Policy, innovation and cost reduction in UK offshore wind

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THE BARTLETT
INSTITUTE FOR
SUSTAINABLE RESOURCES

The Carbon Trust's mission is to accelerate the move to a sustainable, low carbon economy. It is a world-leading expert on carbon reduction and clean technology. As a not-for-dividend group, it advises governments and leading companies around the world, reinvesting profits into its low carbon mission.

Part of UCL's Bartlett School of Energy, Environment and Resources (BSERR), the ISR is a world-leading centre of research and teaching on some of the major challenges facing societies today, including climate change, resource efficiency, environmental protection and sustainable development.

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The Carbon Trust has prepared this report for BEIS and FCO. The report has been written using impartial analysis of primary and secondary sources. For the avoidance of doubt, this report expresses the independent views of the authors.

Table of contents

Table of figures

Executive summary

Offshore wind in the UK has been a remarkable green growth success story. The price of offshore wind is less than a third of what it was a decade ago (Figure 1). In UK conditions, it is now cost competitive with new fossil fuel generation[1]. Indeed, if electricity prices return to pre-Covid levels, the Government would no longer be subsidising new offshore wind; HM Treasury will be earning revenue instead[2]. In parallel, the industry has grown and matured to a point where oil and gas companies are clamouring to enter the market and pension funds are comfortable in investing billions of pounds into construction.

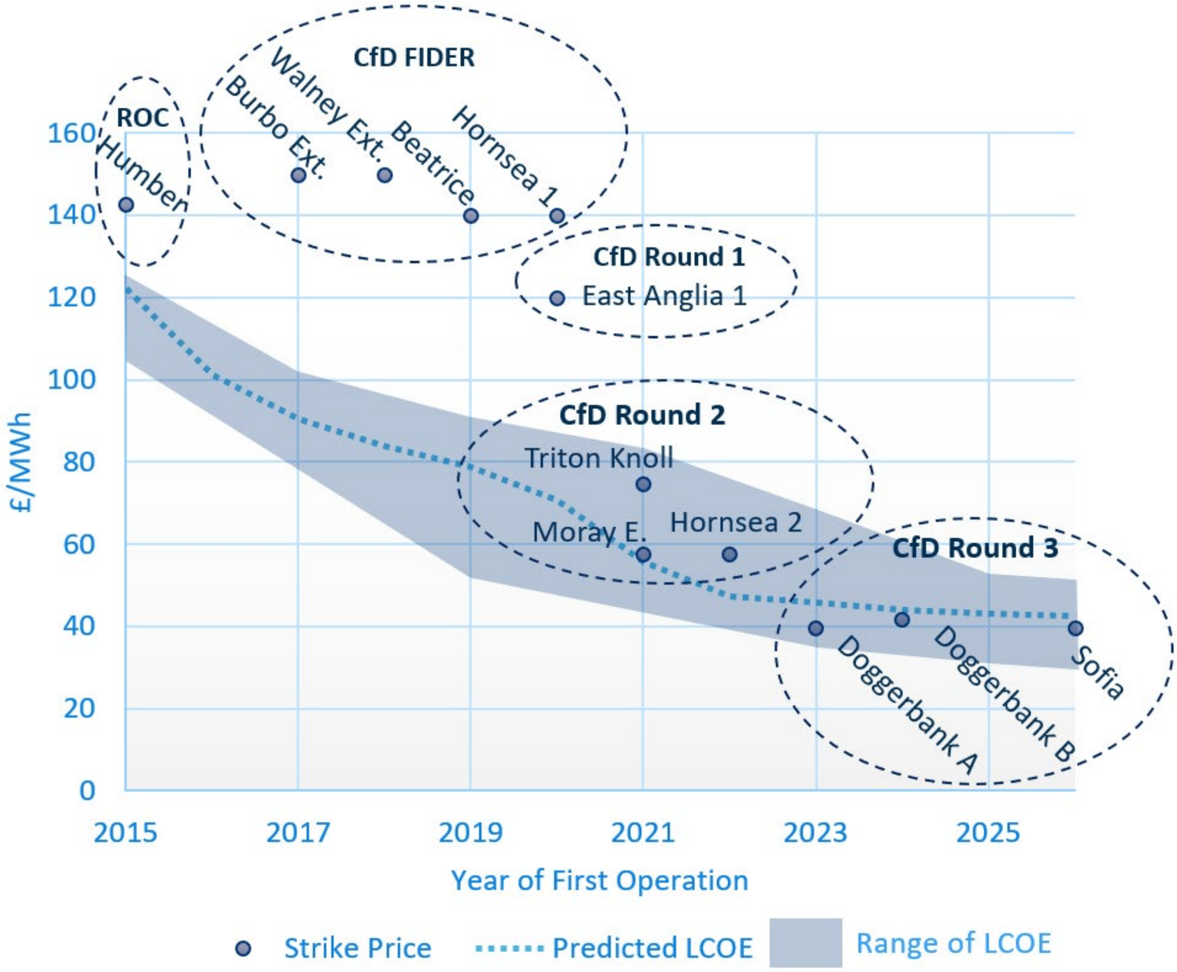

Figure 1 Strike price and estimated LCOE of operational wind farms (dark blue) and predicted average LCOE for Round 3 offshore zones (light blue)[3][4]. Note: 2012 prices for comparability with the early contracts.

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[1] The most recent (2020) Bloomberg benchmark estimate of levelized cost for a new gas (CCGT) investment is £60/MWh, assuming a gradual recovery of gas prices, but with a carbon price still substantially lower than the UK conditions

[2] The wholesale electricity price average over 2017-2019 was £49/MWh. (UK conditions include a carbon floor price)

[3] (Aldersey-Williams, Broadbent, & Strachan, 2019) (Offshore Renewable Energy Catapult, 2019) (4COffshore, 2019)

[4] Prior to the establishment of fully-competitive CfD auctions, the Final Investment Decision Enabling for Renewables (FIDER), was run as an application process

This report shows how policy has been central to this success - particularly 'demand-pull' policy. As a technology develops it moves along the 'innovation chain' (see Figure 3), from its initial invention all the way to maturity. Policy acts at either ends of this chain. 'Technology-push' policy acts on the left-hand side, earlier in a technology's journey. These policies directly fund research and development (R&D) through mechanisms such as R&D grants. 'Demand-pull' policy acts on the right-hand side, developing the market for the technology through the likes of incentive mechanisms. It is UK 'demand-pull' policy that has been at the heart of this decade's offshore wind success story.

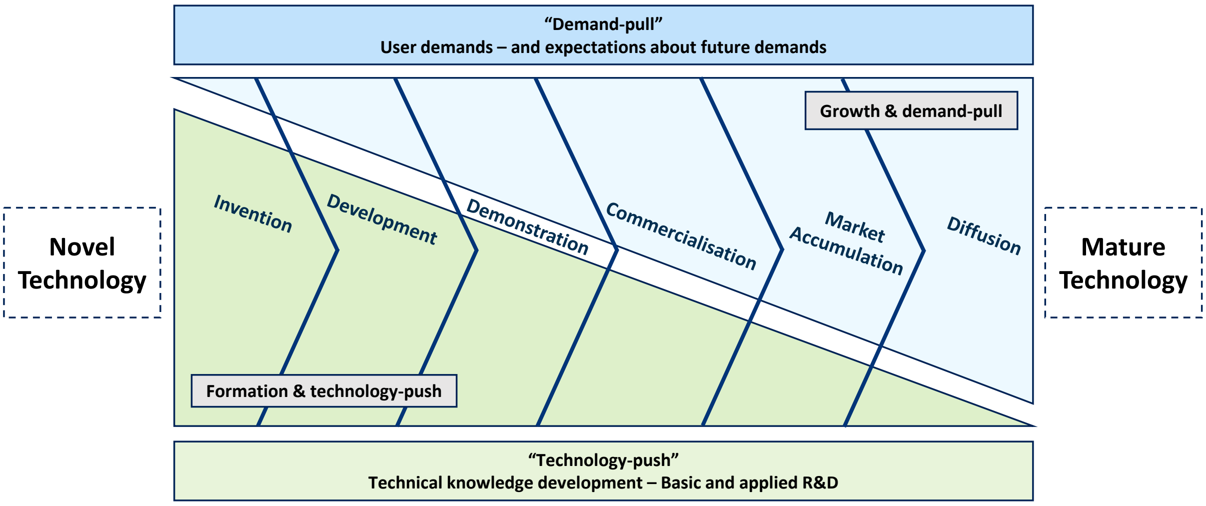

Figure 2 Technology commercialisation R&D pathway[5]

Part B of the report analyses the role of policy in two steps. The first step assesses the underlying cost reduction drivers. The second step assesses the extent to which policy has induced these cost reduction drivers, through its influence on different 'functions' of innovation systems, which drive the technology along the innovation chain.

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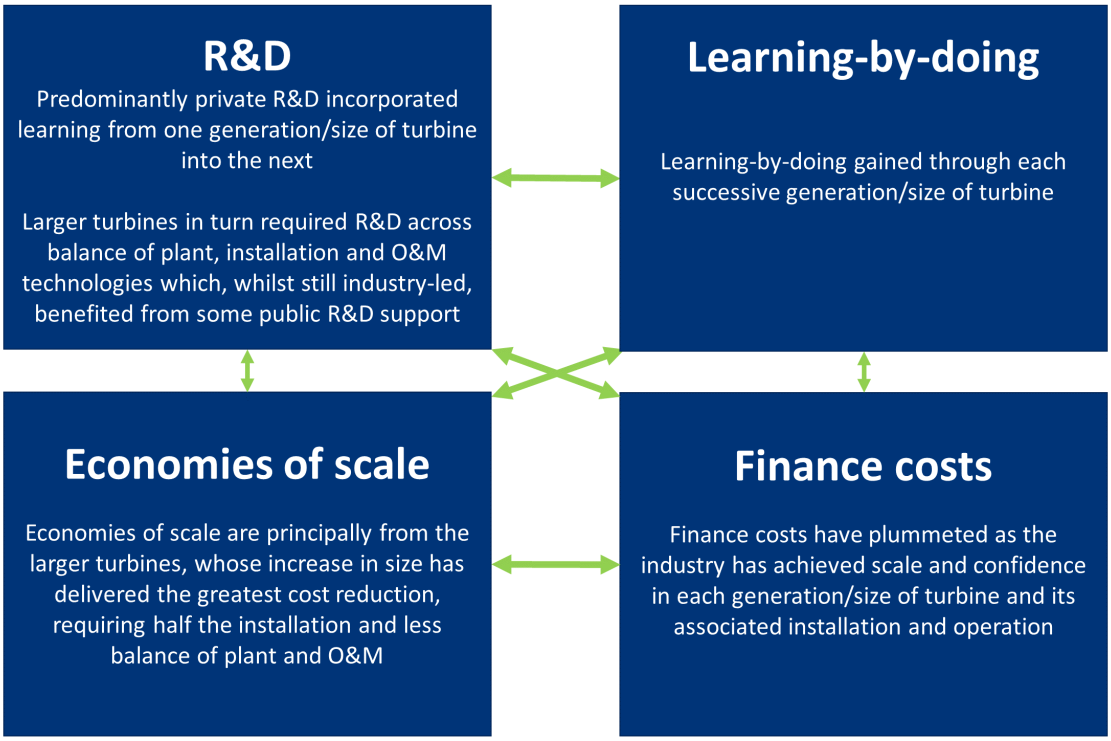
[5] (Grubb, McDowall, & Drummond, 2017)

Cost Reduction Drivers

This work draws on a cost framework, adapted from Kavlak *et al* (2018), that enables cost reduction to be attributed to seven cost drivers:

1. R&D – public
2. R&D – private
3. Learning-by-doing
4. Financing costs
5. Economies of scale
6. Material costs & exchange rates
7. Other, including spillovers from other industries

We asked the leading offshore wind companies and their government counterparts to attribute cost reduction over the last decade to these seven drivers. They all agreed that the increase in size of the turbines was the single largest contributor to cost reduction. Interviewees then attributed turbine size differently across learning-by-doing, R&D (private) and economies of scale. We suggest that all three contributed to larger turbines. Furthermore, confidence in each generation/size of turbine also drove down finance costs. These cost drivers all feed into and from each other in a mutually reinforcing manner as illustrated in figure 3 below.



R&D

Predominantly private R&D incorporated learning from one generation/size of turbine into the next

Larger turbines in turn required R&D across balance of plant, installation and O&M technologies which, whilst still industry-led, benefited from some public R&D support

Learning-by-doing

Learning-by-doing gained through each successive generation/size of turbine

Economies of scale

Economies of scale are principally from the larger turbines, whose increase in size has delivered the greatest cost reduction, requiring half the installation and less balance of plant and O&M

Finance costs

Finance costs have plummeted as the industry has achieved scale and confidence in each generation/size of turbine and its associated installation and operation

Figure 3 Cost drivers and their role in each generation/size of offshore wind turbine

Beyond larger turbines there were a number of other key contributors to cost reduction as the industry matured. Our assessment by each cost driver is summarised below.

R&D (public & private)

Larger turbines have mainly been developed through commercially-funded new product design, testing, and increasing fabrication and manufacturing scale. The development of direct drive turbines represents a more fundamental change in turbine design and required more R&D. R&D, part-funded by the Government, has also been critical to the development of new balance of plant technologies. It supported important innovations in jacket foundations, suction buckets, access vessels, and floating LiDAR. R&D has also been critical to setting new standards that have in turn led to cost reduction; monopile foundations and 66kV cables are two key examples.

Learning-by-Doing

There are at least three ways in which learning-by-doing has driven cost reduction. Firstly, successful design, manufacture and deployment of each generation of wind farm, particularly each generation of turbine, has generated the learning and associated confidence to move rapidly to the next generation. Secondly, greater certainty has led to lower contingencies and associated cost margins. Thirdly, the supply chain has improved productivity through learning-by-doing, particularly in better and faster installation. Learning-by-doing was also cited as having supported UK companies taking an increasing role in the offshore wind supply chain and the clustering of industry.

Economies of Scale

Although increasing deployment, project size and long-term security of demand has allowed component manufacturers to offer bulk-buying discounts, economies of scale have largely been achieved through the development of increasingly large turbines. Wind farms that use larger turbines require half the installations, fewer balance of plant components, and less downtime for operations and maintenance (O&M). 50% of levelised cost of energy (LCOE) cost reduction in coming years is expected to come from the scale-up from 8 MW to 12 MW turbines.

Financing Costs

As the industry learned from experience, major risks such as extended installation time, low turbine availability, and high O&M requirements became better managed. This reduced the risk profile of the investment and the returns required by investors. The WACC[6] offered to developers has reduced from over 10% in 2010 to below 7% by 2020. This has had a significant impact on cost reduction; a 1% reduction in the WACC reduces the LCOE by approximately 7%[7].

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[6] The weighted average cost of capital (WACC) is the average rate that a company pays to finance its assets

[7] (BVG Associates, 2020) (Charles River Associates, 2018)

Policy accelerated the innovation that drove cost reduction

Technology-push policies supported R&D the early development of offshore wind in the UK, but it has been demand-pull policies that created a viable UK offshore wind market by driving cost reduction over recent years, through their impact on the functions of the offshore wind innovation system. Interviewees attributed 80.5% of cost reduction to demand-pull policies, 12.5% to technology-push, and 7% to non-policy factors. The most significant policy instruments for UK offshore wind have been the Renewables Obligation (RO) and Contracts for Difference (CfDs).

Government commitment enabled investment and growth

The UK government has made a visible, long-term commitment to offshore wind, manifested most recently in four rounds of CfDs over the last seven years. Prior to CfDs, the RO gave industry the right level of support to commercialise an emerging technology. The transition between the RO and CfDs did create a hiatus that created supply chain shocks and some cancelled projects but, overall, policy stability and clear government commitment has given industry the confidence to make large-scale investment.

Competition has driven down cost, but change is needed to support disruptive innovation

The CfD auction mechanism has driven intense competition and this has created significant cost reduction as developers now compete on price. This cost pressure has driven incremental innovation but has arguably not supported more disruptive innovation. Less mature technologies, such as floating offshore wind, will be necessary to meet long-term decarbonisation goals; the government is currently consulting on a mechanism within CfDs to ensure floating wind can access support whilst maintaining the element of competition[8].

The right policy at the right time helped a market to form

Both the RO and CfDs have played an important role in enabling the UK market to form. The RO, through a generous and stable level of subsidy that adapted to the maturity of different technologies, gave early investors confidence and kick-started the market. CfDs took that legitimacy and confidence and introduced competition to grow the market and reduce costs.

A strong project pipeline has strengthened the supply chain

CfDs have generated a strong pipeline of projects, further strengthened by the 2019 Offshore Wind Sector Deal, which includes a commitment to CfD auction rounds every two years until at least 2030. This pipeline has enabled the supply chain to prepare and scale up as they have visibility of developments several years ahead. It has enabled the growth of the UK offshore wind workforce, both in terms of size and skills. This has attracted investors, who see a pipeline of increasingly low-risk projects.

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[8] (Department for Business, Energy & Industrial Strategy, 2020)

Knowledge development has been good, but more fundamental innovation is needed

Both the RO and CfDs have effectively supported knowledge development. The RO created space for the early knowledge development and fundamental innovation necessary for an emerging technology and industry. CfDs then forced developers to seek a competitive edge, which they have partly achieved through knowledge development. As mentioned above, CfDs have not supported fundamental innovation and the newer technologies that will be necessary to meet UK decarbonisation targets, but proposed changes to CfDs should address that.

Knowledge sharing has decreased, but good examples still exist

Knowledge sharing has decreased with the competition generated by CfDs, but there are still pockets of cooperation. The Offshore Wind Accelerator (OWA) brings together nine offshore wind developers collaborating on innovation to achieve cost reduction, whilst still competing against one another in the market. Since 2008, the OWA has enabled research across thematic research areas in access systems, cable installation, electrical systems, foundations, wake effects and wind resource, as well as undertaking a number of discretionary projects[9].

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[9] https://www.carbontrust.com/our-projects/offshore-wind-accelerator-owa

Introduction

A history and analysis of cost reduction in UK offshore wind

In just ten years the UK offshore wind industry has developed from being highly dependent on a significant level of public subsidy, to being able to provide renewable electricity at a price lower than its fossil fuel counterparts, and will soon become an active contributor to the public purse. Policy effectively created the UK offshore wind market and stimulated substantial innovation; this report aims to understand how that was achieved. Whilst there have been bumps in the road, the story is one of a stable but progressive and adaptable policy regime that gave the right kind of support at the right time to allow the industry to commercialise and grow.

BEIS and the FCO commissioned this report to demonstrate the impact that well-structured policy measures can have on innovation and cost reduction. The UK experience with offshore wind presents compelling evidence that government policies to stimulate a market for new, initially expensive, technologies can drive deployment and subsequent innovation leading to substantial cost reduction that may not otherwise have materialised. This has significant implications for policymakers in a number of sectors where technologies that would work towards achieving societal goals, such as decarbonisation, are in development, but remain immature and more expensive than the incumbent.

This report aims to set out how policy developed over the last ten years, focusing on how the policy framework created a ‘demand-pull’ for offshore wind. It seeks to analyse the ways in which such policy impacted the innovation systems that enabled substantial cost reduction over this period, drawing on an extensive programme of interviews with key industry players and policymakers in the UK.

UK and Japan energy innovation dialogue

This report was inspired by an ongoing policy dialogue between the UK and Japanese governments. In parallel to this report, the Japanese Ministry for Economy, Trade and Industry (METI) commissioned an investigation into the impact of Japanese energy efficiency policy, namely the Top Runner programme. This research has been carried out by the Institute of Energy Economics, Japan (IEEJ). Throughout this project there has been a close dialogue between the Carbon Trust, UCL, BEIS, FCO Japan, METI and IEEJ, and this report is accompanied by a Joint Conclusions Report that summarises the outputs of that cooperation.

There is significant interest in the UK in the success of energy efficiency policy in Japan, and there is huge potential for the development of offshore wind in Japan. The Carbon Trust is already cooperating with a number of Japanese partners to bring UK offshore wind experience to Japan, and Japanese investors and utilities have been active in the UK offshore wind market for some time. Both the UK and Japan have an interest in floating offshore wind; in the UK in order to increase capacity beyond what can be achieved through fixed offshore wind, and in Japan due to the nature of the continental shelf.

The future of offshore wind in a post-Covid world

This report has been written as the Covid-19 pandemic has unfolded. At a time when a global recession is forecast, the question of how it will impact on the future of offshore wind naturally arises. The prospects for offshore wind, and other low carbon infrastructure, are likely to withstand the impending economic turmoil; private capital will still be looking for a safe home, and offshore wind will continue to offer a stable and reliable return. The nature and extent of economic stimulus packages, beyond the immediate support, is yet to be determined. Nevertheless, whatever these packages contain, the status of offshore wind as a safe investment is likely to remain unchanged.

Carbon Trust and UCL partnership

The Carbon Trust has unparalleled experience in UK offshore wind, having run the Offshore Wind Accelerator since 2008 and having produced a number of key reports for the sector. The Carbon Trust's mission is to accelerate the move to a sustainable, low carbon economy. It is a world-leading expert on carbon reduction and clean technology. As a not-for-dividend group, it advises governments and leading companies around the world, reinvesting profits into its low carbon mission.

For this report we partnered with the UCL Institute for Sustainable Resources (ISR), part of the Bartlett School of Energy, Environment and Resources (BSERR). The ISR is a world-leading centre of research and teaching on some of the major challenges facing societies today, including climate change, resource efficiency, environmental protection and sustainable development.

Report structure

The main report is structured into two parts:

Part A gives the context for policy and cost reduction, including details of the major policies to have impacted on innovation and cost reduction since the first Crown Estate leasing round in 2001, and a summary of the key cost reduction components.

Part B is an analysis of cost reduction drivers and the functions of innovation systems, exploring how the cost reduction described in Part A was achieved, and how policies interacted with the functions of innovation systems to bring about cost reduction.

Methodology & Analytical Frameworks

Stakeholder interviews, literature, and data analysis have been used to investigate how demand-pull policy stimulated innovation in the offshore wind industry in the UK over the last decade, and how this innovation led to the substantial cost reductions experienced. This section presents the methodology used.

The methodology draws on two analytical frameworks adapted from academic literature. The first categorises the drivers of cost reduction and the second categorises different functions of innovation systems.

Cost Reduction Drivers

This work conceives cost reduction in offshore wind to be the result of seven categories of drivers, as presented, along with examples that fall under these categories, in

Table 1 below[10]. These drivers are examined further in the 'Cost Reduction Drivers' section, on pg.7

Cost Driver	Examples of Cost Driver
1. R&D (public)	– Direct funding for technological development from public sources – Direct funding for technological development from private sources (e.g. developers)
2. R&D (private)	
3. Learning-by-doing	– Greater experience and confidence from contractors – Less conservative pricing strategies
4. Financing costs	– Offshore wind now considered a bankable asset class – Lower risk perception leading to preferential lending rates (lower WACC) – Innovative financing models, including a more diverse range of investors
5. Economies of scale	– Larger turbines – Larger individual projects – Larger project portfolios – Project clusters – Cumulative market size – Industrialisation and standardisation – Higher buying-power for some key players – Greater manufacturing capacity
6. Material costs & exchange rates	– Low steel and oil prices – Less competition from other sectors (e.g. downturn in vessel activity for oil and gas)
7. Other	– All other drivers such as location and spillovers[11] adopted from other industries

Table 1 Cost Drivers

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[10] Adapted from Kavlak *et al* (2018)

[11] Spillover – knowledge or technology taken/adapted from other industries, e.g. vessels used in the oil and gas sector for construction and O&M being used on offshore wind farms

Innovation Systems

In order to analyse the impact of policy on innovation within the offshore wind industry, the entire Technological Innovation Systems (TIS) must be considered.

Every TIS is composed of structural elements: actors, institutions, infrastructure[12], and their interactions. Each element's presence or absence and capability has an impact on how the TIS supports the entire technological transition. Taking an innovation systems approach allows for an analysis of innovation beyond R&D[13], and into demonstration and deployment.

Functions of Innovation Systems

The operation of the innovation system for a particular technology or industry, and different influences upon it, may be analysed through key system 'functions'. Following Reichardt *et al* (2016), which examined the influence of policy on innovation in offshore wind in Germany, we draw on the seven functions of innovation systems proposed by Hekkert *et al* (2007).[14] However, for purposes of practicality, we condense these seven to five, as presented in

Table 2.

Function	Definition
1.Goal-setting[15]	The processes that lead to a clear development goal for the new technology, based on technological expectations, articulated user-demand and societal discourse, enable selection, which guides the distribution of resources.
2.Market formation and creating legitimacy	The framework of incentives and conditions for actors to commit to the new technology and execute investments, take adoption decisions, etc.
3.Resource mobilization	The financial, human and physical resources necessary for all activities in the innovation system.
4.Knowledge development	Mechanisms of learning with knowledge as a fundamental resource. This includes experimentation and production by entrepreneurs and their ability to turn the potential of new knowledge, networks, and markets into concrete actions.
5.Knowledge exchange	The exchange of relevant knowledge between actors in the system.

Table 2 Functions of Innovation Systems (adapted from Reichardt *et al*, 2016)

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[12] Infrastructure: physical, knowledge and financial components

[13] (Reichardt, Negro, Rogge, & Hekkert, 2016) (Wieczorek, Harmsen, Heimeriks, Negro, & Hekkert, 2012).

[14] (Hekkert, Suurs, Negro, Kuhlmann, & Smits, 2007)

[15] Experimentation and Guidance of the Search were merged into Goal-setting in this study

Interview questions

In order to assess how demand-pull policy influenced the functions of innovation systems, a set of diagnostic questions was developed.

Interviews were divided into three sections. The first addressed components of cost reduction and cost reduction drivers. Interviewees were asked to highlight the main developments that brought about cost reduction and then to attribute overall cost reductions to cost drivers.

The second section covered policy drivers and functions of innovation systems. A categorisation of policy design features was used to explore interviewees' experience with both the RO and CfDs, but has not been used as an analytical framework for the policy section of this report.

This section also addressed the functions of innovation systems. Some functions were merged in order to simplify the process for interviewees. The Creation of Legitimacy and the Market Formation functions were combined to give a single score, and Experimentation and Guidance of the Search were merged and re-named as Goal-setting. Interviewees were asked to give scores for both the RO and for CfDs.

The third section invited interviewees to discuss the interaction between cost reduction and the functions of innovation systems, and the influence of policy.

Part A: Context for policy and cost reduction in UK offshore wind

Policy Drivers

This study explores the impact of key policy instruments on innovation in the offshore wind industry in the UK, and how this innovation has produced the significant and rapid reduction in cost the sector has experienced. Policy instruments may be divided into two broad categories: 'technology-push' and 'demand-pull'.

1. **Technology-push** – policy instruments that seek to directly fund or otherwise incentivise research and development of new technological ideas and concepts, and drive the early development of these technologies towards demonstration and early commercialisation. Push instruments are used when the incentive for industry to drive such R&D investment themselves is minimal or absent, or the risks are too high. Key examples of such instruments are R&D tax credits, direct grants, prizes and matched equity funding.

2. **Demand-pull** – policy instruments that seek to incentivise and develop a market for a technology that may have been demonstrated, but has yet to become commercialised or achieve cost-competitiveness with incumbent technologies. Pull instruments encourage the (increasingly privately-funded) development of a nascent technology or industry. They induce learning, innovation and cost reduction as the technology deploys into real-world application, expanding from niche markets to widespread adoption. Demand-pull instruments may be 'broad', such as carbon pricing, or more 'targeted', such as feed-in tariffs, supplier obligations, or regulatory standards. This study focused on the role of 'targeted' demand-pull instruments.

The development and deployment of technologies to address the most urgent challenges we face as a society, such as renewable energy to tackle climate change, requires a policy framework that incorporates both technology-push and demand-pull instruments. Both are needed to shape innovation systems to successfully support technologies through successive stages of the 'innovation chain' (Figure 4). As Figure 4 illustrates, technology-push instruments are the dominant influence in 'pushing' technologies from the early stages of the innovation chain, whilst demand-pull instruments are dominant in 'pulling' them through the latter stages towards early and then widespread adoption.

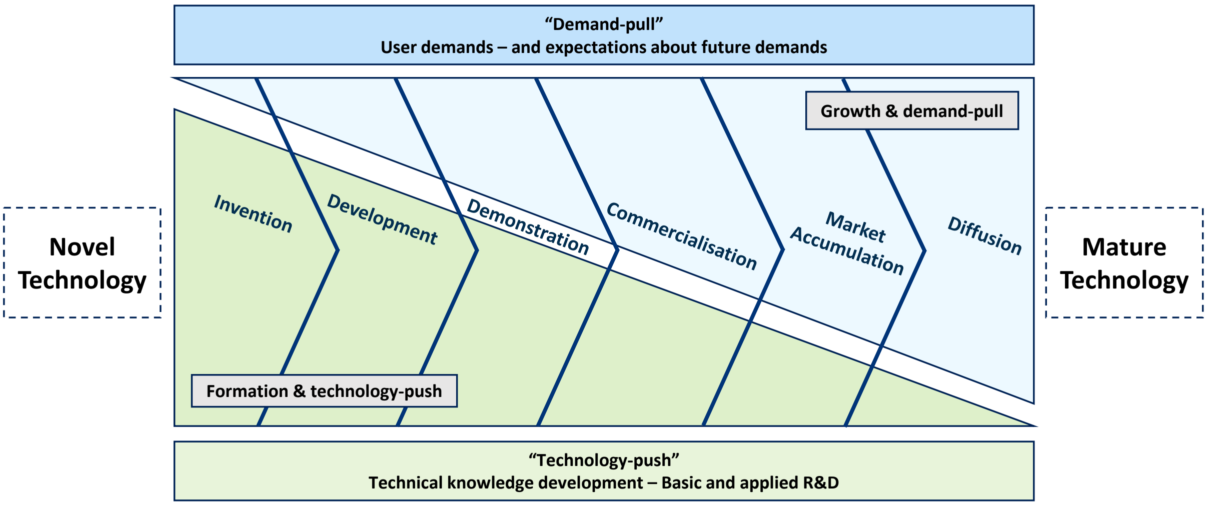

Figure 4 Technology commercialisation R&D pathway[16]

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[16] (Grubb, McDowall, & Drummond, 2017)

Technology-push instruments, such as the DECC Offshore Wind Component Technology Development and Demonstration Scheme in 2012[17], have played an important role in bringing down the cost of R&D in offshore wind, and will continue to have a role in supporting more fundamental innovation. However, it is the demand-pull instruments that established and shaped the market for offshore wind in the UK and that have had the greatest impact on innovation and cost reduction over the last decade.

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[17] This scheme aimed to reduce the cost of offshore wind energy by accelerating the commercialisation of component technologies. The objectives were to: (a) demonstrate component technologies for >5 MW; (b) provide support to the design and construction of new components; and (c) generate learning and practical experience that can improve innovation and drive cost reduction in offshore wind.

UK Offshore Wind – Key Demand-Pull Policy Instruments

A number of different types of policy intervention have been used to support the UK offshore wind market. The most significant policies have been incentive mechanisms, namely the Renewables Obligation (RO) and Contracts for Difference (CfDs). As well as providing an incentive mechanism, CfDs also include a requirement for larger projects to submit supply chain plans that promote skills and innovation. In addition to these incentive mechanisms there have also been several critical enabling policies, including the introduction of the Capacity Market, the unbundling of generation and transmission through the Offshore Transmission Owner regime, and the recent Offshore Wind Sector Deal. Crown Estate leasing rounds are not part of government policy as The Crown Estate is an independent commercial business created by an Act of Parliament, but leasing rounds have been a critical part of the policy landscape as they set many of the parameters within which wind farms can be developed in the UK.

This section looks at each critical policy instrument for innovation and cost reduction in UK offshore wind:

Cornerstone policies:

- The Renewables Obligation
- Contracts for Difference

Other enabling policies:

- Offshore Wind Sector Deal
- Crown Estate leasing rounds
- The Capacity Market
- Offshore transmission and the grid regime

Figure 5 shows the timeline for these instruments since the first Crown Estate leasing round in 2001.

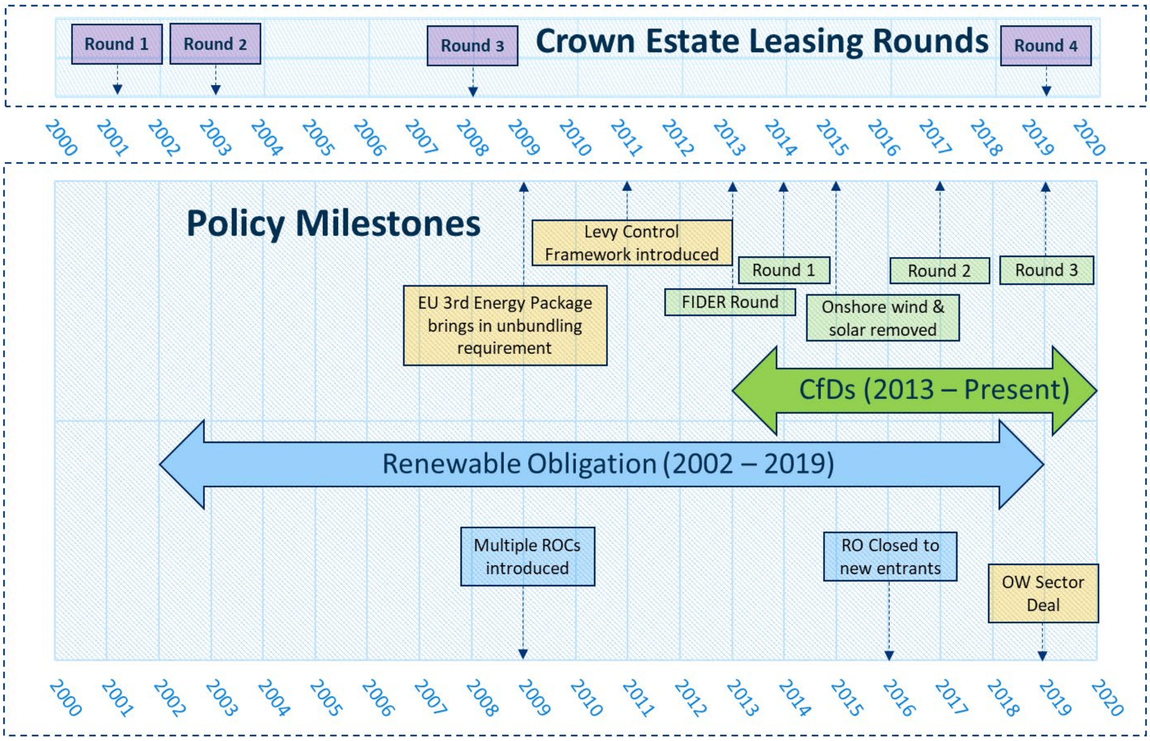

Figure 5 Timeline for key offshore wind policy instruments in the UK (2001-2020)

Renewables Obligation

The UK government introduced the Renewables Obligation (RO) in 2002 in order to incentivise renewable generation and meet their target of 10% renewable electricity by 2010. It followed the Non-Fossil Fuel Obligation (NFFO) and became the main incentive mechanism for large-scale renewable electricity generation in the UK.

The RO, now closed to new applicants, was administered by Ofgem. Energy suppliers were required to purchase a certain percentage of their electricity from renewable generation. In 2002 this was set at 3% but it had risen to 40% by 2018, just before the RO closed[18].

Ofgem issued Renewable Obligation Certificates (ROCs) to renewable electricity operators to match their renewable generation and the operators then sold the ROCs to suppliers or traders. If suppliers could not submit the required number of ROCs to meet the required renewables percentage, they had to pay the 'buy-out' price to Ofgem[19]. The buy-out price for the 2002-2003 obligation period was £30 per MWh and this has increased annually to be £48.78 by the 2019/20 period[20]

ROCs were traded on the open market, although the government ensured the price remained stable (see below), and had a value of around £45 per ROC. The generator received the value of the ROC on top of the wholesale electricity price. The number of ROCs per MWh generated depended on the type of generation technology and the date of commissioning. Under the RO,

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[18] (Ofgem, 2020)
[19] (Department of Energy and Climate Change, 2013)
[20] (Ofgem, 2020)

offshore wind farms receiving two ROCs per MWh (after multiple ROCs were introduced in 2009 – see below) typically received between £140 - £150 per MWh of energy generated.

The RO was not designed for offshore wind

When the RO was introduced in 2002, it was thought that it would support onshore rather than offshore wind, as onshore was already a relatively low cost and reasonably mature technology. However, planning issues, followed by a government moratorium, meant that the development of onshore wind farms did not progress as anticipated (the RO closed entirely to onshore wind generation in May 2016). This gave offshore wind a greater opportunity to access support because it was not competing with lower cost technologies.

Policy flexibility ensured the RO met its objectives

In order to avoid ‘picking winners’, the RO was initially technology-neutral, with each generator receiving one ROC per MWh produced. However, it became apparent that differentiation would be necessary in order to deliver a mix of renewable technologies with varied levels of maturity[21]. In 2009, the government began offering different numbers of ROCs to different technologies. Onshore wind received one ROC per MWh and fixed offshore wind received two ROCs per MWh[22]. Floating wind, which was far less mature than fixed, received 3.5 ROCs for 2014/15 capacity. However, only one floating wind demonstration project of 2 MW, Kincardine, was supported through the RO.

Scale and level of support got the offshore wind industry off the ground

The RO was unusual in that there was no overall budget cap, and no capacity cap. This meant that the only constraint was the amount of capacity that generators were able to bring forward. Ofgem also had a number of levers through which they could control the price of ROCs: they set the level of obligation on suppliers, the buy-out price, and also knew how many ROCs were in circulation at any given time. This enabled them to ensure the price of ROCs remained stable and at the Ofgem target price of around £45 per ROC, even though they were traded on the open market.

Exit RO, enter CfDs

The RO ceased to exist in 2019, after a six-year transition period when it overlapped with CfDs[23]. The transition created some uncertainty and slowdown in the market for around 18 months from when CFDs were first announced. This was due to uncertainty around exactly how CfDs would work.

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[21] (Woodman & Mitchell, 2011)

[22] (IRENA, 2014)

[23] (Bunn & Yusupov, 2015)

Contracts for Difference

The RO was successful in supporting the deployment of renewables during the early years of the offshore wind market in the UK. However, it was too costly to deliver the government's objective to support decarbonisation at the lowest possible cost to the consumer. By 2013, the government judged that the market for renewable technologies was sufficiently mature to introduce a more competitive approach. CfDs were introduced in 2013 and, apart from the Final Investment Decision Enabling for Renewables (FIDER) round in 2013 that accepted applications, used a competitive auction to create a lower cost mechanism to decarbonise electricity generation. CfDs were also intended to give greater certainty to investors as they were offered earlier in the project development process than ROCs[24].

CfDs give investors a guaranteed return

A CfD is a bilateral legal contract between a low carbon energy generator and a government-established company, the Low Carbon Contracts Company (LCCC). The contract guarantees generators a fixed 'strike price' for energy generation for 15 years, with the LCCC paying the generator the difference if the market reference price falls below the CfD strike price. Conversely, if the market reference price rises above the strike price, then the generator must pay the difference to the LCCC. As the strike price is typically fixed for 15 years, the generator can increase margins by reducing costs, or generating more electricity.

FIDER transition round sought to minimise uncertainty

Prior to the establishment of fully-competitive auctions, the FIDER round in 2013 was run as an application process. It was intended to support projects that were due to take final investment decisions during the transition period between the RO and CfDs, which might otherwise have been delayed or cancelled as a result of the transition. Eight contracts were awarded, five to offshore wind, representing 70% of supported capacity at 2.2GW. Agreed strike prices for offshore wind were between £140-£150 per MWh, a similar level of support to that provided by the RO.

Introduction of auctions introduced competition on price

In the 2014/15 allocation round, the auction mechanism was introduced. Developers were invited to submit sealed bids, including a proposed strike price, details on technology type, costs, capacity, and the project delivery year. In each auction, National Grid ranks all submissions in order of the strike price, regardless of the year they plan to start generating. Where the sum total of applications for each year exceeds the National Grid budget for that year (as has been the case in all three rounds to-date), then a competitive auction is held to allocate the contracts. The auctions have a 'pay-as-cleared' format, meaning that all successful bidders receive the same renumeration as that of the highest strike price.

The Levy Control Framework was introduced to control costs

Following a spending review in 2010, the government took the decision to introduce the Levy Control Framework (LCF) in order to control the costs arising from government levies for low carbon electricity support, since these costs would be passed on to consumers through energy bills. It came into effect in 2011/12 and set annual caps for levy-funded spending up to 2020/21. One motivation for setting a 10-year plan was to give investors confidence in the government's commitment to support low carbon generation.

The LCF cap covered the RO, which had no budget cap until its introduction, and CfDs. It also covered the Feed-in Tariff and Warm Home Discount scheme. The cap essentially sets the limit of

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[24] (Department of Energy and Climate Change, 2013)

how much capacity can be awarded under CfDs in each round because assumptions are made about the likely level of generation, strike prices and wholesale electricity price, and therefore what subsidy the government would be liable to pay.

Around 20% of UK consumer energy bills are made up of the cost of these levies, meaning there is significant political pressure to keep costs under control[25].

Offshore wind has dominated CfDs capacity

CfDs were originally intended to support established technologies such as onshore wind and solar PV, and less mature technologies including offshore wind, biomass and energy from waste with Combined Heat and Power, and tidal energy. However, in 2015 the government removed support for new onshore wind and solar PV installations, with the majority of the future budget directed to less mature technologies, and predominantly to offshore wind[26].

In Round 1 in 2015, two of the 27 contracts were awarded to offshore wind. At 1.2GW this represented 54% of supported capacity. Onshore wind, which was still eligible for CfDs at this time, accounted for the second-largest share of supported capacity at 34%, or 0.75GW. In subsequent rounds, the sheer scale of individual offshore wind projects meant that they dwarfed all other technologies. In Round 2 in 2017, three of the 11 contracts went to offshore wind, representing 96% of all newly contracted capacity, at 3.2GW. In Round 3 in 2019, six of the 12 contracts were awarded to offshore wind, accounting for 93% of the total 4GW of newly contracted capacity.

Supporting market formation with skills and job creation

The RO did not include any specific targets or support measures relating to offshore wind job creation or skills. However, CfDs introduced an obligation to submit a Supply Chain Plan for every bid over 300 MW of capacity. This plan must show how the project will promote competition, innovation and skills in the supply chain. Other policy initiatives to support skills development had also been introduced, including the Regional Growth Fund investment in the Green Port Hull initiative (which seeks to build on the presence of the Siemens Gamesa blade factory by supporting local employment and skills development).

However, until the Offshore Wind Sector Deal, there were no overarching targets for skills or job creation in offshore wind.

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[25] (Ofgem, 2020)
[26] (Welisch & Poudineh, 2020)

Offshore Wind Sector Deal

In November 2017 the government published its Industrial Strategy, focusing on four 'Grand Challenges': clean growth, ageing society, future mobility, and artificial intelligence and data. The strategy included a proposal for 'Sector Deals' as mechanisms to enable the government to support growth in the Grand Challenge industries by boosting productivity, employment, and innovation. Sector Deals have been agreed for artificial intelligence, automotive, construction, creative industries, life sciences, nuclear, rail, and offshore wind. The Offshore Wind Sector Deal sits within the Clean Growth Grand Challenge.

Commitment on funding and auctions to offer greater predictability

The Offshore Wind Sector Deal, agreed between the government and the offshore wind industry in March 2019, secured offshore wind's strategic position in clean energy provision in the UK. It aimed to provide forward visibility for the sector, setting a target of 30 GW of total capacity by 2030, and up to £557m for future CfD rounds across regularly scheduled auctions through the 2020s. This is intended to enable the development of supply chains, investment planning and realistic installed capacity targets that ensure UK offshore wind reaches its full potential[27].

The Sector Deal predicts that the domestic and export market for offshore wind is set to reach £4.9bn annually by 2030 and £8.9bn by 2050. There are enough confirmed and pipeline projects to meet the 30 GW by 2030 target, and the government's announcement of regular CfD auctions through the 2020s is designed to encourage investors to make a long-term commitment to the UK and invest in projects beyond the 2030s (Offshore Renewable Energy Catapult, 2019).

Local benefits will be targeted

In addition to setting capacity targets and creating visibility through regularly scheduled auctions, the Sector Deal also targets key opportunities for job creation and growth in domestic supply chains, stating that it aims to 'generate good jobs and greater earning power for all.' It includes a target to treble the offshore wind workforce to 27,000, increase local content to 60% and increase diversity to 40% female and 12% BAME (Black, Asian and Minority Ethnic) representation by 2030[3]. Key initiatives to meet these targets include:

- The establishment of an 'Investment in Talent Group', supported by skilled professionals who can identify needs across the sector and develop curricula and accreditation accordingly. This includes developing an Offshore Energy Passport (recognised internationally) to give offshore workers mobility between offshore renewables and oil and gas.
- Continuing to work with education institutions for post 16-year-olds and to support the development of sector-wide standardised curricula in Institutes of Technology.
- Expanding collaborations with universities to support research and create a highly-skilled RD&D workforce.

In March 2020, a year after the Sector Deal was agreed, a new target was set to employ 3,000 new apprentices. Apprentices will range from turbine technicians and maintenance engineers through to roles in management and finance.

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[27] (Offshore Renewable Energy Catapult, 2019)

Crown Estate leasing rounds

The Crown Estate is an independent, commercial business that manages almost the entirety of the seabed in the United Kingdom up to 12 nautical miles. It owns the rights to natural resources (excluding fossil fuels) and to generating electricity from wind, waves and tide on the continental shelf.

The Crown Estate has given offshore wind developers access to the seabed through four leasing rounds. Round 1 was launched in 2001 and was intended to act as a demonstration round, allowing developers to gain an understanding of the practicalities associated with developing offshore wind farms in the UK. The sites were selected by the developers. These projects were typically small-scale, with no more than 30 turbines, and were close to shore.

Round 2 was launched in 2003. Projects in this round were larger and generally further (8-13km) offshore. The combined capacity of Rounds 1 and 2 was around 8GW. Project extensions for Round 1 and 2 projects were awarded in May 2010.

Round 3 was launched in 2008 and saw the first large-scale developments. Rights to over 32 GW of capacity were awarded across nine zones. To-date, 24 GW of Round 3 projects are in development, a number of which are under construction or in operation. The Crown Estate invested over £80m of co-funding investment capital in Round 3, and also delivered a number of enabling actions[28].

Round 4 was launched in 2019, creating the opportunity for at least 7 GW of new projects. This ongoing round also includes a number of incentives for technical innovation, such as rental discounts for innovative projects, the opportunity for hybrid projects, opportunities for pre-commercial demonstration and testing, and work to identify suitable sites for innovative projects, including floating wind. It also includes an extension of lease terms from 50 to 60 years, meaning they now cover two full project lifecycles.

Round 4 also brings in requirements on data sharing. Developers will be required to participate in The Crown Estate's Marine Data Exchange (MDE), which stores, manages and shares offshore survey data collected by developers and operators. It includes information such as geophysical surveys, data on ornithology, benthic ecology, wind resource, and noise. Developers will also have to participate in the SPARTA offshore wind performance data benchmarking platform[29].

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[28] Strategic enabling actions aimed to advance the offshore wind evidence base and inform the future use of the sea-space. Themes included: improving understanding of environmental impacts; unlocking further deployment via the derogation process; better spatial planning and co-ordination of activities onshore and offshore; delivering net environmental gains.

[29] (Crown Estate, 2019)

The creation of the Capacity Market

The Capacity Market was created at the same time as CfDs as part of Electricity Market Reform[30]. Its aim was to ensure that there is always sufficient capacity to meet the UK's electricity needs during peaks in demand or other events. That capacity is provided through a combination of dispatchable power generation, demand-side response (where consumers reduce or shift their energy use to reduce peaks in demand), and energy storage (although applications from battery storage have reduced over time). The Capacity Market also opened to renewable energy in 2019, although there have not been any agreements to-date.

Applicants prequalify to take part in a Capacity Auction. As with CfDs, the auction mechanism is intended to ensure capacity is made available at the lowest possible cost to consumers. Successful bidders enter into a Capacity Agreement, which obligates them to ensure capacity can be made available when necessary.

It was seen as crucial complementary legislation to CfDs as increasing offshore wind capacity in the energy system also increases the challenge of intermittency in generation.

Offshore transmission assets and the grid regime

Around 10-20% of the total cost of a typical offshore wind farm in the UK is made up of the transmission assets: the onshore and offshore substations and the export cable linking them. As wind farms get larger and further from shore, the cost of the transmission assets increases. There is a significant range in the costs, from projects such as Barrow at £34m and Robin Rigg at £66m, to Race Bank and the Walney Extension at £500m. Transmission assets are costly but low-risk once they are installed and operational.

The EU Third Energy Package of 2009[31] required transmission and generation assets in EU member states to be 'unbundled' – meaning they could no longer be under the same ownership. This meant that existing wind farms connecting to the onshore grid at a voltage of 132kV or above had to sell off any transmission assets they owned. Ofgem introduced a competitive tendering process to award Offshore Transmission Owner (OFTO) licences in order to drive costs down through competition. In fact, there was little or no reduction in operational costs as the asset owners who won the OFTO licences often subcontracted the operation and maintenance back to the wind farms.

However, the separation of the lower-risk transmission assets from the higher-risk generation assets did drive a reduction in the cost of capital for the transmission asset element of the project. Separating the transmission owner's revenue risk from the state of the turbines, the wind, or any other aspect of generation, removed a significant element of risk for investors.

Ofgem also designed the regime so that the OFTO would receive their revenue from National Grid, not the wind farm, so that a much larger and more stable company would provide the revenue.

In theory, the transmission assets can be built and installed by either the wind farm developer or the OFTO. The choice sits with the wind farm developer and in the UK they have so far consistently chosen to build the transmission assets themselves.

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[30] The EU Third Energy Package came into force in 2009 and covered the following five areas: unbundling, independent regulators, ACER, cross-border cooperation and open and fair retail markets

Cost reduction: the strike price & levelised cost of energy

"Anyone that says they weren't surprised by the price reduction is lying" – industry source

In 2011, the Offshore Wind Cost Reduction Taskforce was convened to recommend actions to increase deployment and reduce costs for offshore wind in the UK. The Taskforce reported in 2012, setting a target cost of £100 per MWh by 2020. The CfD Round 2 auction for projects due to start generating in 2021/22 saw offshore wind strike prices of £57-74 per MWh. Strike prices in the Round 3 auction were even lower, falling to £39-41 per MWh for offshore wind farms going online in 2023.

However, the strike price only shows what the generator is paid; it does not reveal the actual cost of producing electricity, most commonly measured by the Levelised Cost of Energy (LCOE) [32], or the subsequent profit margin generated (the difference between the LCOE and the strike price). Figure 6 compares selected strike prices from each allocation round with industry estimates[33] of the LCOE. As shown by the LCOE trend, the cost of generating electricity is set to fall by over 65% between 2015 and 2023, from £120/MWh to around £40/MWh. If realised, this represents a significant cost reduction.

Figure 6 illustrates another trend; the difference in strike price and the range of predicted future LCOEs, and thus profit margins for developers, is set to continue to decrease. At the beginning of the decade developers had higher margins to account for uncertainty, and also as a result of inefficient contracting structures. The industry is evidently becoming more certain in its abilities, can accept the risk of smaller revenues, and anticipates achieving further cost reduction in coming years. Indeed, the £39/MWh strike prices of Round 3 are below the average LCOE estimates from 2023 onwards.

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[32] LCOE is defined as the discounted lifetime cost of ownership and use of a generation asset, converted into an equivalent unit of cost of generation (£/MWh) (Department for Business, Energy and Industrial Strategy (BEIS), 2016). The LCOE metric gives an indication of the unit energy cost over the lifetime of a project, including the capital, operative, and financing costs (Aldersey-Williams & Rubert, 2019). As LCOE considers all key costs associated with installing and operating an installation as a ratio to all the electricity it is likely to generate across its lifetime, it is an effective metric for analysing the impact that policy and innovation have had on cost reduction.

[33] As the LCOE considers all project costs it is uncommon for developers to publicise commercially-sensitive LCOE data. However, a number of studies have modelled LCOE for current and planned offshore zones referenced in this work. (BVG Associates, 2019).

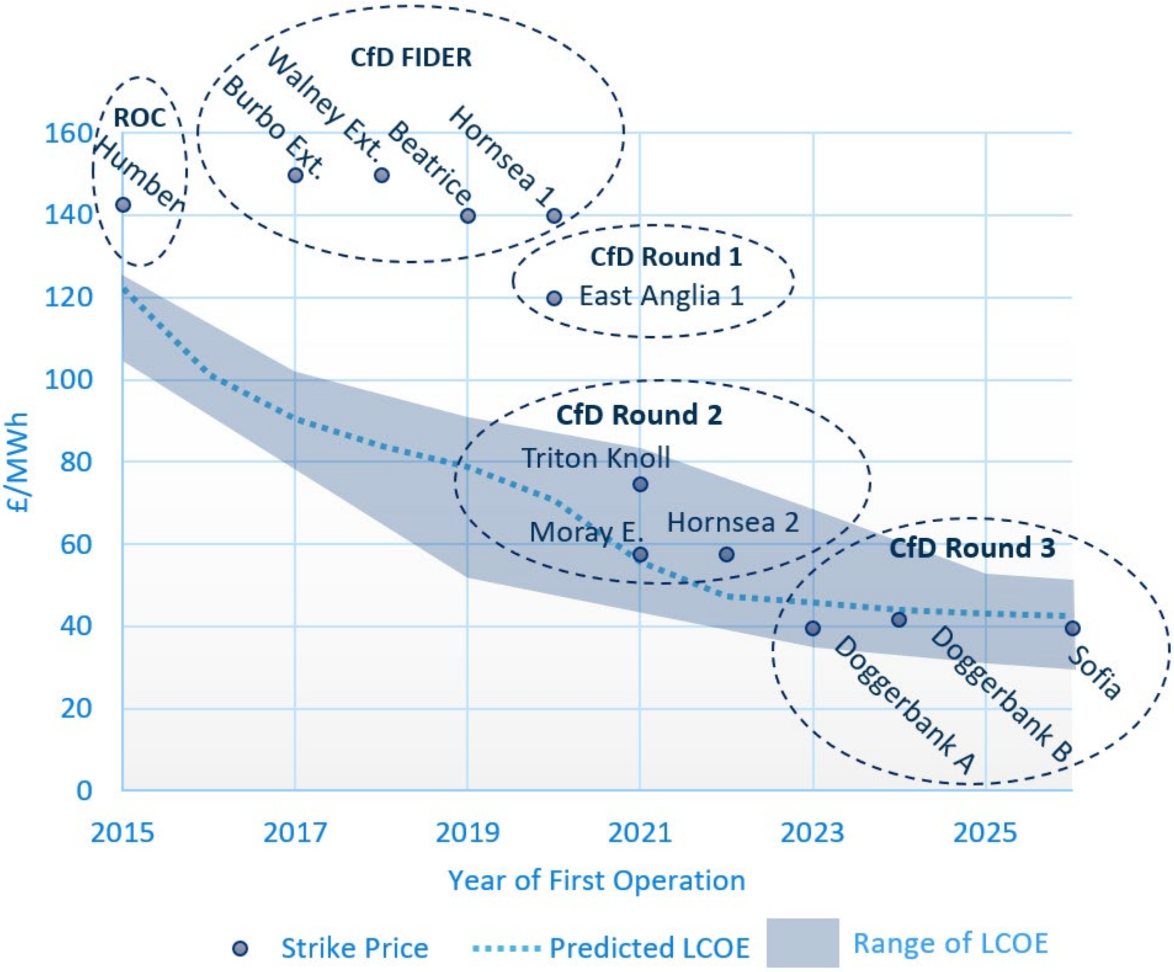

Figure 6 Estimated LCOE of Operation Wind Farms (Dark Blue) and Predicted Average LCOE for Round 3 Offshore Zones (Light Blue)[34]

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[34] (Offshore Renewable Energy Catapult, 2019) (4COffshore, 2019) (BVG Associates, 2019) (Carbon Trust analysis)

Components of Cost Reduction

The costs of installing and operating an offshore wind farm can be divided into five components: turbines, project development and management, balance of plant, installation and commissioning, operation and maintenance (O&M), and cost of capital[35]. Drawing on both a literature review and stakeholder interviews, this section analyses which of these components have reduced between 2010 (for wind farms constructed up to 2015) and 2019 (for wind farms constructed up to 2025), by how much, and why.

As turbines have increased in size and the design and operation of wind farms have improved, the cost of generating electricity has reduced. As illustrated by Figure 7, project costs[36] for offshore wind installations have reduced from approximately £4m/MW in 2010 to £2.5m/MW in 2019[37]. The increase in turbine size has had by far the greatest impact on those cost reductions. With the completion of the Round 3 CfD auction, the industry is now preparing for a further scale-up from 8 MW to 12 MW turbines, which is set to account for 50% of predicted LCOE reductions in coming years[38]. Planned further increases in turbine size will drive costs down even further. In turn, larger turbines have reduced the cost of other components. This is primarily because a wind farm where half the number of turbines are needed to generate the same capacity also only needs half the installations, fewer balance of plant components, and less downtime for O&M.

Improvements in development processes, enabled by technical developments in turbines, balance of plant, and O&M, have contributed to driving up the average capacity factor[39], which has had a significant impact on the revenue a wind farm can generate. Indeed, average capacity factors have increased from below 35% in 2009 to 45% in 2020 and are expected to increase further[40]. Larger turbines also increase the capacity factor; factoring in both improvements in development processes and the move to 10 MW and 12 MW turbines, capacity factors of new wind farms are expected to be greater than 50% by 2021[41].

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[35] Within this analysis the cost of capital and improvements to capacity factors are assumptions built into the BVG cost model
[36] Cost reduction figures are indexed to 2019
[37] The specific costs of wind farms are highly project-specific; these figures are estimates of industry trends
[38] (Charles River Associates, 2018)
[39] The capacity factor is the proportion of energy generated over a period compared to maximum possible output
[40] (Boccard, 2009)
[41] (DNV GL, 2019)

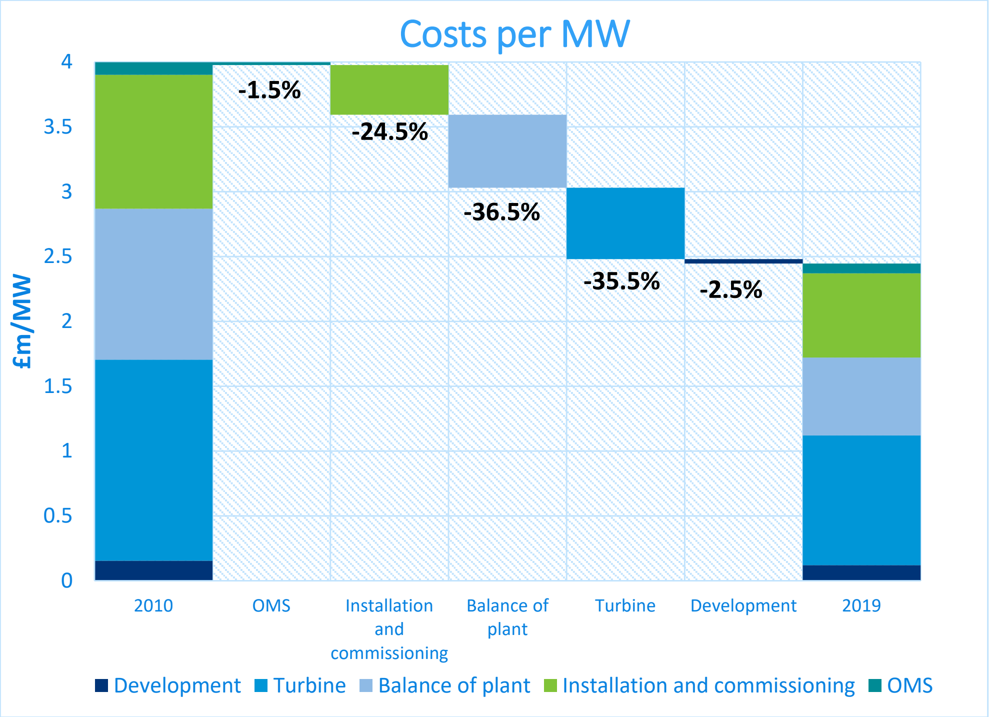

Figure 7 Project Costs per MW, £m/MW (prices indexed to 2019)[42]

Turbines[43]

The turbine manufacturer is at the core of bringing a wind farm together. As the number of turbines per wind farm is approximately proportional to the installation, balance of plant and O&M costs, any changes to the turbine have implications for all other costs. With increasing turbine size, the number of turbines per wind farm decreases, and so do the number of installations and vessel transfers required[44]. For example, Scroby Sands uses 2 MW turbines. Installing 60 MW of capacity with 2 MW turbines requires 30 individual monopile and turbine installations. Doggerbank A will use 12 MW turbines, so installing 60 MW of capacity requires only 5 installations. Furthermore, as there are fewer turbines per capacity of wind farm, there is less overall downtime for maintenance.

As shown in Figure 8, the UK offshore wind sector was built on a foundation of 2-4 MW turbines, which was standard for onshore turbines at the time. The average size of operational offshore turbines in the UK is now around 6.8 MW, and this is expected to progressively increase. The average size of new turbine installations is expected to be around 17 MW by 2026[45] and many sites in the pre-construction stage are now looking to extend consent orders to accommodate 20 MW turbines. This increase has been driven by incremental R&D development, economies of scale and, more recently, increased competition[46]. General Electric's entry to the market following the Round 3 auction has increased competition and Doggerbank will use their Haliade-X 12 MW turbines, which are currently the largest in the world.

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[42] (BVG Associates, 2010) (BVG Associates, 2019)

[43] The turbine represents the biggest cost component within an offshore wind project. Quoted costs consider the components, assembly, and turbine supplier aspects of installation, commissioning, and warranty. Supplying turbines involves the manufacture, assembly, and system level testing with all other wind turbine components such as the nacelle, rotor and tower.

[44] Turbines require regular operative works performed by personnel transferred on vessels from land. With increasing turbine size, wind farms require fewer vessel transfers per turbine.

[45] (4COffshore, 2020)

[46] (Carbon Trust, 2020)

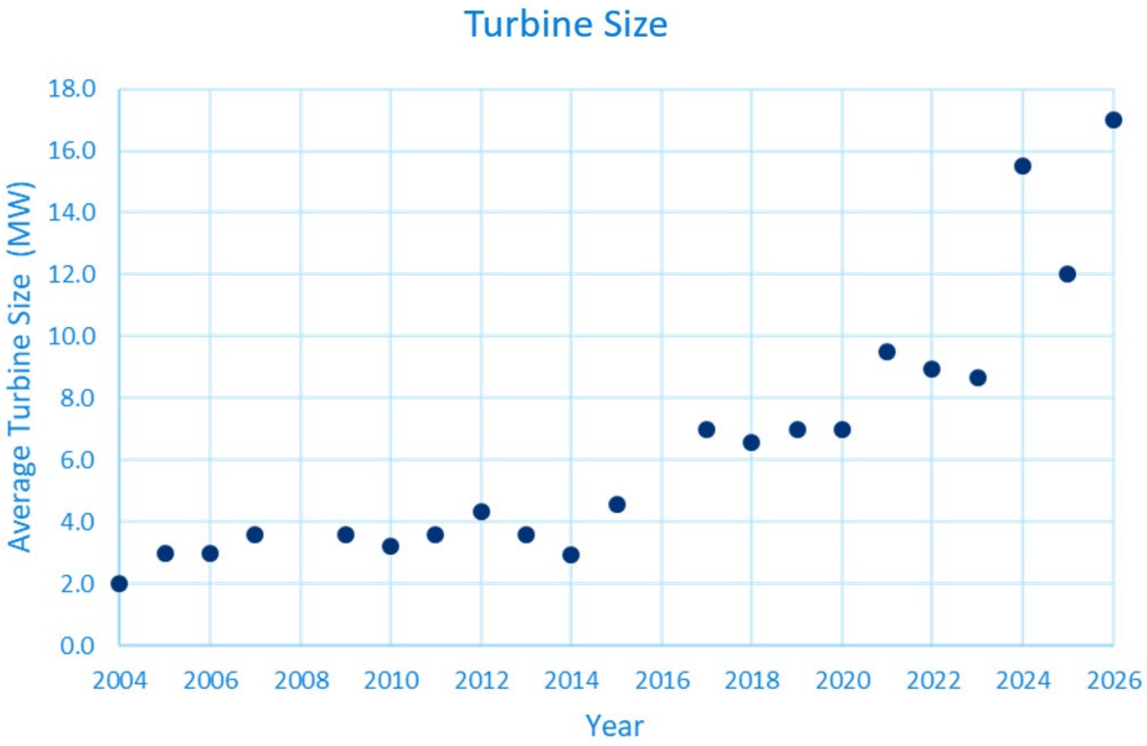

Figure 8 Average Turbine Size (MW) for UK Offshore Wind Farms[45]

The average capital price of a wind turbine has reduced in recent years, from £1.55m to £1m per MW, as shown in Figure 9 below. The rise in cost between 2004 and 2008 was partly due to a lack of competition, partly to limited supply chains, and also partly to the small market size. As the market began to grow, the price began to fall and had reduced again by 25% between 2008 and 2010[47].

Direct drive turbines, although more expensive than the standard gearbox design, are expected to have lower installation and operating costs and are now increasingly prevalent. [48] Due to the growing market, the volume of sales is driving costs down.

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[47] (BNEF, 2018)

[48] This cost saving is achieved through the medium voltage system and converter being enclosed in the nacelle. This enables pre-commissioning testing onshore which is safer and faster thus reducing risk and cost.

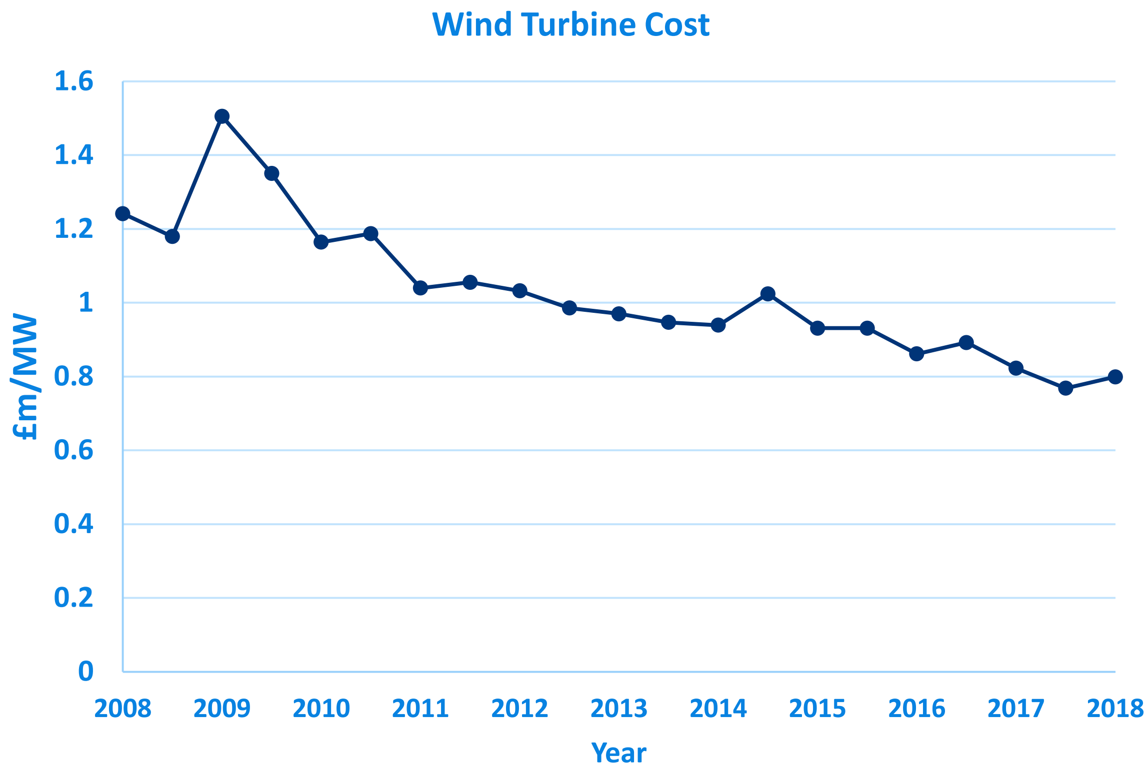

Figure 9 Wind Turbine Capital Cost, £m/MW (BNEF, 2018)

In 2010, the market was dominated by Siemens and Vestas who were both headquartered in Denmark and did not have a base in the UK. There were concerns in the industry that the availability of sufficient turbines and the low number of suppliers could hinder a competitive environment[49]. Furthermore, the supply capacity for large components and assembly in the UK was not located or clustered in coastal areas. The government sought to address this issue by opening discussions with wind turbine manufacturers on establishing coastal nacelle assembly facilities. Government took the view that, although the assembly cost is low compared to overall project costs, the impact of local industry creation on smaller suppliers would be significant[50].

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[49] (Carbon Trust, 2016)
[50] (BVG Associates, 2010)

Project Development and Management[51]

Development costs are estimated to have reduced from around £155,000 to around £120,000 per MW between 2010 and 2019. In 2010 there were concerns that costs would increase due to development in ever deeper waters and a lack of the necessary expertise. A buffer on project costing was consequently applied to account for uncertainty. The industry soon found that it could operate effectively in the previously unfamiliar offshore environment and the buffers were removed in subsequent bids. Furthermore, UK companies were not well-integrated in supply chains and were not located or clustered in coastal zones. Again, this meant that buffers had to be applied and that were subsequently removed once the industry developed.

Balance of Plant[52]

The cost of balance of plant reduced from around £1m to around £600,000 per MW between 2010 and 2019[42]. The greatest costs in balance of plant come from cables and foundations[42], both of which have seen cost reduction through innovation over the last decade.

Cables have seen cost reduction from over £190,000 to £170,000 per MW[42]. Array cables in particular have benefited from R&D and economies of scale over this period and have reduced from over £45,000 per MW to £35,000 per MW. This has partly been driven by the move to 66kV cables. The first generation of offshore wind farms deployed 33kV cables but, when turbines increased above 6 MW, 66kV became more cost-competitive as the high voltage enabled more capacity per string. This in turn reduced the total cable length required.

The foundation supports the wind turbine and transfers the loads from the turbine to the sea bed. The foundation also houses the cables and provides access from vessels. In 2010 foundations cost over £700,000 per MW[42]. They now cost between £280,000 and £350,000 per MW for 30m and 40m depths respectively[42]. Early foundations tended to be over-engineered and optimised designs now use significantly less steel per MW, reducing material costs. It was also found that they didn't need to be driven as far into the seabed as was initially thought, which also reduced costs.

To-date, over 80% of offshore wind turbines use monopiles. Jackets account for another 15%, followed by gravity bases[53]. For currently operational turbines, monopiles require more steel but are cheaper to manufacture and install in volume. Jackets become cost-competitive when used in depths from 45m – 60m, where seabed conditions are particularly uneven or complex. They are also more advantageous when using turbines above 10 MW due to their ability to meet natural frequency requirements[54]. For water depths above 60m, floating foundations are expected to be the most cost competitive and are set to reach commercial deployment in the mid-2020s.

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[51] This includes all services up to construction, including site and environmental surveys, development and consent services, site investigations and project planning. It also includes all project management services for the project throughout the lifetime of the assets.

[52] This includes all wind farm infrastructure that is not a component of the turbine, for example, electrical components and structures, subsea cables for inter array and export, offshore substation equipment, steelwork, turbine foundations, and substation structure supply.

[53] A typical monopile foundation is composed of a single steel tube. A jacket foundation comprises a space frame structure assembled from steel tubular members. A gravity-based foundation is a reinforced concrete caisson structure.

[54] The natural frequency of the hub-tower-foundation system is the fundamental feature on which the response of a wind turbine to wind and wave loads depends. This is due to the dynamic nature of the loads on the wind turbine structure and the general thinness of the system.

Installation and Commissioning[55]

As shown in Figure 7, installation and commissioning costs reduced from around £1m/MW in 2010, to around £650,000/MW in 2019[42].

In 2010 the industry suffered from a lack of suitability and availability of installation vessels, increasing both risk and project costs. Bottlenecks and delays to construction work were a key concern. In some cases, the pool of suitable and available vessels was as small as one, with others being in use by the oil and gas sector. Limited availability resulted in inflated charter rates and meant that vessels were often not suited to the specific operations in which they were employed[56].

As the offshore wind sector developed, the industry began to create bespoke vessels that could perform offshore wind-specific operations more regularly and efficiently. Coupled with ever-increasing turbine sizes, this required less labour and vessel time per MW, and installation times began to reduce. Figure 10 shows that average times for turbine installations have reduced significantly. Between 2008 and 2017 the per MW installation time reduced from 2.9 to 0.5 days. Over the same time the average size of installed turbines increased from 2.5 to 7.4 MW.

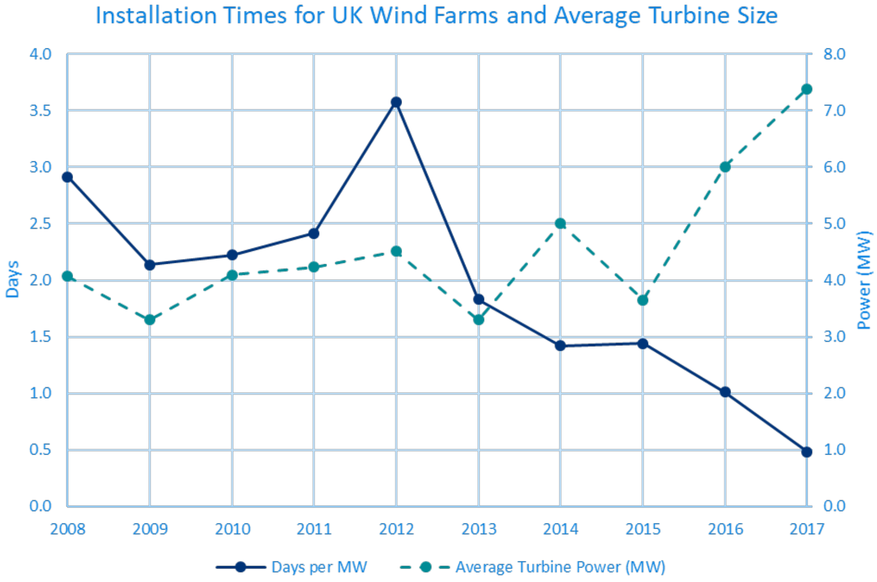

Figure 10 Installation times (days) for UK Offshore Zones[56]

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[55] This cost category includes the installation and commissioning of all balance of plant and turbines (not including installation work exclusive to the turbine supplier). Installation typically takes 3 years and occurs in the following sequence: Onshore substation and onshore export cable, foundations Offshore substations, Array cables, Offshore export cables, and Turbines (Paterson, Amico, Thies, Kurt, & Harrison, 2018).

[56] (Lacal-Arantegui, Yusta, & Dominguez-Navarro, 2018)

Operation and Maintenance[57]

The focus of O&M activity is to maximise returns from investment by optimising the balance between operational costs and energy yield. O&M costs have decreased over the last decade from over £90,000 to around £75,000 per MW. The scale-up of turbine size has been attributed to 60% of O&M savings, largely due to improved turbine availability[58] as turbines can now operate for longer without the need for maintenance. This has been enabled through optimised designs, planning of logistics, and access improvements42. Availability is now between 95 and 98%.

The greatest cost component of O&M is the control of operations, including training, onshore and offshore logistics, support and management, overheads, and health and safety. New technology, such as use of drones, is allowing operators to work remotely, reducing the need for vessels and reducing health and safety costs. Drones could cut offshore wind inspection costs by over £750 per turbine per year according to BNEF[59]. Furthermore, data analytics is increasingly being used to reduce logistics costs and improve plant availability. As the industry develops and accumulates more data (e.g. through the SPARTA platform, described in 'Economies of Scale' on page 8), O&M costs are set to further reduce. As shown in Figure 11, average personnel transfers per turbine per month fell by 40% between 2014 and 2019.

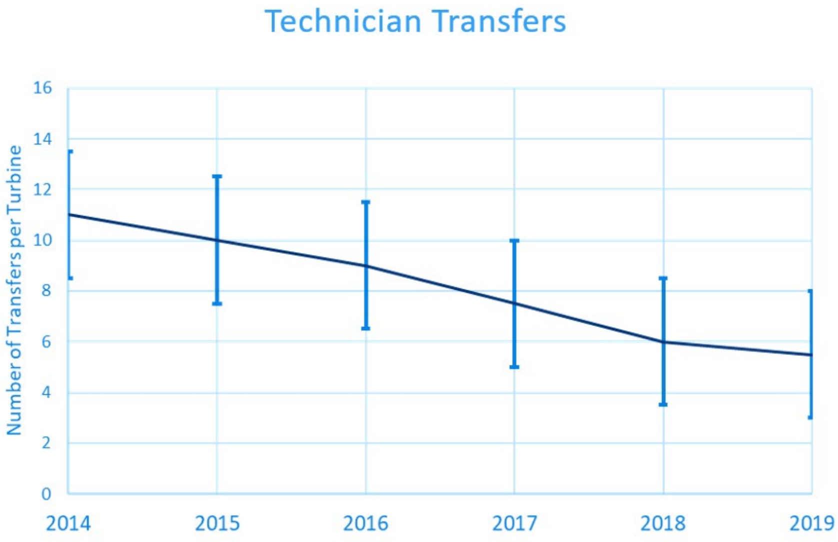

Figure 11 Technician Transfers Per Turbine[60]

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[57] O&M comprises all actions that support the ongoing operation of the turbines, balance of plant, and transmission assets. These actions are considered to commence following construction.

[58] Turbine availability - percentage of time when wind speed is within operational range and the turbine is ready to produce power

[59] (BNEF, 2018)

[60] (Offshore Renewable Energy Catapult, 2019)

Cost of Capital

Due to the capital-intensive nature of offshore wind, the Weighted Average Cost of Capital (WACC) is a key driver of reduction on costs per MW and the overall LCOE. As shown in Figure 12, a 1 percentage point reduction in WACC reduces the LCOE by approximately 7%[61]. The WACC offered to developers has reduced as the industry matured and the pool of equity and debt financing sources has increased.

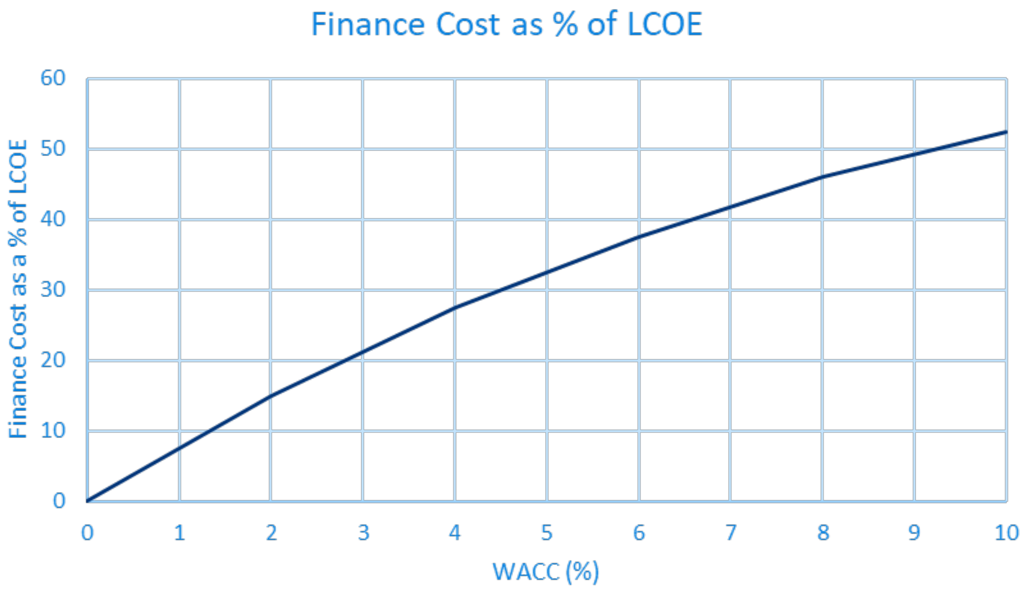

Figure 12 Finance Cost[61]

One of the main drivers behind the reducing WACC has been the shift from equity to debt financing. Prior to 2010, non-recourse debt[62] was unheard of for offshore wind projects in the UK, despite its increasing popularity in Europe since the early 2000s. This was partly driven by the dominance of utilities in the UK offshore wind market. Traditionally, utilities built projects on balance sheet and had dedicated finance teams able to raise capital at a corporate level and obtain due diligence from banks. This made it difficult for small players to enter the market as they could not afford to support themselves during the lengthy period between leasing and generating electricity.

As the industry matured, the pool of investors willing to fund offshore wind projects increased. The result was that affordable debt became increasingly available, particularly from non-recourse financing. From around 2010, pension funds began investing in UK offshore wind and by 2012 both the Gunfleet Sands and Walney offshore zones had obtained funding from non-recourse finance. Since then the UK has seen a progressive increase in affordable debt; by 2014, debt financing of the UK offshore wind industry was comparable to that of other North European countries. Notably, Danish pension funds PFA and PKA invested £2bn in the Walney Extension and simultaneously bought a 25% stake each in Ørsted in 2017. Furthermore, as the industry

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[61] (BVG Associates, 2020) (Charles River Associates, 2018)
[62] Non-recourse debt - debt raised in project finance transactions

developed it became possible for investees to take on risk in the early project stages and infrastructure funds became increasingly popular sources of finance for the sector.

The share of non-recourse debt in new asset finance of offshore wind in the UK has increased from 45% in 2015 to almost 80% in 2019. Offshore wind non-recourse debt across Europe increased from £1.5bn in 2010 to a record £16.5bn in 2018[63].

In 2019, non-recourse debt for offshore wind decreased to £8.8bn across Europe. One reason was the finance sector beginning to take advantage of the secondary market through project acquisition and refinancing. Debt refinancing is driven by the reduction in risk as an offshore wind project develops. Once the wind farm has been commissioned, the risks of construction are replaced by operational risks and, since operational risks are lower, more favourable interest rates can be offered. It is therefore common for a project to restructure its debts (i.e. refinance) upon completion. The completion of large projects since 2016, including Race Bank (573 MW), the London Array (630 MW), and Dudgeon (402 MW), has resulted in significant refinancing of the offshore wind market in recent years.

Analysis of how this finance sector restructuring impacted on the costs of an offshore wind farm is detailed in the Financing Costs section in Part B.

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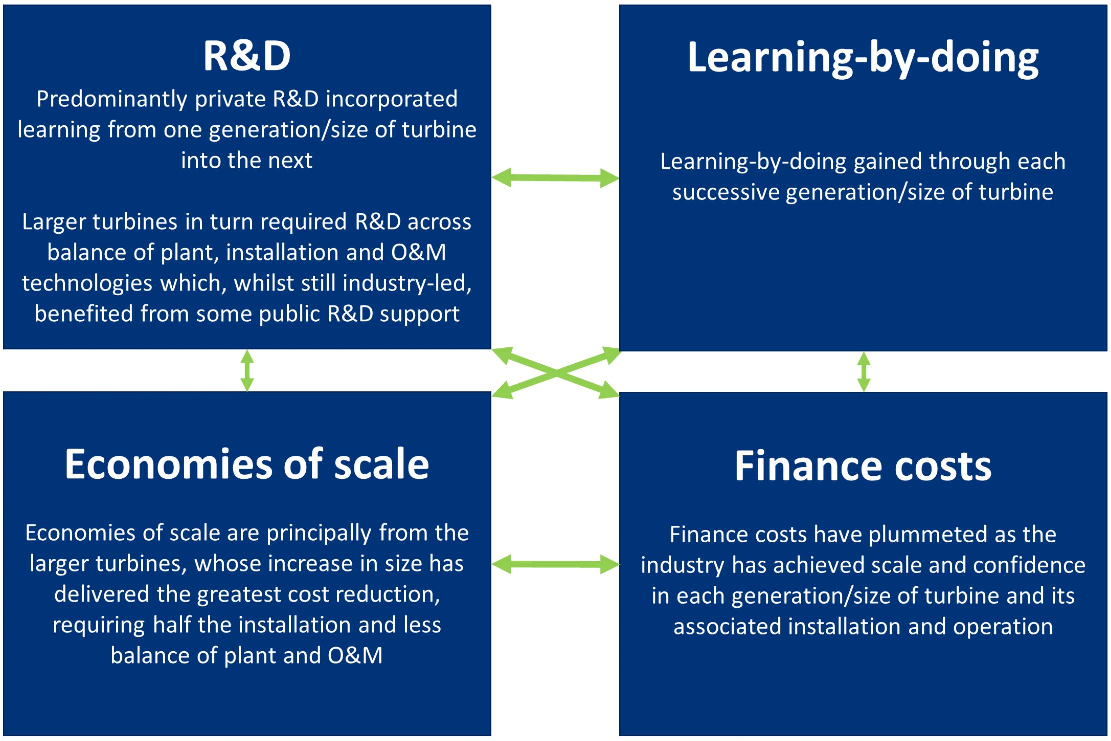
[63] (Wind Europe, 2019)

Part B: Analysis of cost reduction drivers and innovation functions

Cost Reduction Drivers

This section examines how the cost reduction drivers introduced on pg.30 generated the cost reductions described above. It also explores the relationship between the different drivers and their relative significance. The costs drivers are categorised into demand-pull, technology-push, and non-policy.

We asked the leading offshore wind companies and their government counterparts to attribute cost reduction over the last decade to these seven drivers. They all agreed that the increase in the size of turbines was the single largest contributor to cost reduction. Interviewees then attributed turbine size differently across learning-by-doing, R&D (private) and economies of scale. We suggest that all three contributed to larger turbines. Furthermore, confidence in each generation/size of turbine also drove down finance costs. These cost drivers all feed into and from each other in a mutually reinforcing manner as illustrated in Figure 13 below.



R&D

Predominantly private R&D incorporated learning from one generation/size of turbine into the next

Larger turbines in turn required R&D across balance of plant, installation and O&M technologies which, whilst still industry-led, benefited from some public R&D support

Learning-by-doing

Learning-by-doing gained through each successive generation/size of turbine

Economies of scale

Economies of scale are principally from the larger turbines, whose increase in size has delivered the greatest cost reduction, requiring half the installation and less balance of plant and O&M

Finance costs

Finance costs have plummeted as the industry has achieved scale and confidence in each generation/size of turbine and its associated installation and operation

Figure 13 Cost drivers and their role in each generation/size of offshore wind turbine

Economies of scale have enabled cost reduction across the sector, primarily through the knock-on effect of larger turbines. However, this would not have been possible without learning-by-doing, particularly in early years, and R&D innovation throughout. This trend is shown through the commercialisation of technologies including direct drive turbines, 66kV array cables, and bespoke vessels.

Figure 14 highlights averaged stakeholder response from across the industry. As shown, stakeholders associated on average 80.5% of cost reduction experienced between 2010 and 2019 with drivers influenced by demand-pull instruments, 12.5% with technology-push drivers (i.e. public R&D)[64], and 7% with non-policy related drivers.

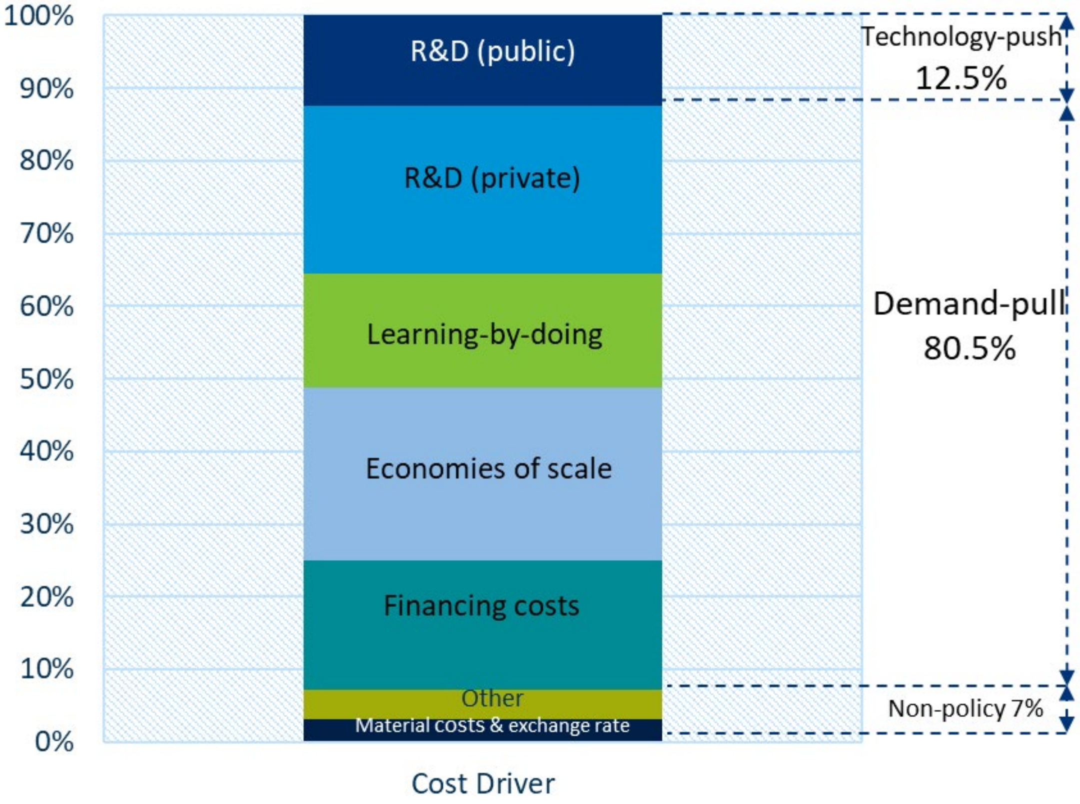


Figure 14 Proportional Role of Cost Driver since the introduction of the Renewable Obligation in 2002

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[64] The average values shown in Figure 14 represent the findings from seven interviews (ten interviews were conducted in total but attributions were only requested in the seven industry interviews). We removed one response where we felt misinterpretation had created an outlying response. It should be noted that this is a qualitative study with a small sample size. The relative attribution of cost reduction to individual demand-pull related cost drivers varied significantly, but there was greater consistency in the overall split between the impact of technology-push and demand-pull.

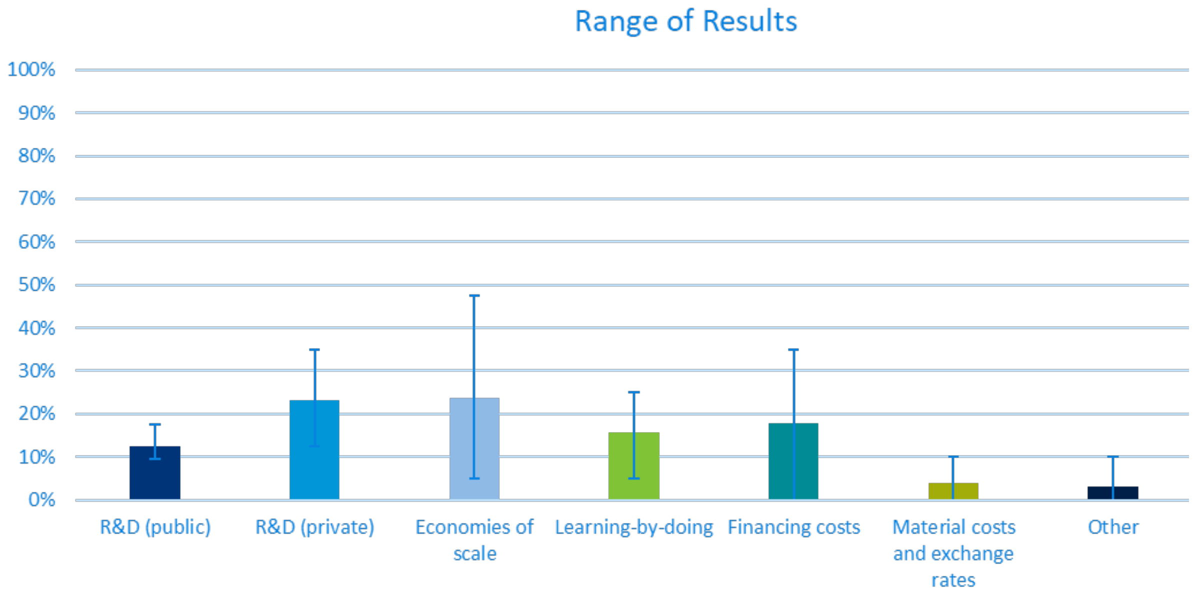

Figure 15 displays the range of values that were apportioned to each cost reduction driver across all stakeholders. As shown, the range of values from interviewees attributed to public R&D is small compared to other drivers, ranging from 9.5-17.5%[65]. Although individual drivers were assigned a wide range of values, the collective range of drivers related to demand-pull policy instruments is 75.5-83.5%. This demonstrates the dominant role that demand-pull policy instruments have played in inducing cost reduction in offshore wind in the UK since 2010.

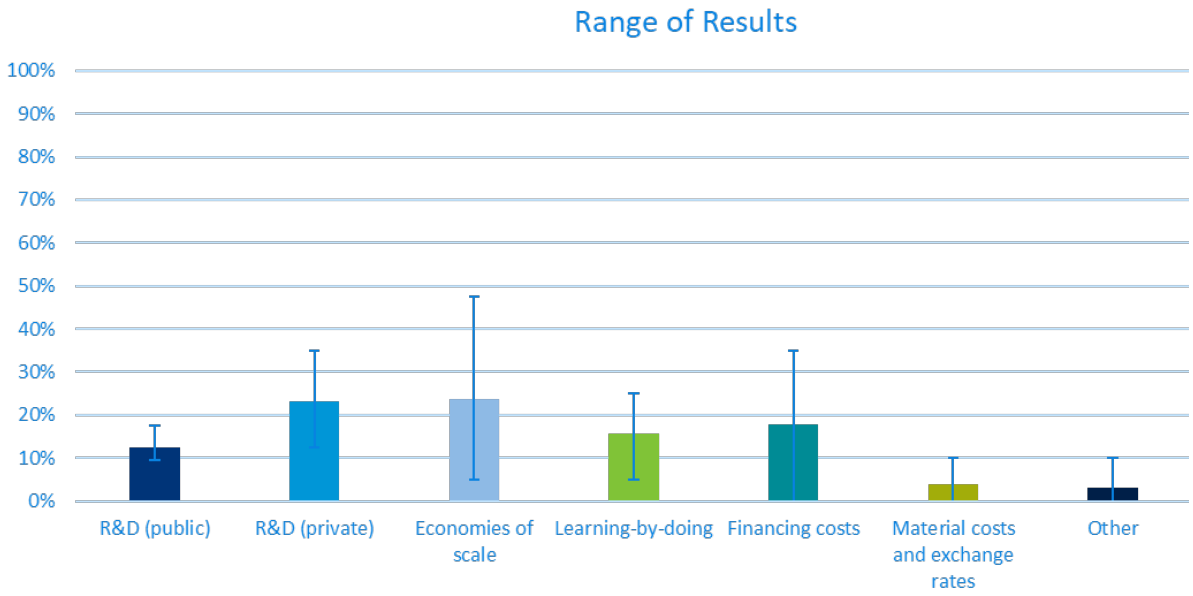

Figure 15 Range of values apportioned to cost drivers

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[65] As private R&D is largely induced only when the investor thinks there is likely to be a market for the technology at some point (a market being shaped by demand-pull instruments), it is considered to be driven by demand-pull in this study. However, co-funding with public R&D helps reduce risk further, encouraging private investment.

Research and Development (R&D)

Larger turbines have, as explained above, made the greatest contribution to cost reduction. Early public R&D was important for the first generation of onshore wind turbines, and the learning-by-doing generated by their subsequent early deployment in the offshore environment. Private R&D has been more important in recent years, and is primarily responsible for the product design improvements, testing, and increasing fabrication and manufacturing scale in terms of both turbine size and volume of turbines produced.

Private R&D in collaboration with public R&D has also been important. The development of direct drive turbines was a fundamental innovation in turbine design and was delivered through private R&D complemented by public R&D. For example, in 2009 Siemens created the Sheffield Siemens Wind Power partnership with the University of Sheffield. This project has supported the successful commercialisation of Siemens' 7 MW and 8 MW direct drive turbines.

The Carbon Trust Offshore Wind Accelerator was also widely cited as an effective initiative. It has received both public and private support but is led by industry (almost all the key developers) and has increased the likelihood that successful innovations will progress through to commercial deployment. The OWA has demonstrated it will deliver savings of £620m for a 1GW project in the UK. Therefore, assuming the 40GW target by 2030 is met, this equates to an overall saving of around £18bn for UK consumers.

As highlighted in Figure 14, public R&D has been attributed to 12.5% of overall cost reduction and private R&D to 23%.

R&D has been critical to setting new standards that have in turn led to cost reduction and monopile foundations and cables are two key examples. The Pile Soil Analysis (PISA) project was a £3.5 million joint industry research project (JIP) led by Ørsted, run through the OWA, and led by Oxford University. PISA supported solutions that reduced steel requirements for monopiles by up to 30%. This was widely-cited by interviews as a key R&D project that brought about cost reduction. The OWA also facilitated industry agreement to adapt an existing standard to cover 66kV cables, which enabled larger turbines as well as loop (rather than radial) connections that increased availability.

Finally, R&D has been critical to developing new balance of plant technologies. Notable examples include jacket foundations, suction buckets, access vessels and floating LiDAR[66]:

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[66] **Jacket foundations:** Jacket foundations were developed with publicly co-funded demonstrations including Beatrice. **Suction bucket jacket:** Borkum Riffgrund is the first suction bucket demonstration, delivered through the OWA with public co-funding. **O&M access vessels:** Notable examples supported by the OWA include developing the Umoe Mandal vessel that is now being deployed by Orsted and the Nauti-Craft that has achieved Design Approval Preview with DNV GL. **Floating LiDAR:** Compared to state-of-the-art meteorological masts, floating LiDAR systems offer many benefits including cheaper installation, and savings of up to 90%. The ability to deploy more systems and move them around also increases certainty on yields, which has a significant impact reducing costs.

Learning-by-doing

There are at least three ways in which learning-by-doing has driven cost reduction.

Firstly, successful design, manufacture and deployment of each generation of wind farm, particularly each generation of turbine, has generated the learning and associated confidence to rapidly move on to the next generation. As detailed on pg 30, the increasing size of turbines has been the single largest component of cost reduction in offshore wind in the UK.

Secondly, greater certainty in future performance and costs has led to lower contingencies and associated cost margins. Interviewees reported that in 2010, due to industry immaturity, it was not possible to accurately estimate operational costs. A lot of contingency was subsequently added to project costs when planning wind farms and this could quickly be removed as projects were built, lessons learnt, and risks reassessed. Early RO-funded projects have been cited as instrumental in teaching the industry how to deploy offshore wind farms as they demonstrated how to operate and bring down costs.

Thirdly, the supply chain has improved productivity through learning-by-doing, particularly in getting better and faster at installation. For example, installation times for cabling are reported to have reduced by a third.

It was also reported in interviews that learning-by-doing has been supported through UK companies taking an increasing role in the offshore wind supply chain and the clustering of industry. This process integrated the industry and encouraged supply companies to collaborate with research institutions.

Economies of Scale

The main impacts of economies of scale on cost reduction are associated with the knock-on effect of larger turbines on other wind farm components[67]. Wind farms that use larger turbines require less balance of plant and associated installation and O&M. Indeed, 50% of LCOE cost reduction in coming years is expected to come from the scale-up from 8 MW to 12 MW turbines. A number of interviewees suggested that many Round 3 bids were based on the industry's assumptions on further cost reduction, primarily enabled through the scale-up of turbines.

For many parts of the supply chain, the scaling-up of turbines also enables new technologies to become cost-effective. Notable examples of this are Walk-to-Work systems[68], 66 kV array cables, jacket foundations, and bespoke vessels.

The transition to larger projects also allows manufacturers to offer bulk-buying discounts due to the security of long-term business. For example, when placing larger turbine orders, manufacturers are able to bring down prices as supplying a single wind farm can require booking out entire manufacturing plants for several years.

As the market grows, more and more data is becoming available. The ongoing Crown Estate Round 4 leasing round agreements will require developers to share data and participate in benchmarking schemes such as the System Performance and Reliability Trend Analysis (SPARTA). The Crown Estate has added this requirement in order to contribute to de-risking investment and to support continuous improvement in the sector.

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[67] Economies of scale does not directly include the use of larger turbines

[68] Walk-to-Work gangway systems are motion-compensated systems that enable easy access from vessel to turbine

Financing Costs

The decreasing cost of capital in recent years has been driven by a maturing and expanding industry that has increasing access to equity and debt financing. The WACC offered to developers has reduced from over 10% in 2010 to below 7% by 2020[69]. This reduction has been driven by lower costs for risk and debt, as well as the increase in revenue generated by offshore wind farms with longer lifetimes.

Prior to 2010, the learning curve was relatively slow and many projects were delayed, overran, or had higher capital costs than expected. During this period the risk premium for equity was around 15% in the pre-construction phase. As the industry learnt from experience, major risks such as installation timings, turbine availability, and O&M requirements have been better-managed and risk profiles have reduced. This lower risk profile supported investors making capital available at a lower cost; between 2012 and 2015 the risk premium for equity return reduced from 5% to 1%. Developers initially agreed individual contracts across the supply chain, with a risk margin built into each contract. More recently there has been a move to turnkey solutions in which one contractor manages the supply chain and the risk margins decrease.

The increased reliance on debt financing has driven down interest rates for loans. Loan terms have been easing since around 2011, with average interest rates decreasing from over 2% in 2015 to below 1.5% in 2019[70].

Finally, as wind farms have developed their operational performance has improved, O&M costs have reduced, and operational lifetimes have extended from around 25 to around 30 years. This results in wind farms generating more revenue over their lifetime and attracting more favourable loan conditions.

Overall, the scale-up of the industry and the learning process it went through enabled favourable financial conditions to be offered to developers.

Material Costs & Exchange Rates

Offshore wind projects have particularly high demand for steel, due to its use in both foundations and turbines. In the past, developers often hedged against steel price fluctuation, particularly during the CfD FIDER round. Since then, developers have gained confidence and kept themselves exposed to the risk of increased material costs. Developers reported that corporates and utilities do not see exchange rates as a way to lower costs.

Overall, interviewees did not attribute material costs or changes in exchange rates to be a significant driver behind the cost reduction experienced, only associating them with 3.9% of cost reduction. Cables and vessels companies gave more significance to this factor than developers and turbine manufactures. A key reason given for this was the fact that material cost fluctuation risk is reported to be pushed down to the supply chain.

Others

Spillovers from other industries have not been significantly attributed to overall cost reduction. Transfer of knowledge and technology from the oil and gas industry was often cited in interviews

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[69] (BVG Associates, 2020)
[70] (Wind Europe, 2020)

but the cost reductions were not detailed. In fact, cost reductions were only observed as the industry became less reliant on the spillover from oil and gas. For example, in 2010, oil and gas vessels were used but, due to the limited number of vessels and greater spending power of the oil and gas industry, bottlenecks in availability were common. These vessels were also not well-suited to offshore wind operations. It was not until bespoke offshore wind vessels, which could perform the necessary tasks far more efficiently than oil and gas vessels, were developed that cost reductions were observed.

Walk-to-work systems have been referenced as an innovation that has contributed to cost reduction and relied on a technology spillover from the flight simulation industry. However, cost reductions from this technology were primarily realised through economies of scale making them financially viable.

Functions of Innovation Systems

Policy instruments have the potential to either support or hinder the cost reduction drivers described above. They do so through their interaction with the functions of innovation systems described on pg. 14. In this section, drawing on the views of developers, investors and policy makers extracted through interviews, we examine how the cornerstone demand-pull policy instruments for offshore wind in the UK over the last decade – the RO and CfDs – and the recent Offshore Wind Sector Deal have contributed to these system functions to induce the cost reduction drivers associated with them.

Goal-setting

"Targets, when backed with financial commitments, have been gold-dust" – industry source

Commitment and scale goals: CfDs gave a clearer, stronger commitment

Launched in 2002, the RO gave a target of 10% renewable electricity generation by 2010. This gave a commitment to a certain level of renewable capacity and the timeframe within which that capacity had to be deployed.

CfDs were very clear in setting goals for decarbonisation of electricity generation as part of Electricity Market Reform. The additional clarity of a commitment to a regular schedule of auctions every two years, given under the Sector Deal, helps give a clear pathway to the target of 40GW of low carbon generation by 2030. This gives clear visibility of the target market scale. That commitment then flows down the supply chain.

However, the transition between the RO and CfDs created uncertainty in the market that led to an 18-month hiatus with knock-on effects in the supply chain that are only now being resolved.

Time goals

The RO gave a clear goal in terms of the date by which projects had to start generating, but the fact that generators lost their ROCs if they missed that date had potentially disastrous consequences. When the delays were incurred at a stage when projects were already in construction, developers had no choice but to continue and accept a lower than expected financial return.

CfDs also come with deadlines by which they have to generate but, in contrast to the RO, this was not raised as an issue by interviewees. This may be related to the length of time for which CfDs have been in place.

Cost reduction goals: RO appropriate to foster innovation for near-commercial technology, CfDs drove cost reduction but not disruptive innovation, including floating wind

The RO's primary goal was not cost-reduction, which was positive in the early stages of UK offshore wind as a near-commercial technology. It allowed innovators in an emerging industry the necessary space to innovate and experiment, learning through trial and error. It was complemented by the Offshore Wind Cost Reduction Taskforce, which reported in 2012 and concluded that it would be possible to reach £100 per MWh by 2020. On the basis that £100 per MWh was achievable, the government agreed to provide the necessary support.

CfDs had no target *price* but drove intense *cost* competition via an auction in which the lowest-priced bids would win. It was very successful in achieving short-term cost reduction, creating pressure to reduce costs all the way down the supply chain. This resulted in a contest that meant only the most competitive suppliers could survive, but some in the supply chain have questioned whether the latest CfD strike prices will result in the supply chain being squeezed too far.

The particularly strong drive on cost reduction also doesn't leave room for the development of local content and supply chain companies entering and growing in the market, as competition is so fierce.

CfDs leave little scope for disruptive innovation, particularly beyond turbine manufacturers in the rest of the supply chain. Some supply chain interviewees suggested that the clear cost reduction goal did not support innovation because developers pushed the supply chain so hard on cost that they had no room to invest in innovation. Others felt that the clarity on both scale and cost reduction goals gave turbine manufacturers a clear target, driving them to develop the larger turbines that have been so instrumental in bringing costs down. Developers tended to view the CfDs' contribution to goal-setting more positively than those in their supply chain.

The scale of investment and the need to forecast costs, since CfDs are awarded several years before turbines are installed, is also a motivation to use proven technologies. The engagement of pension funds in offshore wind has been positive in terms of reducing the cost of capital, but their low appetite for risk may also drive developers to stick with existing technology. Incremental innovation, as opposed to fundamental innovation, is easier to achieve without hitting a risk premium.

Technologies such as floating wind and system-integration technologies are likely to be required if the UK is to hit higher targets of 75GW[71]. One interviewee suggested that a future version of CfDs should include one strand for established technologies such as fixed offshore and another for immature technologies such as floating wind or storage, to ensure they can access support. The government is currently consulting on just such a revision to create separate pots for fixed offshore and floating wind[72].

Creation of legitimacy and market formation

Both CfDs and ROCs aided the creation of legitimacy and market formation as they allowed investors not only to commit to projects, but also to the associated technology choices and supply chains needed to start an industry. By encouraging investment in the creation of a supply chain, both policies enabled the market to grow.

The RO was good at giving early confidence to investors as it gave a secure, long-term income stream with a good return. This was appropriate for the early years of the UK offshore wind market. Whilst offshore wind was already being developed in other geographies, the differences in the marine environment in the North Sea meant that significant learning on how to operate in that specific area was still necessary. Pioneering development required fundamental innovation, significant safety margins, both in over-engineering and allowing for contingencies for cost over-runs; the generosity of the incentive level kick-started deployment.

The RO also offered generous margins that were at the right level to enable market entry, including from local suppliers. The high upfront cost of becoming part of the offshore wind supply chain is a significant barrier to entry.

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[71] (Offshore Renewable Energy Catapult, 2019)
[72] (Department for Business, Energy & Industrial Strategy, 2020)

The level of incentive and lack of competition also enabled innovation. Developers could deploy technologies that had not been deployed in offshore wind before such as jacket foundations and new cable specifications.

A higher ROC multiple of 3.5 was available to floating offshore wind in Scotland in order to legitimise and form a market segment. In spite of this higher multiple, the RO was still not able to support the development of floating wind, with only one demonstrator project of 2 MW supported at Kincardine.

CfDs were effective in building on the foundations laid by the RO, scaling up the market and bringing down costs. The Sector Deal commitment to regular rounds of CfDs increased confidence from industry and investors to the level required to scale up, as outlined in the goal-setting section above.

Furthermore, the certainty and consistency in the CfD strike price made the business case for investment in large, capital-intensive projects attractive, reducing revenue risk. Ofgem had a number of levers to keep the price of ROCs stable but there was no intrinsic guarantee for the value of ROCs, unlike CfDs.

One interviewee suggested that the mechanism itself is less important than the predictability, e.g. the guarantee of CfD auction rounds, and timescales that work for large infrastructure projects with ten-year lead times. Again, the uncertainty caused by the transition from the RO to CfDs and the resulting hiatus had a negative effect on legitimacy and market formation.

Resource mobilisation

CfDs were generally considered to be supportive of resource mobilisation as the auction mechanisms and the recent Sector Deal ensures a strong pipeline of projects that enables the supply chain to prepare. The RO was felt to have been less influential in resource mobilisation. Whilst it was good at supporting emerging technology, it did not support long-term industry growth or drive innovation on a project-by-project basis. The issue of predictability was raised again here, with some interviewees, primarily developers, suggesting again that it was the predictability of the mechanism, more than the mechanism itself, that had the greatest impact on both resource mobilisation and experimentation.

There were three main resources mobilised under the RO and CfD: finance, factories and installation vessels, and workforce.

Finance

The RO laid the foundations for finance mobilisation in that it proved the technology could be deployed at scale with an acceptable installation risk, and that it provided reliable generation.

The scale of development under CfDs, along with cost reduction pressures driven by competition, led to an increased ability to forecast costs, increased certainty and lower risks. This created greater investor engagement in what was becoming an increasingly attractive investment, with investors engaging earlier and earlier in the process.

Factories & installation vessels

The RO kick-started deployment but, initially, the resources employed were primarily from other industries. Turbines were modified from onshore wind, and vessels and cables installation came from the oil and gas industry. The increase in commitment and scale that came with the introduction of CfDs unlocked investment into new factories and vessels. Investment in bespoke vessels, designed around the foundations, contributed to a significant reduction in installation time, from nearly three days per MW in 2008 to just one day per MW in 2017. Bespoke vessels have also enabled the installation of larger and larger turbines.

It should be noted that the sheer rate at which CfDs have accelerated the market, coupled with the intense level of competition they have engendered, has led to some of the supply chain making losing bets. For example, MPI developed turbine installation vessels on the assumption that turbines would not be larger than 6 MW for the foreseeable future. In fact, 10 MW is the current norm meaning these vessels now have no role. As a result, the company folded.

One industry interviewee also noted that their decision to make a significant investment in a new facility was based in part on the commitment demonstrated through the introduction of CfDs, but also the fact that the UK government gave them confidence that they had a long-term and genuine commitment to support the offshore wind market.

Workforce

In terms of the offshore wind workforce, mobilisation differs according to the component. In the case of turbines, established companies have simply redirected their onshore wind design engineers to design offshore turbines, with no fundamental shift in required skills. In the case of balance of plant, installation and O&M, offshore wind represents a far greater shift. That workforce has been formed largely from a combination of repurposed oil and gas employees and new recruits.

The increase in scale and longevity in the offshore wind market brought about by CfDs since 2013 has made the offshore wind employment market far more attractive and better able to compete with oil and gas. The element of competition on cost reduction has also rewarded those companies with the best workforce, reinforcing those with the best skills and improving their ability to train and develop their workforces.

Knowledge development

A strength of the RO was that it created a long-term overall benefit to the industry by allowing scope to be more innovative and experimental. Interviewees felt it was particularly effective in supporting the development of the core technical knowledge needed to build and operate wind farms. The RO supported a lengthy development process and brought in new entrants to build a new industry. This established the baseline pool of competitors who needed to be in place before CfDs could drive the next stage of market development.

CfDs then drove the industry to take the key learnings from the RO phase and build on them to develop the knowledge to enable the industry to become commercially-viable and drive costs down. This new knowledge development pathway enabled the development of a bigger market.

Under CfDs, knowledge development has tended to be very incremental, with small, individual breakthroughs that eventually add up to an innovation. It was suggested that innovation in larger companies often starts with small-scale entrepreneurs, who are then acquired by a larger company.

Interviewees felt that the competition driven by CfDs has forced companies to learn more and learn faster to keep pace and seek a competitive edge. Competition can increase knowledge development but interviewees also stressed that it can simultaneously decrease knowledge exchange.

CfDs currently support incremental knowledge development, but more is needed to reach net zero

The RO created space for early knowledge development, and the CfDs have driven knowledge development by forcing companies to seek a competitive edge. However, CfDs are not currently encouraging the kind of knowledge development that some interviewees suggest is necessary for offshore wind to provide the 75GW needed for the UK to reach net zero by 2050. This may be addressed by the outcome of the current government consultation on a new CfD pot.

Knowledge exchange

Overall, knowledge sharing has reduced with the introduction of price competition through CfDs. The RO was felt to have been more supportive of knowledge sharing but, even then, interviewees raised the fact that the type of basic health and safety information that the oil and gas industry was obliged to share was not initially exchanged in offshore wind.

The Offshore Wind Accelerator (OWA), and other industry-led collaboration, was seen as an anomaly to overall knowledge exchange in the sector. Members of the OWA see the advantage of sharing the costs of specific R&D so they have been motivated to share.

The RO was seen as supportive of open source knowledge exchange within the emerging industry, with the fixed price encouraging supply chains to share knowledge. University integration in decision making was also more common. However, this may have happened without the RO, through industry initiatives such as the OWA.

CfDs were widely reported to be detrimental to open source knowledge exchange as the competitive nature of the policy creates an environment where developers protect knowledge in order to maintain competitive advantage. However, when considering the new partnerships that formed through contracting, CfDs were reported to have been useful as the competitive nature of the policy necessitated innovation through collaboration.

At a high level it was suggested that the greatest source of competition for offshore wind was actually nuclear, rather than other offshore wind developers, and that this overarching competition has driven collaboration and initiatives such as OWA.

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