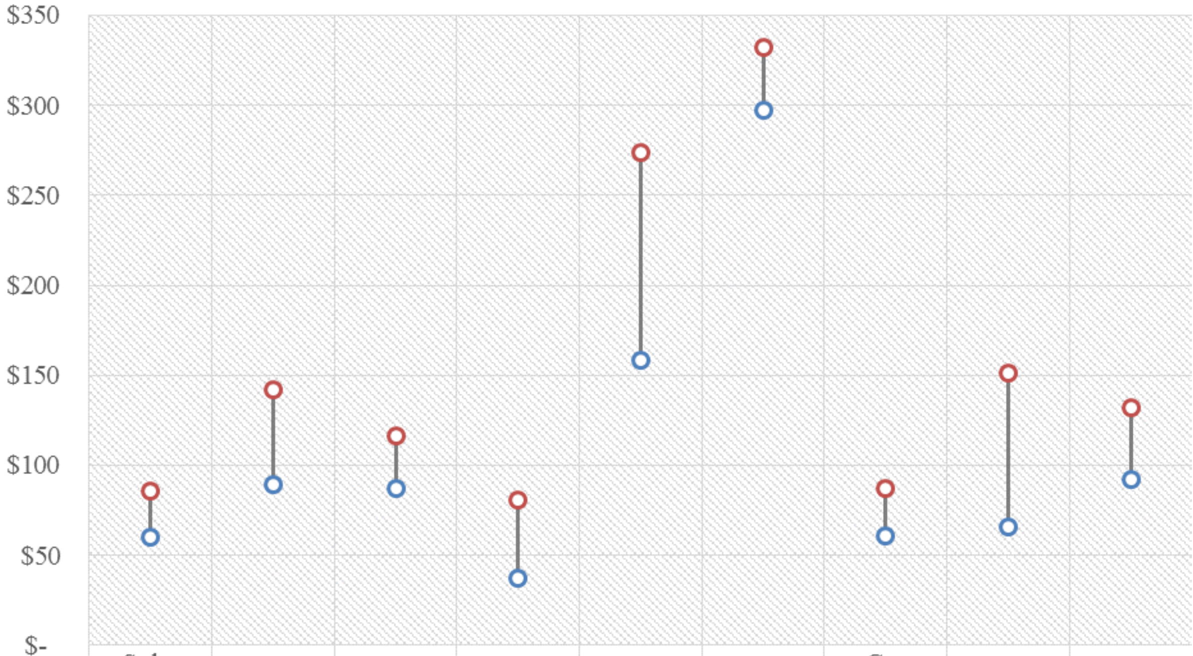
Although it is widely referenced, the LCOE estimation ignores the cost of integration (network reinforcement, backup generation, and storage requirements) relating to a particular technology. Such costs are likely to become more important as penetration of offshore wind power increases. In this case the LCOE can be a misleading metric for comparing the attractiveness of offshore with other technologies. Furthermore, LCOE is only the measure of cost and does not say anything about profitability and competitiveness, which are related to 'market value' rather than LCOE.

As demand for electricity varies continuously and storage is costly, the value of electricity – reflected in price – fluctuates continuously depending on the demand and supply condition. For example, if offshore wind is generating power when and where it has highest value (see Section 1.3) then a plant's economics may be better than suggested by its LCOE value. Conversely, if generation from another technology source occurs when it has a low market value and where it imposes high transmission costs, it may be less attractive than that plant's LCOE might suggest.

[47] (Shruti Shukla, 2014).
[48] EWEA website: www.ewea.org/statistics/.
[49] (Tegen et al., 2012).

Nevertheless, for regulatory and policy purposes, the LCOE figure for offshore wind is often used – not only to calculate subsidies and feed-in tariff levels, but also as a basis of comparison against other power generation plants – despite its inherent limitations. In this research, the authors adopt LCOE for the purpose of 'plant-level cost comparison' only, and argue that offshore wind will become less competitive when full economic costs are taken into account. Figure (2.4) demonstrates the wide disparities between offshore wind and other electricity generation sources on a pure actual costs basis (in other words, without the benefit of subsidies).

Figure 2.4: Unsubsidized LCOE Comparison – $/MWh (in US$)



	Solar (utlity scale)	Geotherm.	Biomass (direct)	Wind (land)	Offshore wind*	Diesel gen.	Gas (Combined Cycle)	Coal	Nuclear
Low	$60	$89	$87	$37	$158	$297	$61	$66	$92
High	$86	$142	$116	$81	$274	$332	$87	$151	$132

Source: Author compiled from (Lazard, 2014).
*Authors' estimate based on various sources and reports.

It should be noted that the LCOE for land-based wind has retreated dramatically in recent years, contracting some 58 per cent over the five years between 2009 and 2014.[50] In some markets, the LCOE of land-based wind now averages as low as $37/MWh, cheaper than most fossil fuel plants. Indeed, land-based wind power production is effectively cheaper per megawatt hour in Australia than coal.[51] Efficiencies in solar PV have been even more pronounced, with a 78 per cent reduction in LCOE over the same five year span.[52]

However, as depicted above, the LCOE range for offshore wind farms can vary widely, depending on a number of factors such as infrastructure, logistics costs, availability of vessels and other equipment

[50] (Lazard, 2014).
[51] GWEC Global Fact Sheet. 'A new wind farm in Australia can supply electricity at a cost of A$80 per MWh, compared with $143 per MWh from a new coal-fired plant [and] A$116 for a new station powered by natural gas when the cost of carbon emissions is included.' www.gwec.net/wp-content/uploads/2013/06/GWEC_global_fact_sheets.pdf.
[52] (Lazard, 2014).

(see Section 2.2.3), and transmission responsibilities (the issue of who pays the cost of grid connection). Even in the more mature markets, such as Germany, where the cost is typically lower because the developer does not have to pay for the transmission infrastructure, the average LCOE is assumed to be around €140/MWh ($158/MWh).[53] Given the wide disparity between offshore wind generation and conventional and renewable generation sources, significant effort is being focused on industry-wide cost reduction.

2.2.3 LCOE targets for offshore wind

The peculiar position of offshore wind has indeed been due to the fact that its installed capital costs, a key driver in LCOE, have continued to rise, rather than fall, for over a decade. As summarized by the report *Offshore Wind Policy and Market Assessment* published by FOWIND (Facilitating Offshore Wind in India) in December 2014, this can be attributed to a number of unique, industry-specific developmental trends.[54] The report chronicles that in the early part of this century (2000–4), initial overzealousness and 'competitive hustle' amongst major EPCI (Engineering, Procurement, Construction, and Installation) contractors bidding on offshore wind tenders resulted in a trend of falling industry-wide CAPEX averages. However, in hindsight these EPCI contractors were effectively failing to anticipate costs and risks properly, and as a result a number of these contractors and suppliers were rendered either bankrupt or out of the business by the mid-point of the decade. This ultimately reduced competition in the European sector, and as more cautious pricing was built into contracts amongst the remaining contractors in the period that followed (2004–10), average project CAPEX began to escalate in the second half of the decade. Adding to this, the rebound in oil prices late in the decade led to restricted availability of installation vessels and other infrastructure previously borrowed from the oil and gas industry, pushing up day rates for equipment.[55]

In the current environment, however, a sharp retreat in competition from the oil and gas sector and 'a clearer understanding of the costs and risks of offshore wind construction have stabilized [costs] to some extent'.[56] Nevertheless, as projects move further from shore and into deeper waters (see Section 3.1.3), the industry risks increasing capital costs, putting further upward pressure on the LCOE.

2020 Targets

The UK government and industry have agreed on the stated LCOE goal of £100/MWh at Final Investment Decision by 2020.[57] To underscore the importance of this LCOE target, an Ernst and Young study, commissioned by the European Wind Energy Association in 2015, noted that the offshore wind industry would be required to shed 26 per cent of its capital and operating costs in order to become 'highly competitive' with other sources of energy by 2023.[58]

In order to reach the 2020 target of £100/MWh, a number of studies have analysed the UK and European offshore wind industry; these studies show a consensus that larger turbines with greater energy capture, together with competition in the supply chain, are the factors that would have the greatest overall impact on cost reductions in the period until 2020.[59] A steady project pipeline allowing for capital investments, particularly in the serial manufacturing of wind turbine substructures (such as foundations), as well as increased competition from contractors and suppliers, would also lead to the greatest reductions in overall capital and LCOE cost through the period 2020. A representation of these contributions is summarized in Figure 2.5.

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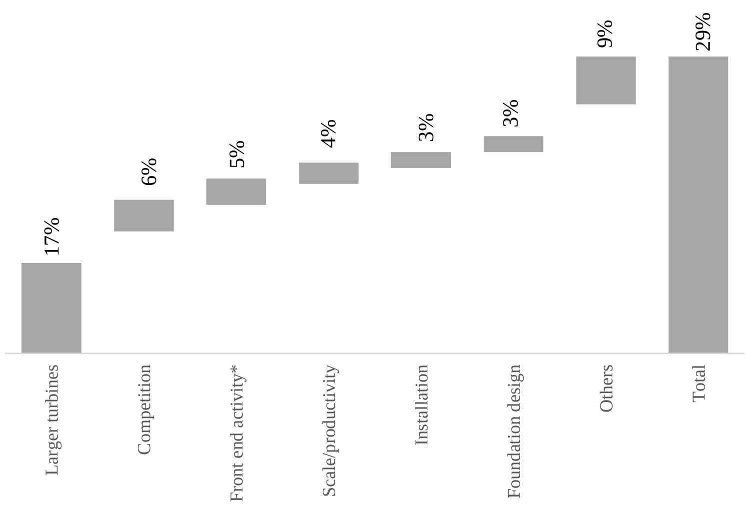
[53] (Shruti Shukla, 2014).
[54] (GWEC 2014).
[55] Lead author (Shruti Shukla, 2014, p. 23).
[56] (Shruti Shukla, 2014, p. 23).
[57] ORE Catapult Website. Last Accessed 18 June 2015. https://ore.catapult.org.uk/crmf.
[58] (Ernst and Young, 2015, p. 2).
[59] For instance (The Crown Estate, 2012) and (Ernst and Young, 2015).

Figure 2.5: Example of Offshore Wind Cost Reduction Opportunities from UK Crown Estate*



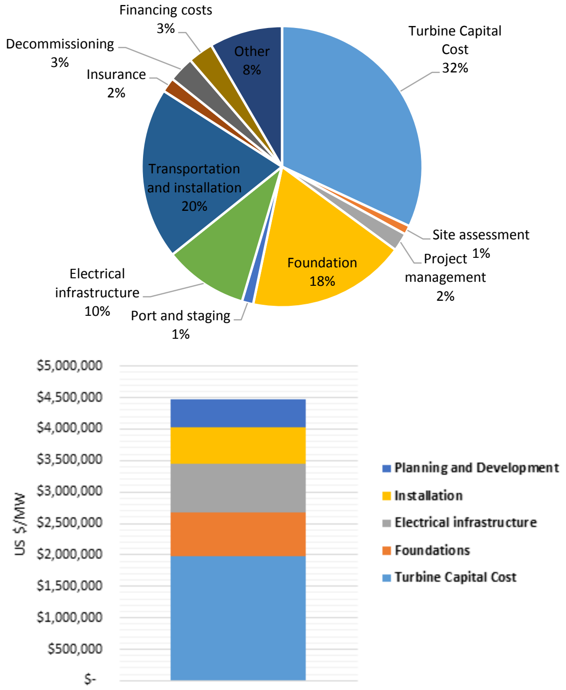
*Methodology note: cost reductions are based on comparison of typical Final Investment Decision in 2011 versus 2020 FID targets.

Source: Author adapted from: (The Crown Estate, 2012, p. 16).

3. Technical hurdles and cost drivers

3.1 Cost breakdown of offshore wind turbine and substructure

Figure 3.1a, b: Cost Breakdown of an Offshore Wind Farm



Source: (New York Energy Policy Institute, 2014).

CAPEX associated with the offshore wind structure can be broken down into five major project cost centres (Figure 3.1a, b): the wind turbine generator cost, fabrication of foundations, electrical infrastructure, installation, and planning and development costs (which include permitting and financing fees, among other costs). Although these figures can vary significantly market by market depending on existing infrastructure, the availability of installation vessels, and competition amongst industry participants, the clear industry challenge is that:

> "... costs remain high because the offshore wind industry is immature and learning curve effects have not yet been fully realized."[60]

The harsh offshore environment and mobilization of resources for operations and maintenance through a 20 to 25 year plant life also pushes the OPEX higher than traditional land-based plants (notably land-based wind farms). As such, higher CAPEX and OPEX together drive up the capital requirements for offshore wind farms. Although innovations in energy capture (larger turbine size) can help reduce the LCOE, market consultancies suggest that the costs further down the structure will become increasingly relevant as distance from the shore and technical hurdles increase:

> "The added complexities of the offshore wind market mean that non-turbine costs may take on heightened importance ... As a result, cost-reduction opportunities may arise not only from advancements in wind turbine technology but also from emerging trends and conceptual models in any one of several categories, including, trends in manufacturing, foundations, logistics and vessels, electrical infrastructure, and operations and maintenance strategies."[61]

3.1.1 Wind turbine generator market

Because few turbine manufactures have experience with offshore wind turbines generators (WTGs) the market has been thus far almost entirely dominated by one WTG supplier, Siemens, which, as of 2014, accounted for 65 per cent of all turbines installed offshore in Europe.[62] This concentrated market structure is, in many ways, an outcome of the temporary exit of turbine manufacturer Vestas from the offshore wind market in 2007. That move effectively left only two offshore wind turbine suppliers in the market: Siemens and Repower.[63]Although this market dominance is slowly easing, as non-incumbent competitors secure more commercial orders for competing larger turbine machines,[64] it could be suggested that the dominance of just one player in the market for the past several years has made itself felt in higher prices than would otherwise have been seen, had there been more competition in the market. The emergence of new players into the market thus far suggests that more pricing competition will enter into the sector, which could substantially impact the LCOE for offshore wind farms.

3.1.2 Substructure considerations

To date, the relatively shallow water depth of major European commercial leases has allowed for the predominant use of 'monopile' foundation types. By 2014, these structures accounted for 79 per cent of all WTG foundations installed in Europe, or 2,301 foundations.[65] These cylindrical steel structures, suitable for shallower waters and the turbines currently on the market (see Figure 3.2), generally require less demanding fabrication techniques and installation conditions, for a myriad of reasons. Notably, the steel diameter for the monopiles demanded by the market, generally 3–6 metres, can be 'rolled' in existing fabrication yards in north-west Europe that have traditionally been used for oil and gas. Likewise, installation vessels borrowed from the North Sea oil and gas exploration sector are, in

[60] (Navigant Consulting, 2013, p. 46).
[61] (Navigant Consulting, 2013, p. xvii).
[62] (EWEA, 2015).
[63] (Shruti Shukla, 2014, p. 23).
[64] Vestas, after re-emerging in the industry and recently partnering with MHI, has recently secured a number of commercial orders with its 6MW and 8MW offshore wind turbine.
[65] (EWEA 2015).

most cases, capable of installing these foundations at the water depths of the projects currently under development.

However, as we discuss in more detail below, the consequences of a shift towards larger turbine sizes (>5MW) with greater loadings, together with a trend towards deeper waters, will all contribute to more strenuous requirements for offshore wind foundations. Not only will more streamlined and serial manufacturing capabilities in fabrication yards be required, but also more purpose-built installation vessels with greater crane hook capacity and more installation equipment.

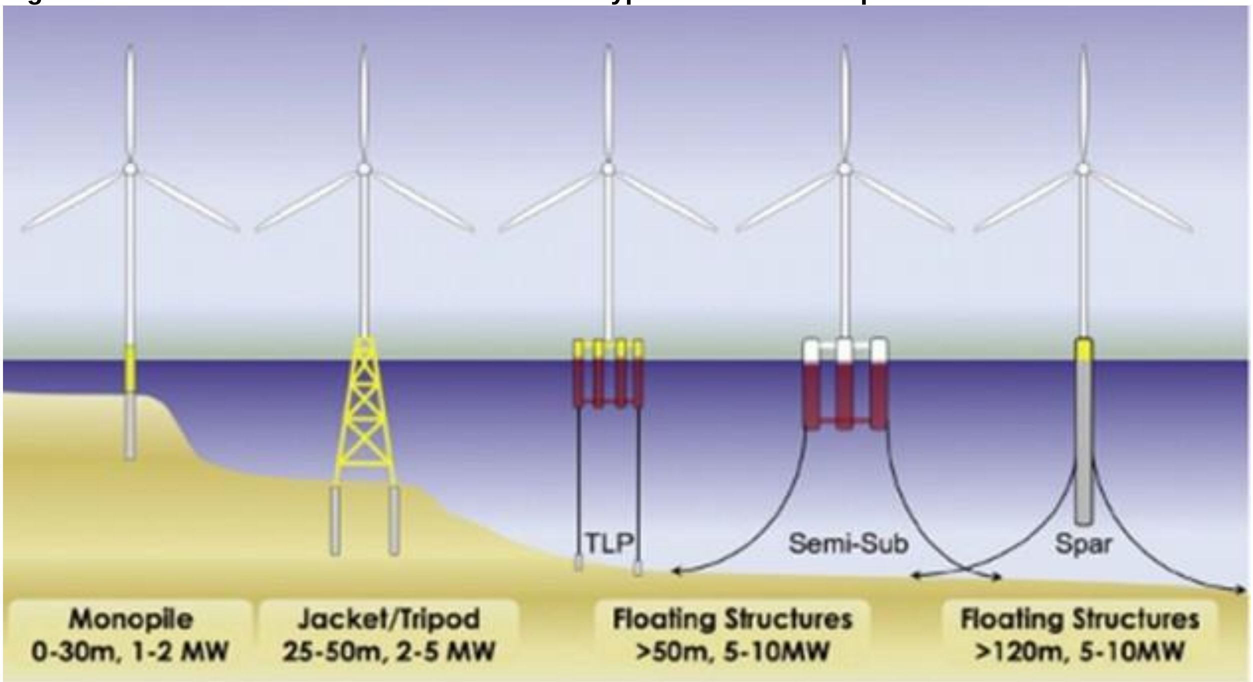
3.1.3 Trends impacting capital requirement

Development of offshore wind farms generally starts out in shallower waters that are relatively close to shore. In China, for instance, the majority of the projects installed thus far have been in shallow, near-shore waters. These inter-tidal projects are in such shallow waters, in fact, that most of the sites even dry out at low tide.[66] Generally, construction and installation of wind farms closer to shore reduces project costs. This is not only because less vessel transport time is required between the wind farm and port (minimizing the accumulation of vessel day rates), but more importantly because the foundation types and installation requirements are less demanding.

In Europe, the average water depth and distance from shore has been on an upward climb as projects move into the UK Crown Estate's Round 3 seabed lease. According to EWEA, the average water depth of work carried out on European wind farms in 2014 was 22.4 metres, a 10 per cent rise on 2013 (20 metres).[67] Meanwhile, the distance from shore also increased to 32.9 km, up 2.9 km from the previous year.[68] This trend will have a number of implications on capital costs. With foundations, for example, a combination of deeper waters, more diverse geotechnical conditions, and larger turbines with greater load bearings will push the industry away from the relatively cheap monopile foundations towards alternatives such as jackets, tripods, gravity base structures, floating structures, and suction caissons (See Figure 3.2).[69] The same is true of wind development zones where difficult geotechnical conditions will require novel foundation designs that in some cases will present more installation challenges, such as drilling and expensive seabed preparation. Already, offshore foundations account for over 60 per cent of all installation costs.[70] Tougher geotechnical conditions and greater turbine loadings are likely to increase upward pressure on installation costs, as foundations get heavier and more complicated to install in the deeper wind deployment zones.

[66] (GWEC, 2014)
[67] (EWEA, 2015, p. 9).
[68] (EWEA, 2015, p. 9).
[69] (Navigant Consulting, 2014).
[70] The UK Crown Estate shows that foundations account for 61% of installation costs, array cables 22%,, and turbines 17%. (The Crown Estate, 2012, p. 25).

Figure 3.2: Offshore Wind Turbine Foundation Types at Different Depths



Source: www.pbo.co.uk.[71]

The implication of these trends is that as markets mature to deeper waters and more difficult site conditions, the capital requirements are more likely to continue escalating. Assuaging escalating costs will thus require ongoing technological innovations in foundation design, investments in purpose-built installation vessels (as well as in a larger fleet), and the creation of new manufacturing facilities incorporating automation welding and manufacturing technology, to produce foundations in a serial, cost-effective manner.

3.2 Grid connection of offshore wind

The connection of offshore wind power to the mainland grid is costly and it becomes even costlier as the distance from the coast increases. Unlike the early years of the industry where installations were close to the coast, most of the current wind farms are relatively distant from the shore. Being further away from the coast can have several advantages, including reduction in visual impacts and noise emissions, as well as the opportunity to install larger wind turbines with higher throughput. Nonetheless, distance from the shore increases the cost of grid connection considerably, because of the need for special equipment – offshore substations, subsea cables, insulators, switchgears, and protection equipment, among other items – that is compatible with a harsh marine climate. Farm-to-shore grid investment already constitutes 15 to 25 per cent of the total costs of new projects.[72]

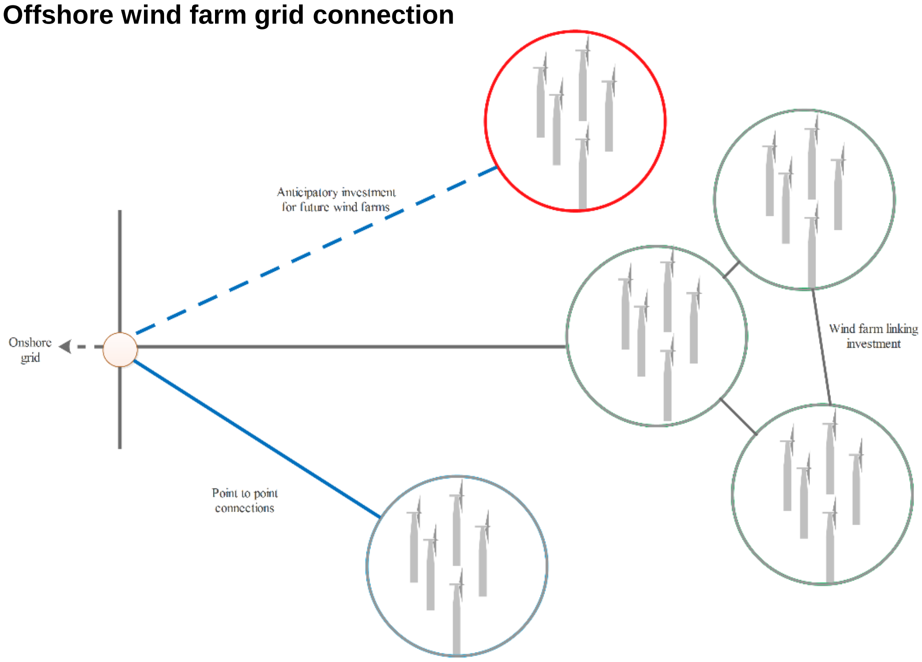
At the same time, the design and operation of offshore transmission lines evolve as the need for more optimized grid connection methods increases. To date, wind farms are mostly operating independently of each other. Thus, a point-to-point connection, where each wind farm is directly connected to the mainland grid, has been the common approach. As interconnectivity among wind farms increases, the entire transmission infrastructure needs to be optimized at once, taking into account topology, control, and interoperability of equipment. Some of these changes are already underway as, for example, high voltage alternating current (HVAC) linking methods are being

[71] (Hodgetts, 2013).
[72] (Meeus, 2015).

replaced by a high voltage direct current (HVDC) link in places where wind farms are situated far from the coast.[73] Figure 3.3 shows schematically the offshore grid connection methods.

There is a huge potential for regional cooperation in building the offshore interconnections. In the EU, the issue of transmission infrastructures in the North and Baltic seas is high on the agenda of policy makers, mainly because of the anticipated large-scale offshore wind farm projects. In this respect, the North Sea Country Offshore Grid Initiative (NSCOGI) was formed in 2010 (NSCOGI, 2014) to facilitate cooperation among relevant EU countries, in order to build an integrated interconnection for offshore wind farms as well as other renewables. The key challenge however, is to overcome the regulatory, planning, and economic obstacles of connecting offshore wind power to the network.

Figure 3.3: Offshore wind farm grid connection



Source: Authors.

The regulatory model of grid connection is critical for investment incentives in offshore technology because it governs the distribution of costs between project developers and grid operators or third parties. Currently, there are three main regulatory approaches for the treatment of offshore grid connection costs. The first one is a generator model, which requires wind project developers to bear the entire cost of grid connection. In such a model, wind farm developers have a high incentive to implement a cost efficient connection because high cost or low availability directly affects their profits from the wind farm (Green & Vasilakos, 2011). At the same time, a generator model significantly increases the project developers' costs. This model is currently being practiced in some countries, such as Sweden. The second approach is based on the idea that the transmission system operator (TSO) is responsible for extending the grid in order to reach the wind farm. This model is the dominant method for onshore grid connections and several countries, such as Germany and Denmark, have extended it to their offshore projects.

The third approach is the UK model, in which a tender is run in order to appoint a third party as the Offshore Transmission Owner (OFTO). The OFTO would then be responsible for building, owning and operating the connection asset between the wind farm and the mainland, bound by a set of standards and codes applicable to the industry. This model, which launched in 2009, entitles OFTO licence holders to 20 years of revenue stream, subject to a satisfactory performance, indexed to the retail

[73] The first connection of a wind farm through an HVDC transmission link was completed in Bard Offshore I in Germany.

price index (RPI) in the UK. The OFTOs' revenue, which comes from the National Electricity Transmission System Operator (NETSO), is independent of wind farm performance, as the transmission asset owner is only required to ensure its availability, irrespective of actual power transmitted. As the UK was previously working under a generator model, the OFTO regime applies both to the transmission assets acquired from the wind farm developers as well as to the transmission assets newly built by OFTOs. The first licence for an OFTO was granted in 2011 and by March 2014 there were around nine operating offshore transmission owners (Ofgem, 2014).

Although all three regulatory models mentioned above have a common feature, in the sense that the cost will be finally borne by the end users, they are not necessarily similar either in terms of cost efficiency, or of compliance with wider energy policy objectives (Weißensteiner, Hass, & Auer, 2011). The key advantage of the OFTO approach is that it allows new entrants to enter the market and thus can deliver cheaper and timelier offshore grid connections through the enabling of competition. Additionally, the OFTO model focuses on a generator's needs and provides flexibility for future offshore generation requirements. Also, this approach is subject to light-handed regulation and is protected against generator failure and credit risk. However, despite these appealing characteristics, Meeus (2015) argues that in the case of the OFTO and generator models, several entities are involved in the process of design and development of offshore grid connection. Thus, it is not straightforward to adopt either of these as the EU target model for the offshore cross-border interconnection. Instead, the TSO model involves fewer parties, and related institutions already exist and are mature. Therefore, the TSO model can better serve as the EU target model for offshore interconnections. Nonetheless, due to the absence of competition in the TSO model, it is not suitable for large-scale offshore wind integration at some distance from the coast. Consequently, a trade-off arises between opting for a more competitive but complex model (for example, the OFTO approach) and a more straightforward but probably less efficient regulatory model for offshore wind farm grid connection (for example, the TSO model).

4. Current policy mechanism frameworks

Thus far, a number of policy mechanisms have been implemented in various markets with the goal of supporting demand for offshore wind and providing either revenue support guarantees or incentives to developers. In this section, we briefly outline the major policy mechanisms currently supporting the offshore wind industry. This is followed, in Section 5, by a presentation of novel policy approaches that seek to better target cost reductions in the industry through competitive models, collaboration, and/or research and development (R&D) programmes.

4.1 Indirect policies

Indirect policies supporting greenhouse gas (GHG) reduction and the implementation of national renewable energy targets have broadly set the foundation for power generation from renewable energy sources. The EU's commitment to binding GHG reduction under the Kyoto Protocol, for instance, and subsequently the EU's 2020 mandates and nationally tailored energy strategies (NREAPs), have all set a foundation for offshore wind in member states. Looking forward, the upcoming United Nations Convention on Climate Change (UNFCCC 21) to be held in Paris in late 2015 may very well help guarantee the increasing role of renewable energy sources, particularly in the power generation sector, should further national commitments for emissions reduction targets be established.

These indirect policies have a trickle-down effect that impacts the national appetite for renewable energy generation and, by extension, for offshore wind. As discussed in greater detail below, in many cases private and state-run power suppliers are now obliged to source a percentage of the power they sell to end users from renewable energy sources, although they typically have the option of which energy to source. Implementing this guaranteed demand structure for power generation from renewables, in combination with a variety of direct policy mechanisms such as long-term tariff subsidies, has funnelled private investment into renewable energy technologies. According to a recent report by the Renewable Energy Policy Network for the 21st Century,[74] new investments in renewable power and renewable (bio) fuels in 2014 were at least $249.4 billion. As the theory would imply, this flood of investment has come hand-in-hand with increasing private sector competition, greater cost efficiencies in renewable power plants, and ultimately a phasing out of public financial support. However, offshore wind has again proven the exception to the rule; only attracting a fraction of these investments annually.[75]

4.2 Direct Policies

Direct polices to promote offshore wind generally consist of revenue support mechanisms, typically in the form of long-duration contracts for renewable power generation. There are a number of different models for this support structure. Most commonly, as seen in Europe, long-term feed-in tariffs are offered to developers either on a fixed or variable basis over a span of ten to 20 years with varying payout models.[76] Asian countries have also started to follow this model, with China, Taiwan, and Japan each implementing feed-in tariffs for offshore wind generation (see below). As an alternative, in the USA, renewable portfolio standards (or quotas) are imposed on power suppliers by state legislatures, and then market-style '(green) credits' for renewable power generation are brokered by a state clearing house or public utility commission in a market exchange format. This latter system, in theory, allows for premiums on the wholesale electricity price based on increasing demand for renewable energy credits. However, the potential over-build of renewable energy generation capacity, as well as uncertainty over future demand, pose significant threats to project developers and private investments under this support scheme.

4.2.1 Feed-in tariff subsidies

Feed-in tariffs (FITs) are purchase agreements (typically between a government and the power generator) that essentially act as a mechanism to improve investment confidence in the sector by offering a 'bankable' guarantee on the revenue stream. FITs typically represent the maximum price that the government would pay for power, and have thus been criticized in more mature offshore wind markets (such as the UK) for not promoting competition. Nevertheless, in many countries in Europe and Asia, FITs are the preferred mechanism for incentivizing project development. In PR China, a national level feed-in tariff of RMB 0.75 per kWh ($0.12) for inter-tidal projects and of RMB 0.85 per kWh ($0.14) for near-shore projects was announced in June 2014.[77] These FITs will cover projects that come online before 2017, after which time the level will be reviewed by the government. The Taiwanese government, in order to support its target of 600 MW of installed offshore wind power by 2020, has recently awarded two projects with government development grants,[78] and set a special FIT rate at TWD 5.56/kWh ($0.17). In Japan, a market that must rely primarily on less-proven floating offshore wind turbines and foundation concepts, offshore wind generation receives a tariff of JPY

[74] (REN21, 2014).
[75] In 2013, offshore wind attracted a cumulative $30 billion in investments, according to Ernst and Young. (Ernst and Young, 2015, p. 12).
[76] In Germany, for example, a 'compression' FIT model offers higher upfront payments over an initial term of eight years, in order to help investors recoup investment more quickly in an effort to assuage risks built into financing.
[77] (GWEC, 2014).
[78] 'In October 2013, grants were awarded to two projects: the 108 MW Fuhai wind farm and the 122.4 MW Formosa wind farm.' (GWEC, 2014).

36/kWh ($0.30). It should also be noted that in Japan, the offshore tariff is now 1.6 times higher than the onshore tariff, in order to improve investment in the sector.[79]

4.2.2 Reverse subsidy auctions and 'contracts for difference'

New competition mechanisms such as reverse auctions for feed-in tariffs, whereby the project's developer essentially submits a competitive bid to the government for a tariff price, are aimed at ultimately reducing the cost of energy by promoting more competition amongst project developers. This framework is currently being implemented as part of the UK's Electricity Market Reform, replacing the current Renewable Obligation Scheme (RO) and Renewable Obligation Credit (ROC) incentives for developers.

The new policy framework is largely a response to fatigue over high subsidy prices for offshore wind and ratepayer burden. In March 2015, the *Financial Times* reported that UK subsidies for generators of offshore wind had been over three times the prevailing wholesale prices for power.[80] Indeed, the UK government contended that 'If we [had] continued with current policies, average annual household electricity bills could rise by around £200 by 2030.'[81] Under the new Contract for Difference (CfD) scheme, a fixed budget is allocated to different carbon-free generation technology pots (Table 4.1), and generators within that pot must compete for, or bid on, the limited number of contracts available for that technology class 'pot'. Under the new framework, 'pot 1' includes established technologies such as land-based wind, solar PV, and hydro. Offshore wind is considered a less established technology, categorized under 'pot 2', along with such technologies as tidal stream, wave, and advanced conversion technologies.

Table 4.1: UK CfD Budget– Total Renewables Energy Support Payments by Delivery Year (£million)

Year	2015–16	2016–17	2017–18	2018–19	2019–20
CfD Budget	50	220	325	325	325
Pot 1 (established)	50	65	65	65	65
Pot 2 (less established)	-	155	260	260	260

Note: originally published budget in 2014 of £205 million was increased in January 2015 to £220 million
Source: DECC (2014) and GWEC (2014).

The CfD acts as a long duration (15 year) contract between a low-carbon electricity generator and the government. 'Top up' payments are provided to generators when the market price for power is below the intended level of total revenue, or the 'strike price', that the developer bids on for the CfD. In this way, the CfD is intended to provide certainty and stability of revenues to generators by reducing their exposure to volatile wholesale prices, whilst at the same time protecting consumers from paying higher electricity prices.[82] According to the government:

> "CFDs will be allocated to the cheapest projects first, regardless of their start date, as long as they fit under the budget profile."[83]

As well as ensuring the lowest possible price tag for offshore wind support, the guaranteed revenue structure also seeks to open the door to new forms of project finance and lower the overall financing risk premium.

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[79] (GWEC, 2014).
[80] (Clark, 2015).
[81] (DECC, 2011, p. 12).
[82] 'Offshore Wind hit hard by Catch 22 in new UK CfD Policy', Susan Kraemer, Wind Energy Update, 10 December 2014. http://social.windenergyupdate.com/offshore-wind/offshore-wind-hit-hard-catch-22-new-uk-cfd-policy
[83] (DECC, 2015).

Allocation
The first allocation round for CfDs commenced in October 2014 and the overall budget for that round was confirmed on 29 September of that year. The originally published budget figure was originally set at £205 million for projects from 2015 onward, but the CfD budget was increased as the bidding round came to a close in January 2015. This allowed for the 'less established technologies' to battle for a larger total pot (pot 2) of some £260 million in each round from 2015–21. Given the fixed budgetary constraints, however, competition for the CfDs in each auctioning round will be fierce amongst competing technologies. This was shown in the first allocation round, when only two of the five utility-scale offshore wind projects applying for the CfD were awarded contracts. The winning bids, submitted by Neart na Gaoithe wind farm and East Anglia 1, reportedly submitted 'strike prices' of £114.39/MWh and £119.89/MWh, respectively.[84] Given this competition, and the limited amount of resources for each technology pot, the industry advocate Renewable UK suggests that only one in every six megawatts of offshore capacity is likely to be awarded contracts under the CfD scheme.[85] On the one hand, the implications for investment in the industry, resulting from a restricted project development pipeline, remain to be seen. On the other hand, however, obliging offshore wind to compete with other technologies for a fixed pot of subsidies means that only the most efficient and cost-effective will move forward, thus alleviating the burden on tax and ratepayers.

4.2.3 Renewable obligation mandates and credits

Renewable Obligation (RO) schemes mandate that regulated or licensed electricity suppliers source a proportion of electricity sold to customers from renewable energy sources. This policy mechanism seeks to incentivize investments in large-scale renewable energy generation which are underpinned by guaranteed demand for electricity from renewable sources. Credits for renewable energy generation are typically sold on markets for 'Green Certificates', with wholesale market prices varying – based on demand for renewable power generation.

In the USA, renewable obligation frameworks vary on a state-by-state level. This has resulted in uneven and uncoordinated renewable obligation targets. Some states have implemented specific 'carve-outs' for offshore wind in their Renewable (Energy) Portfolio Standards (RPS), while others have not. Nevertheless, the trend of implementing Renewable (Energy) Portfolio Standards (RPS) is increasing. To date, some 29 states have RPSs for power sellers.[86] This figure includes most of the states in the US Mid-Atlantic and New England, where the offshore wind energy resources are among the strongest (Table 4.2). In certain states, such as Massachusetts and New Jersey, Class I targets (new energy technologies including offshore wind) are now featured just as prominently in the RPS as targets in Class II (existing technology). Maryland, New Jersey, and Massachusetts have also each implemented special 'carve-out' targets for offshore wind in the RPS. It should be noted, however, that these carve-outs for offshore wind are extremely vulnerable to changing state-level politics and electoral cycles.

[84] (UK Government, 2015).
[85] (Navingo Maritime & Offshore Media Group, 2015, p. 30).
[86] (National Conference of State Legislatures, 2015).

Table 4.2: State Renewable Energy Portfolio Standards (USA)

	Class II (established technologies)	Year	Class I (New technologies)	Year
Maine	30.0%	2030	10.0%	2017
New Hampshire	24.8%	2025	10.5%	2020
Massachusettes	5.5%	2015	15.0%	2020
Rhode Island	16.0%	2010	NA	NA
Connecticut	NA	NA	20.0%	2020
Pennsylvania	18.0%	2020	NA	NA
New Jersey	20.4%	2021	20.4%	2021
Delaware	25.0%	2025	NA	NA
Maryland	NA	NA	20.0%	2022

Source: www.dsireusa.org (DSIRE NC Clean Energy Technology Center, 2015).
Note: states without offshore wind resources are excluded from table.

Despite the simplicity of renewable energy obligation mandates and the corresponding renewable energy credits (ROCs), several countries have moved away from this policy framework in recent years, particularly in regards to offshore wind. This is primarily attributed to uncertainties in future revenues, and the fact that these policy frameworks often benefit the more mature renewable energy sources.

According to a 2010 policy paper:

> "…in marked contrast to fixed prices, the RO creates uncertainty for investors, since future ROC prices are uncertain and could even conceivably collapse if excess renewable generation is built. Wholesale power prices are also uncertain over the long time periods investors must consider. This makes the cost of capital higher and makes investment most attractive to large companies able to manage risks and finance development on the balance sheet. Because of this, RO effectively favoured mature, lower cost generation technologies like landfill gas over less mature, more expensive technologies like offshore wind and wave power."[87]

4.2.4 Tax production credits and incentives

To spur the development of renewable energy infrastructure in the USA, The American Recovery and Reinvestment Act of 2009 had permitted offshore wind facilities placed into service by 31 December 2012 to receive an investment tax credit (ITC) worth up to 30 per cent of capital investment expenditures. However, on its expiration, the ITC was barely renewed in 2013, due to palpable bi-partisan resistance in the US congress.[88] Since then, the ITC has repeatedly gone back and forth between expiration and being extended for one year increments. This uncertainty, not surprisingly, has eroded confidence in the offshore wind industry in particular. Although the ITC has been recently renewed until the end of 2015, the stop-and-go nature of this incentive, particularly given staggered election cycles in the US congress, has rendered this tool particularly ineffective for offshore wind projects with long lead times.

5. Approaches to cost reductionpolicy frameworks

Many of the policy mechanisms described in the previous section have been effective in carving out demand and have had some success in supporting investor confidence in the sector. However, they

[87] (Gross, 2010).
[88] The ITC was not renewed until January 2013, two days after the 2012 expiration.

have not made sufficient progress towards reducing costs effectively, to the point at which offshore wind would represent a viable, competitive industry moving forward.

To this end, two major questions can be asked of current and future policy approaches:

1. How can policies drive competition without jeopardizing scalability of the industry?
2. How can incentive frameworks impact innovation, collaboration, and technology costs reduction?

5.1 Competitive approaches

In more mature markets, such as those within north-west Europe, there is a growing consensus for a number of practical steps that will target costs reduction in the industry.

These can be summarized, in order of priority, as:

1. Upscaling wind turbines generators to increase energy capture.
2. Encouraging greater competition in the market.
3. Supporting the commissioning of new projects.
4. Industrialization through purpose-built facilities and vessels and automation of the manufacture of large structures and components.
5. Establishing Green Banks and other public financing bodies to reduce costs and risks of project financing.
6. Design life extension beyond 20 years.

Source: (GWEC, 2014).

United Kingdom

The UK has implemented the most novel competitive approaches in order to address some of these steps. A number of new policy mechanisms were recently introduced under the UK's Energy Market Reform, to promote cost reduction via market competition:

- Promoting price competition from project developers under the CfD policy.
- Stimulating the local supply chain through capital grants and other financial and fiscal support.
- Establishing Green Investment Banks to help alleviate financing costs.
- Launching cost monitoring framework.

In particular, the UK Contract for Difference scheme is proving effective in terms of putting strong pressure on industry-wide cost reductions. This extends from project developers down to contractors and the entire supply chain. However, while the promotion of competition has been effective in driving down costs (the most competitive offshore wind 'strike price' bid for the 2014 CfD round was reported at £114.39),[89] it is also likely to narrow the volume of projects that will move forward to final investment decision each year.

In a developed offshore wind market such as the UK, a competitive style of subsidy framework may prove advantageous, as the guaranteeing of a large number of projects would continue to be hugely expensive while not necessarily promoting sufficient competition amongst project developers. However, the implications of this on the downstream supply chain are yet to be seen. In emerging markets such as those outside of Europe, such a policy can adversely impact investment incentives in

[89] (UK Government, 2015).

the long run. This is because, although certain grants and incentives are available to actors who invest in infrastructure related to the offshore wind industry,

> "It is not safe to assume that the supply chain will continue to invest in the required technology innovations if the size of the market is not sufficient."[90]

Dissuading private capital investment may indeed undermine the potential for sustainable industry-wide cost reductions. By introducing competition along the supply chain to drive down costs, when the size of the industry is not sufficiently large, competitive tenders for revenue support contracts risk coming at the expense of a robust project pipeline and further scalability that can result in cost reductions across the industry. While, in the short term, a policy objective may be fulfilled, it could inherently risk longer term cost reductions through investments in infrastructure along the industry supply chain.

Germany

To combat a bottleneck in projects (caused by transmission constraints) that has ailed the industry in recent years, the German government made several amendments to its Renewable Energy Act. Importantly, the government set a target of 6.5 GW of installed offshore wind capacity by 2020, providing clarity to the size of the market. This has proven particularly important in terms of instilling confidence in project development and investment. The government also extended a 'compression' model of feed-in tariffs, in which wind farms connected to the grid by the end of 2019 will receive \$0.19/kWh for the first eight years, followed by \$0.03/kWh for the remaining 12 years of the contract.[91]

The effect of these policies has been clear. In 2015, Germany will install more offshore wind capacity than any market in the world, overtaking the UK for the first time with some 2,000 MW being installed, over the 817 MW in the UK. However,

> "like other states in the EU, Germany is being encouraged by Brussels to move towards 'market-based' support systems for renewables."[92]

In a move similar to that of the UK, the German government is currently in discussions to introduce competitive auctions for subsidies in 2016 that would impact projects commissioned from 2021 onwards.[93] While the outcome is not yet decided, it could have similar implications to the UK, whereby price reductions may be achieved, but with longer-term repercussions on investments and infrastructure. Moreover, narrowing the pipeline may indeed jeopardize the country's offshore wind targets themselves.

5.2 Collaboration, innovation, and R&D support

The long-term implications of introducing competitive market-style policy frameworks need to be carefully considered before other, less developed markets seek to implement similar policies. In the nascent markets outside of Europe, the experience offered by earlier European models – for collaboration and innovation – would likely provide a useful roadmap to policy formulation. This is primarily because, particularly in markets in early stages of development:

> "Rapid technology innovation means that significant amount of uncertainty continues to be priced into projects. This can be overcome by increased collaboration and better monitoring to increase data availability and improve analysis tools."[94]

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[90] ORE Catapult website. Last accessed 18 June 2015. ORE Catapult (2015).
[91] (Navingo Maritime & Offshore Media Group, 2015).
[92] (Radowitz, 2015).
[93] See (Radowitz, 2015).
[94] ORE Catapult (2015).

Collaboration and knowledge sharing amongst commercial actors with genuine shared interests can help to de-risk and commercialize new technologies, with the shared goal of reducing overall industry costs.[95] This is demonstrated by the UK Carbon Trust's Offshore Wind Accelerator (OWA), which was established in 2008 as a consortium of nine major European project developers with a stated goal:

> "to reduce the cost of offshore wind by 10% in time for cost savings to be realized in time for Round 3."[96]

The OWA (which is two-thirds funded by industry and one-third funded by the UK Department of Energy & Climate Change)[97] has been successful in demonstrating new technologies. Notably, this has been seen in foundation design, where four innovative wind turbine foundation designs (Keystone's inward battered guide structure or 'twisted jacket', Dong Energy/SPT Offshore's Suction Bucket jacket, the Universal Foundation, and a Gravity Based foundation), have been demonstrated in European waters to prove fabrication and technology, and to help de-risk the concepts.[98] This framework has been enormously helpful in getting new cost reduction technology to the demonstration phase and on the road to commercial viability. As indicated in Section 3, this will be particularly important given the increasing reliance on novel types of foundations in Europe and elsewhere, as the markets mature.

In order to implement innovation frameworks, governments should also consider funding or co-funding research and development (R&D) for technology consortiums, and, as in the UK, joint public–private partnerships, to demonstrate new technology. These technology consortiums must be combined with well-stated objectives and targets, as the premise of knowledge sharing is having a clearly defined purpose and genuinely shared goals.

> "For actor-oriented innovation programs, this is particularly important because many organizations (which are likely to have divergent company level goals) are pooling their resources."[99]

If goals are not genuinely stated or shared, or if there is a competitive driver conflicting with knowledge sharing, then 'coordination and cooperation are likely to break down, making the whole project ineffective.'[100]

We contend that steps to promote and facilitate innovation should include:

- Data and knowledge-sharing frameworks.
- Technological collaboration including pooling of financial resources to invest in new technology.
- De-risking concepts through demonstration of new technology.
- Seabed allocated to demonstrate and prove novel technologies.

As the offshore wind industry, globally, remains in an early stage of development, with the learning curve not fully realized, innovations in technology will be paramount for several decades to come. Therefore, the establishment of policy frameworks that might have the effect of driving a wedge between shared commercial interests should be carefully considered. And, in most cases, national governments should seek to establish forums for advancing, sharing, demonstrating, and de-risking new technology, particularly until advances can be set by learning curve efficiencies.

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[95] See (Madsen, 2013)
[96] Carbon Trust (2015).
[97] Carbon Trust (2015).
[98] Carbon Trust (2015).
[99] (Madsen, 2013, p. 130).
[100] (Madsen, 2013, p. 131).

6. Conclusion: Supporting cost reduction policy frameworks

Both the proximity of offshore wind farms to demand centres and the scalability of the industry suggest that offshore wind can play a prominent role in helping countries to achieve their renewable energy and carbon reduction targets through the long term. The advantages of offshore wind power are, furthermore, underpinned by the ability of offshore wind farms to provide power during peak demand hours and thereby ease transmission bottlenecks. The closure of fossil fuel generation capacity across much of the EU, as well as the decommissioning of scores of nuclear reactors globally, also provides strong rationale for offshore wind in the context of national energy security, particularly in Europe and Asia.

However, from a policy standpoint, our analysis suggests that the substantial public cost of directly supporting the capital-intensive offshore wind industry must be reconciled with the potential of competing technologies that may offer the same benefits at a lower cost to tax payers and ratepayers. The high relative cost of the long-duration feed-in tariffs currently required to make offshore wind projects viable means that direct policies to support projects on a utility-scale are exorbitantly costly to the public. Moreover, our analysis asserts that the capital cost requirement for offshore wind farms will continue to be pushed higher in the medium to long-term, as site leases move further from shore and into deeper waters. This trend will require the commissioning of larger installation vessels, more days at sea, and the mobilization of specialized construction and installation equipment offshore, quickly accumulating costs. There is also no clarity, given the capital cost drivers unique to offshore wind, that the cost curve will continue to flatten out significantly past the LCOE target of £100/MWh, even when accounting for larger turbine size. These trends suggest that direct policy support for this generation source will continue to remain expensive relative to other 'clean' generation technologies currently available.

For this reason, policy frameworks that seek to introduce more competition amongst and between offshore wind technology and other low-carbon or zero-carbon technologies are a step in the right direction. As detailed in our analysis, one effect of the UK Contract for Difference scheme is that it eliminates the need for governments to choose between which technologies to subsidize. By making new technologies compete against each other for a fixed 'pot' of available government funding, the competitive framework not only controls the overall costs of subsidies, but it also protects taxpayers and ratepayers from unnecessarily high costs by ensuring that only the most cost-competitive projects move forward.

Nevertheless, our analysis also implies that premature introduction of competition-based policies carries the risks of deterring gains from learning curve efficiencies and economies of scale. Although competition-based policy is effective in controlling the high public cost of funding offshore wind projects, it also inherently narrows the pipeline of projects moving forward. This threatens to dissuade private investment and the mobilization of capital investment along the entire supply chain in immature markets such as those outside Europe. North-west Europe is afforded some unique flexibility in this regard. Not only does the industry benefit from existing oil and gas infrastructure, there is also currently a strong market incentive (provided by low oil and gas prices) for those asset owners to diversify into new industries that can keep their assets utilized. In countries that simply lack adequate infrastructure, however, policies that promote scalability of the offshore wind industry are likely to be a preferable policy option, at least during the industry's nascent stage.

Whether policies promoting scalability, or those promoting competition, will be more effective at facilitating cost reductions must also be weighed against the role and necessity for offshore wind in a country's power generation mix and wider energy policies. As European countries continue to approach their EU 2020 targets, offshore wind is likely to have a fluctuating role in their respective national energy strategies, both throughout this decade and in the next, as regards their 2030 renewable energy targets. Similarly, the adoption of new technologies related to renewable energy, as well as fossil fuels recovery impacting natural gas in East Asia and China, may also impact the public and political appetite for supporting offshore wind with expensive subsidies. Nevertheless, the level of current investments in the industry, together with ongoing experience with costs reductions and policy frameworks, suggest that offshore wind will continue to be an important, if challenging, carbon-free and utility-scale power generation source in an increasing number of energy policies globally.

Appendix

Appendix A: Share of Energy from Renewable Energy Sources in the EU (In % gross final energy consumption)

	2004	2010	2011	2012	2013	2020 Target
EU 28	8.3	12.5	12.9	14.3	15.0	20.0
Belgium	1.9	5.7	6.1	7.4	7.9	13.0
Bulgaria	9.5	14.1	14.3	16.0	19.0	16.0
Czech Republic	5.9	9.5	9.5	11.4	12.4	13.0
Denmark	14.5	22.0	23.4	25.6	27.2	30.0
Germany	5.8	10.4	11.4	12.1	12.4	18.0
Estonia	18.4	24.6	25.5	25.8	25.6	25.0
Ireland	2.4	5.6	6.6	7.3	7.8	16.0
Greece	6.9	9.8	10.9	13.4	15.0	18.0
Spain	8.3	13.8	13.2	14.3	15.4	20.0
France	9.4	12.8	11.2	13.6	14.2	23.0
Croatia	13.2	14.3	15.4	16.8	18.2	20.0
Italy	5.6	10.5	12.1	15.4	16.7	17.0
Cyprus	3.1	6.0	6.0	6.8	8.1	13.0
Latvia	32.8	30.4	33.5	35.8	37.1	40.0
Lithuania	17.2	19.8	20.2	21.7	23.0	23.0
Luxembourg	0.9	2.9	2.9	3.1	3.6	11.0
Hungary	4.4	8.6	9.1	9.5	9.8	13.0
Malta	0.1	1.0	1.4	2.7	3.8	10.0
Netherlands	1.9	3.7	4.3	4.5	4.5	14.0
Austria	22.7	30.8	30.9	32.1	32.6	34.0
Poland	6.9	9.2	10.3	10.9	11.3	15.0
Portugal	19.2	24.2	24.7	25.0	25.7	31.0
Romania	17.0	23.4	21.4	22.8	23.9	24.0
Slovenia	16.1	19.3	19.4	20.2	21.5	25.0
Slovakia	5.7	9.0	10.3	10.4	9.8	14.0
Finland	29.2	32.5	32.9	34.5	36.8	38.0
Sweden	38.7	47.2	48.9	51.1	52.1	49.0
United Kingdom	1.2	3.3	3.8	5.1	5.1	15.0

Source: recreated from (Europa.eu, 2015).

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