Department of Mechanical and Aerospace Engineering

Effect of Government Policy on the Development of Renewable Generation in the UK

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Abstract

This report details the work carried out as the MSc Thesis for the degree Sustainable Engineering: Renewable Energy Systems and the Environment. The work studied focussed on research into the policies utilised to promote an uptake of renewable electricity generators in the UK, set out by the government from 1990 until the present day. Many different types of renewable generators were investigated, from their beginnings on the UK electricity grid until the present day, looking into: technological advancements, project scale increases and overall capacity growths. In particular, this report focuses on onshore wind turbines, offshore wind turbines and marine energy technologies as these three technologies are at varying stages of deployment in the UK and globally.

Tables, graphs and charts of the analyses carried out are documented in this report and a concise and thorough discussion on the policy changes made since 1990 and the impact each has had on the renewables capacity in the UK. Lastly, a discussion on what the future holds for renewables, now that policy has changed from Renewable Obligation to Contracts for Difference.

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Firstly, I would like to thank my supervisor Cameron Johnstone for helping me find a topic I found thought-provoking and important all the useful knowledge and ideas he shared with me.

I would also like to thank all the lecturers within the Energy Systems Research Unit and all my fellow students on the course. This year has been truly inspiring, it has opened my eyes to the importance of sustainable engineering and made me realise why my true interest lie as an engineer. I hope everyone has an exciting career ahead in the field of renewables and sustainable engineering.

To my friends and family, thank you for putting up with my continuous chat about wind turbines and sustainability and for all your words of encouragement.

Lastly to my parents, I owe the biggest thank you for encouraging and supporting my move home to Glasgow to study for the Masters degree, I couldn't have done it without them.

Contents

List of figures

List of tables

Nomenclature

BEIS	Department for Business, Energy and Industrial Strategy
BETTA	British Energy Trading and Transmission Agreement
BOWL	Beatrice Offshore Windfarm Ltd
CAPEX	Capital Expenditure
CCC	Committee on Climate Change
CfD	Contracts for Difference
CHP	Combined Heat and Power
DECC	Department for Energy and Climate Change
DNC	Declared Net Capacity
EEG	German Renewable Energy Sources Act
FIT	Feed in Tariff
GHG	Green House Gas
kW	Kilowatt
kWh	Kilowatt hour
LCCC	Low Carbon Contracts Company
LCF	Levy control framework
LCOE	Levelized Cost of Electricity (£ per kWh)
LIMPET	Land Installed Marine Powered Energy Transformer
MWh	Megawatt hour
NETA	New Electricity Trading Agreements
NFFO	Non-Fossil Fuel Obligation
O&M	Operation and Maintenance
OFGEM	Office of Gas & Electricity Markets
OPEX	Operating Expenditure
OTM	Offshore Transformer Module
PV	Photovoltaic
RO	Renewables Obligation
ROC	Renewable Obligation Certificate
RPS	Renewable Portfolio Standard
SRO	Scottish Renewables Obligation

1 Introduction

1.1 Motivation

There have been a number of dramatic changes in the renewable energy sector within the UK in the past three decades, since the privatisation of energy generation in 1989. The number of onshore wind generators increased to produce 17% of UK electricity from wind power in 2017. The UK has become the market leader in offshore wind installations and the research and development for marine technologies is showing that tidal stream technology can now be confidently invested in, with 22 tidal stream technology companies currently active in the UK (EMEC, 2017) .With the push from the UK and EU governments, as well as the Paris Climate Agreement, a change in energy production methods to reduce the impact of climate change is required. It is still essential that we continue working towards cleaner and more sustainable sources of energy as an increase of renewable electricity generators is needed to replace current polluting fossil fuel power stations in the UK. To aid in reaching climate change goals, the UK government has implemented a series of different renewable energy policies from 1989 to present. These policies have had varying successes and a diverse number of failures which have potentially hindered progress towards the climate goals. It therefore would be beneficial to identify recurrent issues that occur throughout all policies, that lead to less development in the renewables industry than desired. If issues are identified then the ultimate goal to meet the climate change targets could be met faster by increasing the current rate of progress towards a cleaner energy system in the UK.

The current energy policy of the UK is detailed in the Energy White Paper of May 2007 and the Low Carbon Transition Plan of July 2009. The policies were created by DECC (Department of Energy and Climate Change) and the focus of the policies was to reform the electricity market, rolling out smart meters and improving the energy efficiency of buildings. BEIS (The Department for Business, Energy and Industrial Strategy) took over the responsibilities of DECC on 14th July 2016 after a merger of DECC and the Department for Business, Innovation and Skills.

This thesis focuses primarily on the policies affecting the electricity market.

1.2 Aim

The overall aim of this thesis is to investigate the effect of the different policies and incentives utilised in the UK to promote the uptake of renewable energy generators.

Initially an understanding of the different policies used in the UK had to be attained, including the Non-Fossil Fuel Obligation, Renewables Obligation and Contracts for Difference (CfD). The knowledge required included why they were introduced, the benefits of the policy and the overall outcomes of the policy. It is important to identify why modifications to policies were made and why policies changed throughout the years from 1990 to present.

A secondary aim was to study the overall success of different types of renewable electricity in the UK and any limitations or boundaries, due to policies or external influences not within policy control. To proceed, it was necessary to identify whether or not policies and legislation had an effect on the uptake on renewables throughout the UK and Europe.

Lastly, it was anticipated that an overall understanding of the Contracts for Difference (CfD) policy, recently introduced in the UK, would be achieved and a view of how successful the policy will be, looking towards the future, and what impact CfD may have on the UK's energy system.

1.3 Objective

To achieve the overall aims of this thesis project, many different research and investigation methods were required including online research of government legislation, reading journal papers and textbooks and gaining an overall perspective of the current renewable electricity climate in the UK.

The objectives therefore included:

1. Quantifying how many onshore wind farms were built in Scotland from 1995 – present and the scales and capacities of these windfarms. As well as studying the quantities in the UK as a whole.
2. Identifying the role large scale energy companies play in the electricity market in terms of renewable electricity and their involvement in driving innovation and progress towards a greener energy system.
3. Researching the progress of wind energy from concept design to the current turbines installed globally today.
4. Investigating the key drivers of each renewable energy policy and the potential positive effects it has had on the boosting of renewable generators. Also, in contrast, any negative impacts or barriers policies may have had on the development of all renewable generators in the UK.
5. Studying Offshore Winds success in the UK and the reasons why offshore has taken off in Britain much more rapidly than onshore did, in comparison to other market players. Looking to the future of what offshore winds success will be with Contracts for Difference now having released its second round of awards in September 2017.
6. Investigation into the future for marine energy and whether the market will be able to continue research and development whilst still only playing a minor role in renewable energy generation in Britain.
7. Conclude on whether marine energy will eventually have its time to thrive in the market just as onshore and offshore wind have in recent years.

1.4 Report Structure

The thesis report will be structured to mimic the process followed while carrying out the project work. Figure 1 shows the process followed to reach an overall conclusion on whether the policies implemented by the UK government have an impact on the uptake of renewable generation.

Figure 1: Report Structure Flowchart

The report will follow with the key areas shown on the flow chart as the chapter headings: Literature Review, Research, Analysis, Discussion and Conclusions to give a clear and concise view of the overall study carried out, to reach an informed conclusion on the subject area. The literature review will introduce the key policies used in the UK and moving to the next chapters a focus will be on the technologies: Onshore Wind, Offshore Wind and Marine technologies. Lastly, the discussion and conclusion will indicate whether the policies are compatible with the current expectations for renewable energy in the UK and further afield.

2 Literature Review

2.1 Background

In the early 90s, the electricity market in the UK was privatised from being a Government owned and operated business, to the assets of the Central Electricity Generating Board, being transferred to the national grid and 12 Regional Electricity Companies (RECs) operating in the original area boards. This change influenced the electricity generation methods used in Britain substantially. Companies were competing against each other to make a profit and the generation, transmission and distribution of electricity was now divided to different responsible companies (Ray, C., 1997). Privatisation introduced many new generation companies which added benefit to the electricity grid as there became more diversity in supply availability. However, due to the capitalist nature of private companies the goal was to maximise profit and reduce cost. In the early 90s, the cheapest method of generating electricity was through fossil fuel combustion and therefore after privatisation, the CO2 emissions of UK electricity went up (Oberthür, 2010).

In the same time frame as electricity was privatised in the UK, discussions were being held for the first time by the European Council with relation to climate change. In 1990, the first goal towards climate change was implemented by EU leaders. The aim was to stabilise the increase of emissions to ensure the level recorded in 2000 would not be higher than 1990 levels (Oberthür, 2010).

The introduction of this EU goal coincided with the introduction of the first renewable energy policy in the UK, the Non-Fossil Fuel Obligation (NFFO), which will be discussed in detail in the following section.

In 1997, the Kyoto Protocol was established which furthered the UK and the EU's commitment to reducing the impacts of climate change. The goal for European countries, established from the Kyoto Protocol, was an 8% reduction of greenhouse gas emissions of 1990 levels by 2010. This was a further 8% reduction of the goal set out for 2000 (United Nations, 1998).

When the Kyoto Protocol was agreed, the UK was still implementing the NFFO and Scottish Renewables Obligation (SRO) to increase renewable generation penetration, and reducing the emissions from electricity generation, was the UK's main method to reduce greenhouse gas emissions overall.

In March 2007, the emissions targets were again expanded to be 20% by 2020 by the EU Heads of State. The current EU goal is still focused towards greenhouse gas emissions, and now we have less than two years until the deadline date. This target was set during the time of the Renewable Obligation which replaced the NFFO in 2002.

In 2008, the EU renewable energy allocations required the UK to source at least 15% of its energy needs from renewably generated sources. Energy needs included electricity and heating as well as fuel used in cars and other transportation. Therefore, the UK aimed to produce up to 37% of their electricity from renewable sources such as hydro, solar and wind in order to ensure the target 15% could be met without having to rely on reducing heating or transportation emissions (GWEC, 2008).

Ultimately, all of the policies implemented have been to encourage growth in the renewables sector. Growth in renewable energy would directly lead to a reduction in reliance of fossil fuel generation in the UK and steer towards many older coal, oil and gas-fired power stations being decommissioned. However, due to the nature of the electricity market, it is not as simple as introducing a policy to help encourage investment. There are many other factors which control the expansion of renewables and, for the large electricity generating companies, it is not always financially viable to invest in renewable generation when they are still operating successful fossil fuel combusted power stations. The different policies used within UK energy policy are further discussed in more detail later in this report.

2.2 Non Fossil Fuel Obligation

The UK electricity market was privatised in 1990 (Stridbaek, 2006) and new private energy suppliers were established from the original UK public electricity suppliers (PES). Non Fossil Fuel Obligation (NFFO) legislation was created during electricity privatisation. The obligation was called Scottish Renewables Obligation (SRO) in Scotland. In Mitchell and Connors 2003 paper *"Renewable energy policy in the UK 1990–2003"* they state that the UK government asked the European commission for permission to support nuclear power through a 'non-fossil fuel' funding mechanism (Mitchell & Connor, 2004).

The obligation was created to encourage the new private suppliers to buy renewable energy from generators and to ensure the UK's generation mix had a percentage generated from fossil fuel free means. However, the European Commission only granted permission to run the NFFO with support of nuclear for eight years (Mitchell & Connor, 2004).

When the electricity market was deregulated, private investors had to purchase the current energy generating plants e.g. Peterhead Power station was bought by Scottish and Southern Energy plc. Investors were hesitant to purchase nuclear power plants as there were many unknown factors surrounding the future of the nuclear plants in terms of subsidies and decommissioning (Taylor, 2007).

Therefore, the UK government created the NFFO policy to ensure the government goal to reduce the carbon emissions was met in relation to electricity generation but did not make the policy exclusive to renewable generators. OFGEM was responsible for ensuring that all electricity suppliers were fulfilling the requirements of the NFFO. Electricity suppliers had to buy a certain amount of generated electricity from renewable and nuclear generating plants and therefore this was an incentive for more non fossil fuel plants to be constructed (Mitchell, 1995).

The NFFO generators had a 5-year grace period after being awarded a contract, to obtain planning permission for their project. Once permissions were granted the non fossil fuel project then had 15 years to earn NFFO payments (Mitchell & Connor, 2004).

There were five NFFO orders between 1990 and 1999 which assisted the increased of renewables generation to 3271MW of Delivered Net Capacity (DNC) to the UK electricity grid.

However, although the NFFO encouraged growth in the renewables sector there were many failures of the legislation: there were no fixed targets on renewable generating capacity, public anxieties about the number of windfarms being constructed developed with NIMBY's (Not In My Back Yard focus groups) becoming more prevalent, deployment was slow due to planning permission constraints and there was no penalty for uncompleted projects (Mitchell & Connor, 2004) and (Gardner,I., 2014). The NFFO had policy objective changes throughout its lifetime from 1990-1998 to try to mitigate the issues directly caused by policy disparities and oversights. The NFFO policy also highlighted the major aspects in relation to renewable energy and also made clear that there was a strong pathway for renewable energy to become a large percentage of the electricity generation market makeup. During the 90's renewables in the UK finally began to follow the lead of other western European countries such as Germany and Denmark. However it is now apparent that the NFFO the UK followed was actually much more expensive than the support mechanisms used throughout Europe (Mitchell, 1995).

Mitchell and Connor's end comments in their ***"Renewable energy policy in the UK 1990–2003"*** paper indicate that they thought the NFFO could have been successfully implemented if there had not been such a strict cost cap that potentially limited larger scale projects from being commissioned (Mitchell & Connor, 2004).

Ultimately, the Government replaced NFFO with the Renewables Obligation (RO). Using the lessons learned and the key issues ingrained in the NFFO policy, the RO was developed to ensure progress towards lower carbon electricity was made. Now ex-NFFO projects are auctioned off within the Renewables Obligation every six months by the NFPA (Mitchell, Bauknecht, & Connor, 2006). Registered bidders bid in terms of pence per kWh and it is then the winning bidders' responsibility to maintain output from the generating plant and the renewable benefits for the term (NFPA, 2018).

The last NFFO funded project is due to end in 2019 (OFGEM, 2016).

2.3 Feed in Tariffs

Feed in Tariffs have been successful drivers of renewable development in many countries. The UK however decided to choose a Renewable Portfolio Standard method in the Renewables Obligation to encourage growth in the larger scale renewable sector. Many researchers and academics in the subject believed the UK electricity market would have benefitted far greater if Feed in Tariffs had been introduced. David Toke, a well-respected academic in the field of energy politics and policy at the University of Aberdeen, started a campaign for the Government to introduce a small scale FIT (Feed in Tariff) in 2007. He claimed a FIT scheme would encourage much faster growth in the sector than the Renewables Obligation had (Toke, 2011a).

The Feed in Tariff was introduced in the UK on 1st April 2010 for generation of electricity up to 5MW or 2kW for CHP (Combined Heat and Power). Different from the Renewables Obligation, the FIT is a market development tool which is designed to bring technology forward to be independently functional in the marketplace. Participants of the scheme were able to earn money from the energy generated from their renewable installation as well as earnings from any energy exported, paid for by electricity suppliers.

The energy sold back to suppliers is called the “export tariff” and the maximum a household could sell is half of the electricity generated. However, all schemes above 30kW, must have a meter installed to monitor the units of electricity generated.

In the book “***Feed-in tariffs: accelerating the deployment of renewable energy”*** Miguel Mendonca states that the feed in tariff scheme is a guaranteed price policy and therefore is the most common method of ensuring a fast rate of uptake in renewable energy generation (Mendonça, 2012). However, in the UK the feed in tariff is limited to small generators and therefore the effect of the FIT is felt on a much smaller scale than if it was the legislation applied to all sizes of renewable generators.

The FIT does however allow consumers to become much more aware of their energy usage and consumption due to a greater awareness of both generation and demand. The social implications of a household having a feed-in tariff can be considerable. Studies show people tend to be more frugal with their usage, choosing to use high demand appliances only when their renewable device is generating enough electricity and turning off appliances that are running idle. When it is possible to run the device at a profit, it is likely to be the desire of the household to strive for this (Mendonça, 2010).

This change in social attitude was the reasoning for DECC to push the feed-in tariff to be split into two payments: generation and export. Generating electricity earned 41.3p per kWh versus 3p per kWh for export. This was due to DECC deeming rewards to on-site use to be the most effective technically, and most likely to drive behavioural change in electricity use in households (Mendonça, 2010). Whilst this incentive did incite change in the way consumers used their electricity, it led to the FIT being more an incentive to generate for own use rather than to feed back to the grid. Mendonça states that this type of tariff becomes more of a production tariff than a feed-in tariff system (Mendonça, 2012).

When taking a view of the FIT specifically for wind generation, the price paid for generated electricity decreased dramatically over the eight year period from 1st April 2010 until 1st April 2018. Figure 2 below shows the price decreases for a 1.5kW wind turbine installation.

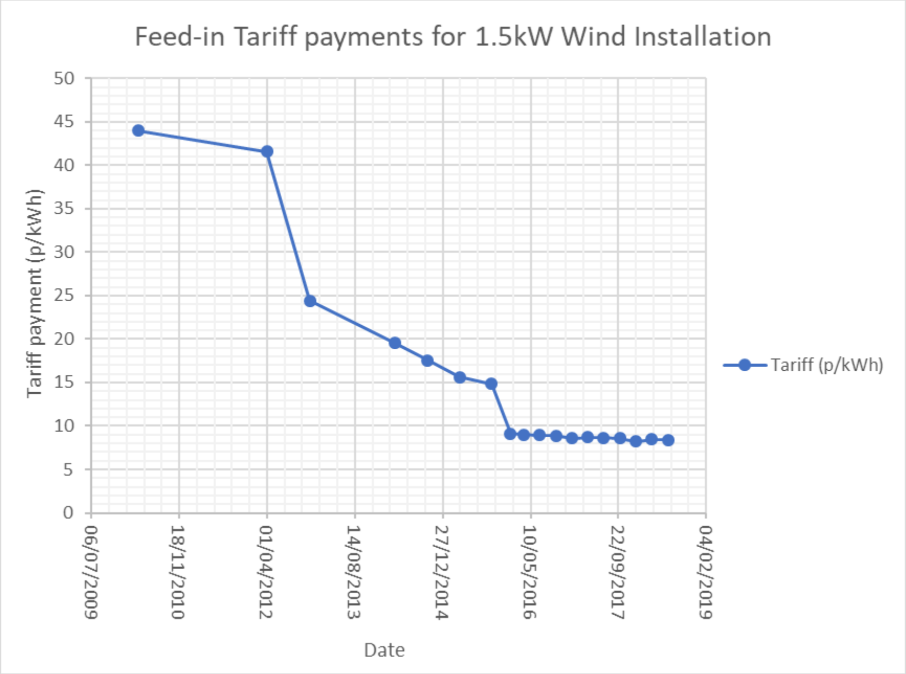


Figure 2: Feed in Tariff Payments for 1.5kW Wind Turbine

The cost paid per kWh for tariffs taken up from April 2010 until April 2012 was 44.01p for a small wind turbine. Now in 2018, the price paid for the same size of installation is 8.46p per kWh. (OFGEM, 2018b).

A view of OFGEM’s graph of wind generation installations under the FIT throughout the same period was taken to understand the effect of the price change in uptake.

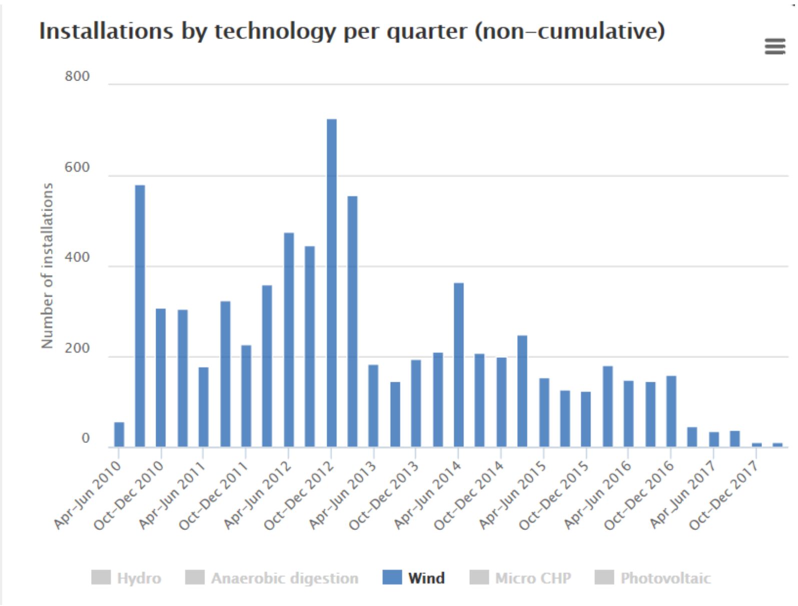


Figure 3: Number of Wind Installations on FIT per quarter (OFGEM, 2018d)

When comparing the total number of installations per quarter with the price awarded from generation, the price has a direct relation to the number of installations made. The spike of installations between Oct-Dec 2012 happened just before the tariff was dropped from 41.59p/kWh to 24.39p/kWh, Either the spike was due to the prior knowledge of the price drop, encouraging more people to install earlier, or the price was dropped to curb such a dramatic uptake (OFGEM, 2018a).

In 2016, there was another dramatic decrease in the number of installations made and this is during the period that the subsidy was dropped to around 9p/kWh.

As stated previously, the FIT primary goal was to aid in technology advancement to allow the installation of small renewable schemes to be more affordable, by giving cash incentives to consumers installing home technologies. The FIT was thought to aid in increase production of such renewable technologies and therefore lower overall running costs of devices.

However, it is clear that the price awarded to generation from home technologies through renewables has decreased to levels that are no longer motivating new installations from consumers. It would be expected that the graph showing the yearly installations (Figure 3) should remain somewhat stable after the initial spike, and that the tariff payment would be reduced at a rate that would still encourage growth in the market.

Potentially, this discrepancy was due to the first tariff payments being too high to sustain. The future of the feed in tariff should provide a steady uptake in new installations .However, with a reduction in new installations it can be assumed that the only major benefiters of this incentive were those who got the 20 year tariffs at the much higher rate of around 40p/kWh.

Lastly, the FIT was to encourage individual ownership of renewable technologies and home production but this introduced many previously unconsidered problems. When generators were feeding back to the grid at the lower distribution levels, they introduced many issues causing interference with the grid. The normal flow of electricity had historically been from a large power plant at high voltage, down to consumer voltage levels. Now, low voltage electricity was being fed back up the grid and causing frequency and current issues on the electricity line. It is not clear if any portion of the FIT was distributed to upgrading the grid and maintaining healthy power lines.

Also, due to the nature of the FIT being for people to install in their own homes, it was criticised for being a tax on the poor. To benefit from the FIT you had to have the right to install a technology on to your own land but also the funds to pay for the upfront costs yourself. It therefore was disadvantageous to poorer people who were not only less likely to own their own home but also less likely to have the money to install a PV panel or wind turbine to their house. If it was a council or privately rented home it also would not be the tenant’s decision to install a device. Similarly, once the technology was installed, many households’ electricity bills became £0 or they were actually earning money from the suppliers. Unfortunately, the suppliers still have to maintain a profit but also ensure they are maintaining their assets, and this loss of profit is expected to have been passed onto the electricity consumers and therefore the poorest customers would be hit the hardest (Mendonça, 2010).

2.4 Renewables Obligation

The Renewables Obligation (RO) was introduced to the UK energy market in April 2002 (Armitage, 2003). The RO modified the rules of the Non-Fossil Fuel Obligation to try to increase the percentage of renewable generators producing electricity at a faster rate. Unlike the NFFO, contracts were awarded on a short term basis for the RO which allowed the price of renewable energy to fluctuate at a much quicker rate and the price was based more on supply and demand profiling (Mitchell et al., 2006). The RO was much more market driven than the NFFO and was intended to oblige the renewable developers to be involved with the electricity market. By developers being involved in the market, it was thought this would keep electricity prices competitive (Mitchell & Connor, 2004). The renewables obligation was solely the supplier’s responsibility to fulfil. Suppliers had to purchase a certain proportion of the electricity sold to their consumers from a renewable means, whereas the NFFO allowed suppliers to hold contracts to specific renewable generation projects.

Initially, the percentage of renewable energy suppliers obliged to buy was only 3% annually, in the original RO it was stated that the percentage would be increased to 10.4% by 2011 (Mitchell & Connor, 2004).

The Renewables Obligation first introduced in 2002 agreed that for every MWh of electricity generated from a renewable source, one Renewable Obligation Certificate or ROC would be granted to the generator company. ROCs are in effect a digital certificate which is issued by OFGEM to supply companies. ROCs can be traded between a generator and a supplier company for a fee. Each electricity supplier is obliged to distribute a proportion of electricity to consumers from renewably generated sources (Armitage, 2003).

The certificates were introduced as an incentive for companies to invest in the UK renewable energy market and to expand the number of renewable generators producing electricity in the UK and to reduce the CO2 emissions related to power generation.

ROCs act as proof that a supplier is meeting their Renewable Obligations target and traded for economic return. The value of a ROC was initially set to £30/MWh in the period 2002/2003 and gradually increased throughout the RO implementation period.

The value of a ROC currently sits at £45.58 in the period 2017/2018 and has increased annually since 2002 in relation to inflation (Renewable Energy Foundation, 2018).

All Energy suppliers aim to reach their target to ensure a percentage of the electricity they have supplied to consumers was generated from a renewable source. Therefore, suppliers must purchase ROCs to prove that they paid for the energy proportion they needed from a renewable generator.

Targets set for all suppliers within the Renewable Obligation from the period 2003-2009 and the actual outputs obtained are shown below in Table 1.

Variable	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**
Renewable Electricity Target (%)	3.0	4.3	4.9	5.5	6.7	7.9	9.1
Actual Renewable Electricity Generated (%)	2.4	3.58	4.23	4.55	4.96	5.5	6.6

Table 1: Percentages of electricity generation in the UK during RO period (Wood & Dow, 2011)

It is clear from these figures that the target set was not met in any of the years displayed. Although the renewable electricity percentage does increase throughout the period, the figures show that the RO introduced a slow and steady uptake of renewables. This is potentially contradictory to what would have been required to change the overall electricity market mix to reach the 20% target hoped to be achievable by 2020 (Woodman & Mitchell, 2011).

The penalty for not meeting the RO target resulted in a fine of £30/MWh of the difference between the renewable energy actually generated to the target value (Renewable Energy Foundation, 2018). This charge was put into a "Recycled Buyout fund" which was distributed to supply companies who did meet their targets. In practice, if a company bought 5% of the total ROCs required to meet the overall target then they would receive 5% of the recycled fund. This method meant that companies could decide to not fully comply with their target, to ensure the buyout fund had revenue for them to recoup for the overall percentage they did contribute. If all suppliers did meet their targets, then the recycle fund would be empty and no company would receive the bonus payment.

As the value of the ROC fluctuates on the market, it can be hard for supply companies to determine if it would be economically advantageous to pay a premium for ROCs or to take the fine for not meeting the target.

Also, in terms of generation, it can mean companies have to decide to commission a renewable generation plant dependent on the return value predicted from ROCs. If renewable energy and the equivalent ROCs are highly sought after, then the profit the generator can make is inflated. If ROCs are not in demand the generating company could potentially receive no income from their certificates and the corresponding electricity generated. As more renewable generation plants are built, the value of a ROC is predicted to fall and therefore it becomes less viable for a generating company to build a new plant. The Renewable Obligation although helped drive the market in renewable electricity it also potentially stalled further developments. Targets for suppliers had to be increased at a comparable rate to the percentage renewable electricity available to ensure new generation is created. However if targets are higher, the price of ROCs would also remain high.

Figure 4 below was taken from Woodman and Mitchell's 2011 paper "***Learning from experience? The development of the Renewables Obligation in England and Wales 2002–2010"*** and was developed from information from OFGEM. The flowchart highlights the ROC process clearly and effectively, indicating the cash flow between generators, suppliers, OFGEM and energy brokers by means of ROCs.

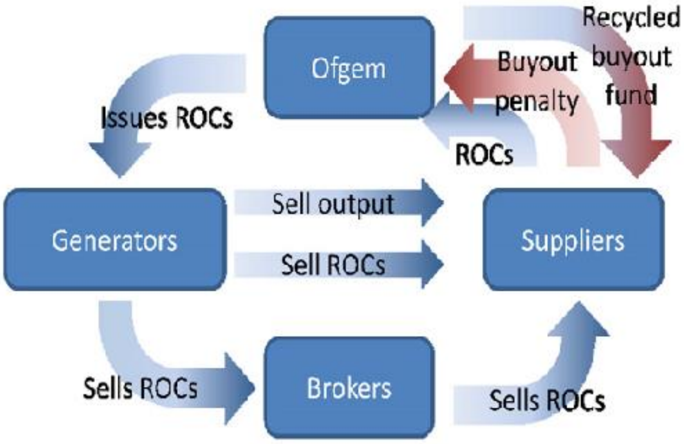


Figure 4: Renewables Obligation process (Woodman & Mitchell, 2011)

The renewables obligation offered much more flexibility than the NFFO as it allowed suppliers to have much shorter-term agreements with generators, but the risks involved in guaranteeing the targets were met were much higher for suppliers within the RO than within the NFFO. The Renewables Obligation was supposed to be technology non-specific as it initially had no technology banding, yet it was much more difficult for the less researched technologies to gain funding as they were ultimately more expensive. Therefore, the majority of renewable generation methods installed during the renewables obligation period were onshore wind and solar PV which had been heavily invested in other regions of the world. Newer technologies and those unsuitable in the leading renewables countries were not invested in, e.g. offshore wind and wave which were not viable technologies in many of the major countries involved in renewables and the RO did not allow flexibility to test the viability in the UK for these technologies.

Also, due to the risks involved in constructing a renewable generation plant and the uncertainty of generating enough electricity and therefore enough ROC certificates to be sold to suppliers, the Renewables Obligation was fairly biased towards large companies. Due to the need to have the capital requirements and certainty of electricity output, many smaller scale companies could not afford to take the risk to build a large windfarm which may not payback economically as quickly as desired (Mitchell & Connor, 2004).

The Renewables Obligation was reformed in 2009 to reverse the initial decision to have no technology banding. This change was to spark development in different renewable technologies as the 2002 set up was very predisposed towards well researched and implemented technologies: landfill gas and onshore wind. In the 2009 reformation, the most advanced technologies had their ROC/MWh value reduced or frozen and less advanced technologies were awarded more ROCs/MWh.

Generation Technology	**ROCs/MWh**
Landfill Gas	0.25
Sewage Gas and Co-firing of biomass	0.5
Onshore Wind	0.9
Offshore Wind	1.8
Wave, Tidal Stream	5

Table 2: ROC bandings after 2009 reformation (BEIS, 2017)

The Renewables Obligation ended in 2012 with all schemes closed by March 2017 with some technologies such as onshore wind closed May 2016.

Similarly to the NFFO there were many failures of the RO both internal to the policy and from external influences. One of the major downfalls of the legislation, was that developers had to take on the risk to increase the renewables percentage by 7% from 2002 to 2011 to reach the 10.4% target. Therefore, in 2003 the target was changed to be 15% by 2015-2016 to allow adequate time for developers to finance and construct projects to meet the targets (Mitchell & Connor, 2004).

Woodman and Mitchell conclude, in their 2011 paper, that the nature of the renewable obligation changed significantly throughout the life of the legislation. The first issue of the obligation was that the legislation encouraged competition into the renewable market which ultimately morphed into an obligation that offered more stability for investors in mature technologies than those researching and developing infantile technologies. Woodman and Mitchell do however state their opinion that the Renewables Obligation is far riskier to investors than similar Feed in Tariff (FIT) schemes employed in other western European countries. Therefore even by making changes to the banding of technologies, the UK legislation would have been lacking in comparison to FIT schemes (Woodman & Mitchell, 2011).

A major criticism of the Renewables Obligation was that it was introduced to meet the European targets to reduce CO2 emissions but it only benefitted large electricity generation plants and no parallel policy was created to reduce emissions produced by heating our homes or transportation. Also, the cost of energy had to be cheaper than the 6–7p/kWh and almost all emergent technologies could not compete with this figure (Mitchell & Connor, 2004).

Mitchell and Connor state the three key risks introduced by the Renewables Obligation in their energy policy 1990-2003 paper which was published in 2003 as:

- Price risk
- Volume risk
- Market risk

Some of the major risks that followed on from the NFFO were also highlighted in Wood and Dows 2011 paper, these included: limited lifespan of the mechanism, too much focus on keeping costs low and excessive competition. Major external influences that caused failure were grid and planning permission issues and New Electricity Trading Agreements/ British Energy Trading and Transmission Agreement (NETA/BETTA) issues (Wood & Dow, 2011).

NETA ensures that all electricity generated is despatched from one systems operator and generators must inform NETA of their electricity availability and bid to be allowed to produce electricity from their system (Mitchell & Connor, 2004).

Woodman and Mitchell highlight that it was not only the RO that stopped growth in the renewables sector in the UK:

"It would be wrong to suggest that the design of the RO was the sole reason for the UK's slow deployment of renewable generation. Two other factors – the planning regime and access to the network – also play an important role."

The Beauly – Denny upgrade took three years to go through the planning stages, which was a much needed grid upgrade which potentially hindered development of many large scale renewable generation facilities in the North of Scotland (renewableUK, 2007). Also, many projects that reached planning stages did not get final planning permission, with only 25% of the wind energy capacity applied for, being accepted for planning approval. It is thought that the transmission grid between Scotland and England was to blame for this low approval rate as there was a rush of project applications north of the border yet the transmission grid was not be able to accommodate that level of electricity.

2.5 Contracts for Difference

Electricity Market Reform (EMR) is a UK government policy change first documented in July 2011 in a Government White Paper. The change in energy policy in effect enabled more governmental control over the renewable generation market as well as allowing nuclear generation to be brought back into the energy generation discussion (Toke, 2011b). Likewise, to previous policies (NFFO and RO) the main aim of the Electricity Market Reform (EMR) is to decarbonise the electricity market.

The pressures on the government were heightened during the release of the White Paper to ensure renewable energy did not compromise the strength of the National Grid and its capacity. Many major fossil fuel plants closures were discussed and this is supported by plants now being decommissioned such as Ferrybridge and Longannet with the UK government hoping to decommission all coal plants before 2025 (Cockburn, 2017).

Longannet had the generating capacity of 2400MW and was the highest capacity plant in the whole of Scotland. When Longannet shut down, a massive proportion of despatchable generation capacity was lost and the quantity of instantly available electricity supply was compromised. These closures would have played a major decision in how the carbon emissions goals would be thought to be achieved by the UK government and therefore potentially influenced a policy that was not discouraging towards nuclear energy.

In the 2011 paper ***"UK Electricity Market Reform – revolution or much ado about nothing?"*** David Toke discusses the 4 key parts of the EMR proposal:

- Floor carbon price
- Contracts for difference for Nuclear Power
- Contracts for difference for Renewables
- Capacity payments

In his paper, he states that the "carbon floor price's" primary goal is to increase the cost to produce fuel by means of gas or coal. However, the price that is actually paid for carbon generation is not high enough to deter production and even with the fee is still arguably cheaper or on a similar level to other generation types (Toke, 2011b).

In terms of Contracts for Difference, Toke identified a potential ambiguous element in the way subsidies may be awarded. It may be difficult to distinguish between Contracts for Difference awarded to nuclear or renewable plants as they will all fall under the same umbrella (Toke, 2011b).

The push for nuclear generation in the UK is coming from many different bodies such as EDF energy and the Committee on Climate Change (CCC). The CCC's main focus is how the UK can aim to reduce carbon emissions by 80% by 2050 and they have carried out many studies in how this figure can be realistically achieved.

In 2011, the CCC called for the construction of offshore wind to be constrained as they concluded nuclear energy was the most effective zero carbon fuel source. In his 2011 paper, Toke argued that the estimate of costs made by the CCC were not accurate and the conclusions made could not be relied upon as onshore and offshore windfarms were possibly compared at higher than precise costs, in terms of construction (Toke, 2011b).

However, in the 2018 progress paper published by the CCC they were still confidently backing the requirements for nuclear generation to be added to the UK through the Hinkley Point C project.

"…at least 130-145 TWh of low-carbon generation should be added in the 2020s to reach the 255-270 TWh of low-carbon generation in 2030…. We would expect another 70 TWh to be delivered through funding already announced for further Contract-for-Difference auctions, and through the successful delivery of the nuclear plant Hinkley Point C…" (Committee on Climate Change, 2018)

The issues caused by expensive electricity generation through the Renewables Obligation are expected to continue in the CfD scheme due to electricity suppliers having to trade on the electricity market.

In 2011 Toke, stated that ***"Investment in wind power is in fact a (politically) safer and certainly more knowable bet than nuclear power."***

However, we now know that the UK government chose to fund Hinkley point C over a wind energy alternative (Toke, 2011b) and (Vaughan, 2017).

The Contracts for Difference scheme is a support mechanism for low carbon generation and is essentially a legal contract between the developer or electricity generator and the government Low Carbon Contracts Company (LCCC) (renewableUK, 2015). Contracts last for 15 years and are awarded for a given 'Strike Price'. The developer can guarantee to be awarded the Strike Price (£/MWh) for each MWh of energy generated and therefore the developer can guarantee a profit even if their cost of generation is below the strike price.

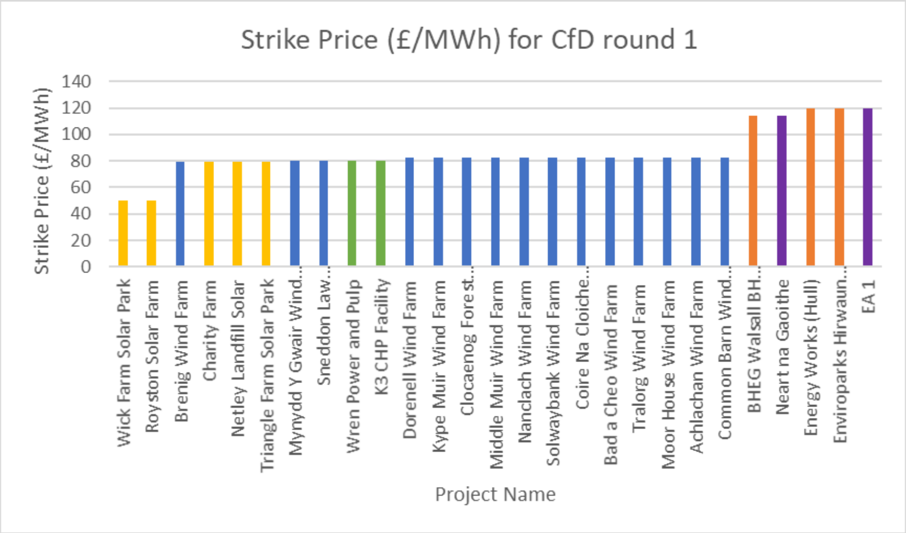
The LCF (Levy Control Framework) is the body that caps the annual spend on low carbon generation. The Budgets set are shown below in Table 3 with the total projected spend being £7.6 billion by 2021.

Period	**2015/16**	**2016/17**	**2017/18**	**2018/19**	**2019/20**	**2020/21**
LCF Budget	£4.30bn	£4.90bn	£5.60bn	£6.45bn	£7.00bn	£7.60bn

Table 3: LCF Budgets per year (DECC, 2013)

BEIS is the owner of the private company LCCC and they decided to release the CfD funding annually up to the total amounts shown in Table 3**.** Round 1 of the allocations took place on 26 February 2015 with contracts awarded to many different types of generators with strike price values ranging from £50.00/MWh to £129.89/MWh.

Figure 5 below shows the difference in strike price range per technology. Only two offshore wind projects had successful bids in 2015 at £114.39/MWh and £119.89/MWh. In contrast, the Solar PV projects had the lowest strike prices, and onshore wind and energy from waste being middle table. Advanced conversion technologies also had very high strike prices similar to offshore wind. In accordance with DECCs categorization of solar PV and onshore wind being established technologies, it is not startling that PV is the cheapest and onshore wind being the most abundant in awards.



Solar PV	🟨
Onshore Wind	🟦
Offshore Wind	🟪
Energy from Waste with	🟩
Advanced Conversion	🟧

Figure 5: Awarded Strike Prices for CfD round 1 (DECC, 2015)

However, although only being awarded two projects, offshore wind was in fact the highest capacity winner by far. EA 1 project scheduled to be developed by Scottish Power Renewables beginning 2017-2018 was a massive 714MW capacity and Neart na Gaoithe offshore windfarm due to be developed 2018-2019 on the east coast of Scotland was 448MW. These massive farms ensured that over 50% of the capacity allocated was to offshore wind with a further 35% to onshore wind distributed between 15 different farms.

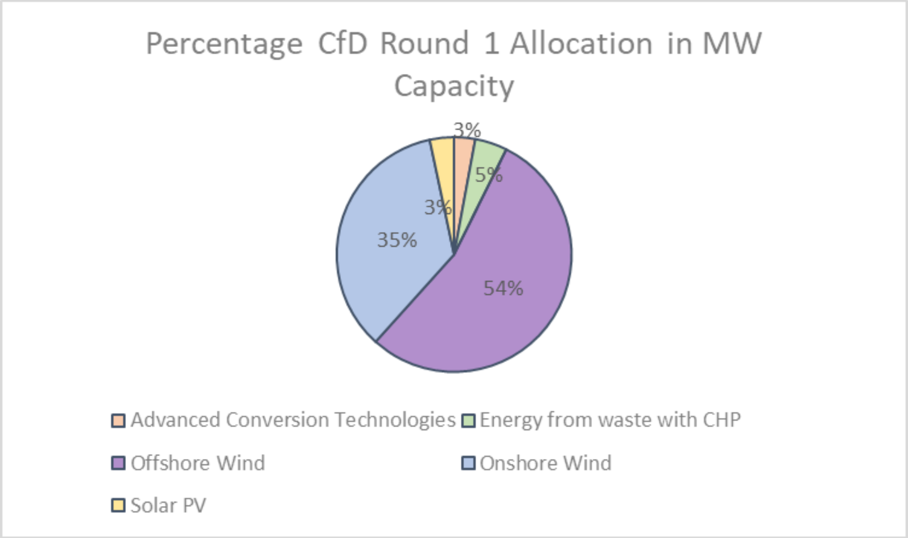


Figure 6: CfD Round 1 Allocation Percentage Award per Technology

Contracts for Difference is operated similarly to a bid process with the lowest bidding projects likely to be most successful. However, it is also essential to award to a variety of different technologies and also to award enough contracts to ensure a suitable MW capacity is awarded. In 2015, a total capacity of 2138.9MW was awarded.

Round 2 Allocation results were published in 2017 with a reduction of the number of projects being awarded from 27 in Round 1 to 11 in Round 2. However, many of the successful projects were very large-scale offshore windfarms with three projects totalling 3196MW capacity.

Interestingly, the strike prices for Round 2 contracts had vastly reduced from 2015 to the 2017 awards for offshore wind. The strike prices had reduced from £119.89 - £114.39 /MWh to £74.75 - £57.50 /MWh.

Looking to the future, it is expected that between 1 and 2GW of contracted capacity may be awarded for offshore wind in the third allocation round of CfD, to be installed after/throughout the 2020s. The third auction will take place in May 2019 and is expected to allow onshore developments on small islands to bid for contracts which may modify the generation composition in Scotland and its islands.

Contracts for Difference has been in legislation since 2016 and has modified the way in which renewable generators make an income from their developments. There is much more control for generators and security that they will receive dividends from the electricity generated. Also, there is less uncertainty with the removal of ROCs that they must try to gain power purchase agreements from suppliers not only for the electricity but also the certificates.

However, there has been a huge reduction in the number of onshore windfarms being developed in the UK but CfD has driven the UK’s offshore wind industry to be the most successful offshore wind industry globally.

2.6 Policies in other EU countries

The UK has implemented many different policy types throughout the years of private electricity with different aims and objectives.

In 1990, the first system implemented was quota based with the NFFO. Then in 2002, the renewables obligation was introduced which was essentially a Renewable Portfolio standard. A renewable portfolio standard is a mechanism which ensures that electricity supply companies purchase a set percentage of the electricity they sell to the consumer from renewable generation sources. The RO was thought to be a more successful policy than the NFFO, as it was a more market based subsidy, and the RO also ensured renewable electricity generators had to be much more involved in the electricity market and have an increased awareness of the cost of production and their individual place within the market. The RO mechanism is fully dependent on energy supply and demand and as the required electricity production fluctuates, the value of the certificates (ROC) fluctuate with the electricity demand of the end consumers (Mitchell et al., 2006).

During the period of NFFO and RO, Germany, Denmark and many other European countries with large quantities of renewables, consistently stuck to a Feed in Tariff type policy to promote renewable electricity in their countries.

The feed in system most commonly utilised is entirely dependent on the market price of electricity and therefore it ensures that the generator company will always receive a price above the market value for the electricity they produce as the premium payments are pre-determined by the legislation.

In Lipp's paper ***"Lessons for effective renewable electricity policy from Denmark, Germany and the UK"*** she states that RPS or RO is too prohibitive to small companies due to the price criteria and less financial security than for bigger players. She indicates that fixed price premiums are thought to create more market certainty which would encourage investment and development from all sized companies (Lipp, 2007).

Therefore, her paper essentially states that the policies implemented in Germany are far more likely to lead to an uptake of renewable generation than the policies enforced by the UK government. This can be corroborated by the quantities of wind turbines installed in Germany in comparison to the UK during this period. In 2001, the capacity of onshore wind in the UK was approximately 474MW whereas in Germany it was 8754MW, by 2010 the UKs capacity had increased significantly to approximately 5259MW, but Germany had also increased their capacity by 18333MW.

Although the UK managed to increase their wind capacity significantly within the period they were unable to keep up with the front runners of wind power, despite the UK being the windiest country in Europe.

Another major hindrance to UK wind power development was planning constraints.

"The UK planning debacle is, in large part, caused by a small number of RE (especially wind) dissenters who have managed to yield incredible influence over local councillors who ultimately make the decisions about which projects can go ahead" (Lipp, 2007)

The UK planning legislation can be lengthy and hindered by many parties. There were no measures taken by the government to ensure that local council areas and governments were taking the same view on renewable energy projects and subsequently many windfarms' planning permission requests were denied, with others taking over 10 years to be granted. With the uncertainty of planning permission timescales, there was a lack of confirmation as to whether projects would reach development stages in time to be granted NFFO or RO funding. Another major unknown factor for development of a wind project in the UK was grid connection costs. Many of the planned wind farms were/are in far remote areas of the country, particularly north of Scotland, and the grid connection costs would be more costly. Developers have to contact their local DNO to request a connection cost for their project and this can vary massively due to the capacity available on the grid at the desired connection location.

However, in Germany the EEG guaranteed a grid connection for any renewable generator as well as preferential despatch and this ensured that it was less risky for a small generator to connect to the grid (Bensmann, 2010).

However, although the EEG was successful in aiding Germany to become a front runner in renewable energy, it has been criticised for not being robust enough to meet the goals for climate change set by the German government. They desired 80% of the electricity to be generated from renewable resources by 2050.

3 Research

3.1 Methodology

To ensure the research and analysis for the thesis study was conducted accurately and efficiently, a concise methodology was followed. The key background research areas and the analysis areas investigated are shown in the flowchart below (Figure 7).

Figure 7: Methodology of Analysis

The main focus of this research is to identify if the energy policies implemented by the government, had a positive effect on renewable energy projects being developed. It was therefore imperative that a sound understanding of the policies used in the UK was found. This research on policy was mainly conducted by reading journal papers and textbooks but also government papers and documents. It was also useful to gain information from news articles and renewable energy developers and generators, as the main affectees of energy policy.

Secondly, it was deemed appropriate to have a large proportion of the research focussed on renewable generators. The main technologies studied were: onshore wind turbines, offshore wind turbines and marine technologies including wave power, tidal barrage, tidal stream and current turbines. These technologies were chosen due to both their level of advancement being very varied, their current dependence on legislation being at different requirements and the level of overall global uptake varying significantly.

Technologies were researched in detail to determine the best options to study against the policy. Hydro power has been a well-established technology in the UK and specifically in Scotland since the 1900s and it is also a technology that can only be established if the geology of the landscape is appropriate. In conjunction, although solar

PV technology can be installed successfully in the UK, it was felt that it is unlikely that Britain will ever harvest large quantities of solar energy similar to the USA’s Topaz Solar Farm producing 550MW (Sneed, 2014), as the largest solar farm currently in the UK is Shotwick solar farm with 72MW peak capacity (Tisheva, 2017).

After deep research into the technologies chosen, and the influences on increasing generating capacities in the UK, a select number of individual projects or case studies were chosen to be studied in greater depth. The projects chosen feature different policy implementation upon project construction, varying size of project and different motivations for construction. The key projects researched are documented in this report in the subsequent sections.

Key factors studied were: project development, timescales, size of capacity, overall cost and risk, as well as the success rate of the projects.

Ultimately the risk and cost of the different technologies were identified to play a key role in the development of projects and subsequent works. Therefore, these two factors were studied in more depth to establish if policies were aiding to reduce these factors or if the risk and cost uncertainties were maintained throughout the transformation of energy policy in Britain.

By studying these factors, it was desired that a forecast for the future of renewable energy in the UK would be predictable and whether, as some of our older onshore wind turbine projects begin to reach the end of their lifetime, if the future of renewables will still be dominated by wind power.

3.2 Onshore Wind Technologies

Onshore Wind is wind energy that is extracted through the deployment of a wind turbine situated on land with a connection to the National Grid electricity network. Scotland has been recorded to be the most wind abundant country in Europe and currently there are 536 windfarms operating successfully in Scotland of varying size (renewableUK, 2018). Scotland is also home to Whitelee Wind farm, which is the largest onshore wind farm in the UK and the second largest in Europe after Fântânele-Cogealac Wind Farm in Romania (The Wind Power, 2018).

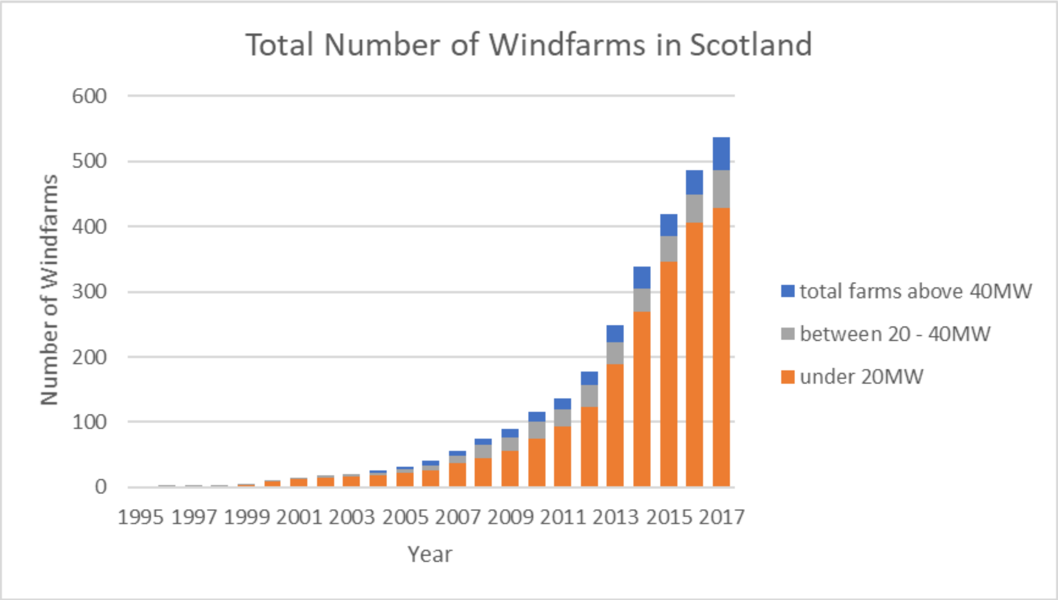


Figure 8: Cumulative Total Number of Windfarms in Scotland

Figure 8 above shows the progression of wind energy extraction through wind turbines since 1995, with the blue portion of the bar indicating windfarms above 40MW, grey being farms between 20MW and 40MW and the orange bars show windfarms below 20MW capacity. It is clear from the graph that there was an exponential growth in the construction of windfarms, as after 2007, the total number of farms grew dramatically from 56 to more than double the value in 2010 at 115. There was a continual rise in quantity of windfarms, but interestingly the quantity of medium sized and large windfarms increased equivalently. In 2018, we have 536 windfarms with an overall capacity of 7751MW which is equivalent to 74% of the total renewable energy capacity of Scotland (Waters & Spry, 2018).

3.2.1 Hagshaw Hill Windfarm

The first commercial windfarm built in Scotland was Hagshaw Hill Windfarm located near to Douglas in South Lanarkshire. Hagshaw Hill began operation in 1995 with 26 Bonus B44/600 turbines and had a maximum generating capacity of 15.6MW.

The windfarm was developed by a consortium company, Trigen and comprised of three separate entities: Tomen of Japan, Seawest of California and Ecogen of Cornwall (Gazeteer for Scotland, 2016). Hagshaw Hill proved that extracting energy for the wind not only made ecological sense but economical sense too as it was a fuel cost-free technology with the potential to generate large quantities of carbon free electricity.

In 1996, the windfarm was purchased by Scottish Power for £15 million. It is thought the sale happened due to the windfarm being less economically successful than initially intended. Controversially, this may have been due to difficulties in receiving funds from the SRO (Scottish version of the NFFO) which caused financial trouble for the company.

The consortium company could not recoup the initial capital cost they had expended at the rate they needed to make the windfarm profitable to them and therefore selling to Scottish Power made financial sense. With Scottish Power already being a major player at the time, in the wind energy industry in Wales, they would have been more financially stable to take on the risk of late payments from the SRO.

Scottish Power would potentially also have had a greater influence in ensuring the payments were received due to their position as one of the big six generating companies and also one of only two grid operators in Scotland (Wind Power Monthly, 1996).

Additionally, there were already controversies in the SRO policy creation, the potential reason for a hinderance to the initial success of Hagshaw Hill. The NFFO had been well established by 1995 in England and Wales, however the first version of the SRO had only just been formulated by the Scottish Government and it was stated that the developers of Hagshaw Hill had potentially acted too soon in their construction of the windfarm.

However, NFFO – 3 and SRO – 1 are documented to have become legislative from 1994 and it was also reported that Scottish Power and SSE were charging grid connection prices 50-100% more than thought acceptable from global project experience. Therefore, it could be speculated that the project was compromised from the outset due to escalated grid costs and teething problems with the SRO funding (Safe Energy Journal, 1995).

As Hagshaw Hill was built in 1995 it fell under the times of the NFFO (SRO in Scotland) and therefore Hagshaw Hill was obliged to have a Power Purchase Agreement with Scottish Power. A power purchase agreement essentially ensures that the electricity generated will be bought by the electricity distribution company and sold to the consumer. The PPA would have been to a set value of £/MWh for electricity generation and therefore a guaranteed source of income for the windfarm.

In 2006, when the NFPA Scotland became the electricity purchasing body the generated output from Hagshaw Hill was sold through the Renewables Obligation (RO) earning ROCs for the electricity produced. Hagshaw Hill has earned approximately 2400 ROCs per month since April 2006 to March 2018 for its 15.6MW capacity and therefore averaging approximately 21% capacity factor. The majority of the ROCs generated from Hagshaw Hill since 2006 were purchased by Scottish Power Energy Retail Ltd (OFGEM, 2018c).

Hagshaw Hill was further upgraded in 2008 with the addition of 20 Siemens SWT-1.3 turbines which increased the windfarm to a figure of 41.6MW generating capacity. This upgrade of 26MW would have been also eligible to receive Renewable Obligation Certificates for the electricity generated.

Figure 9 below shows the ROCs received for Hagshaw Hill extension from 2009 to 2017.

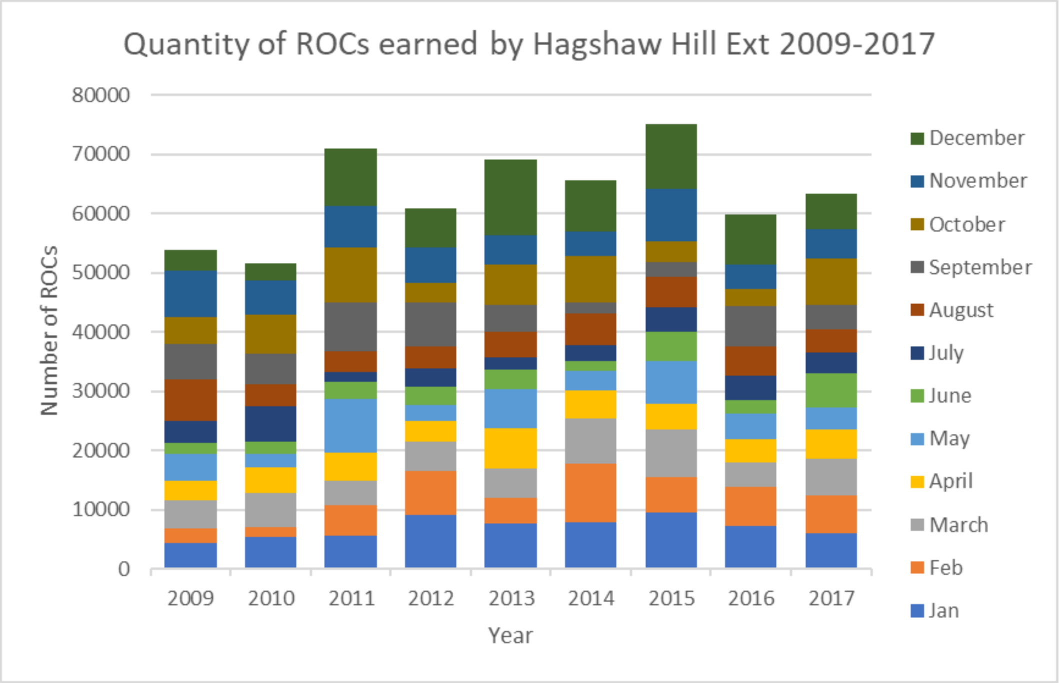


Figure 9: Quantity of ROCs earned by Hagshaw Hill Extension 2009 – 2017

It is clear from the graph that the number of ROCs earned by the Hagshaw Hill extension varies considerably month to month. The highest value of ROCs in a month was earned in December 2013 and the highest number of ROCs earned in a year was 2015. 2015 was recorded to be Scotland’s windiest year and therefore the quantities are realistic of the potential electricity generated by wind (Met Office Press Office, 2014).

Below in Figure 10 a graph of the total potential income generated at Hagshaw Hill through the trading of ROC certificates.

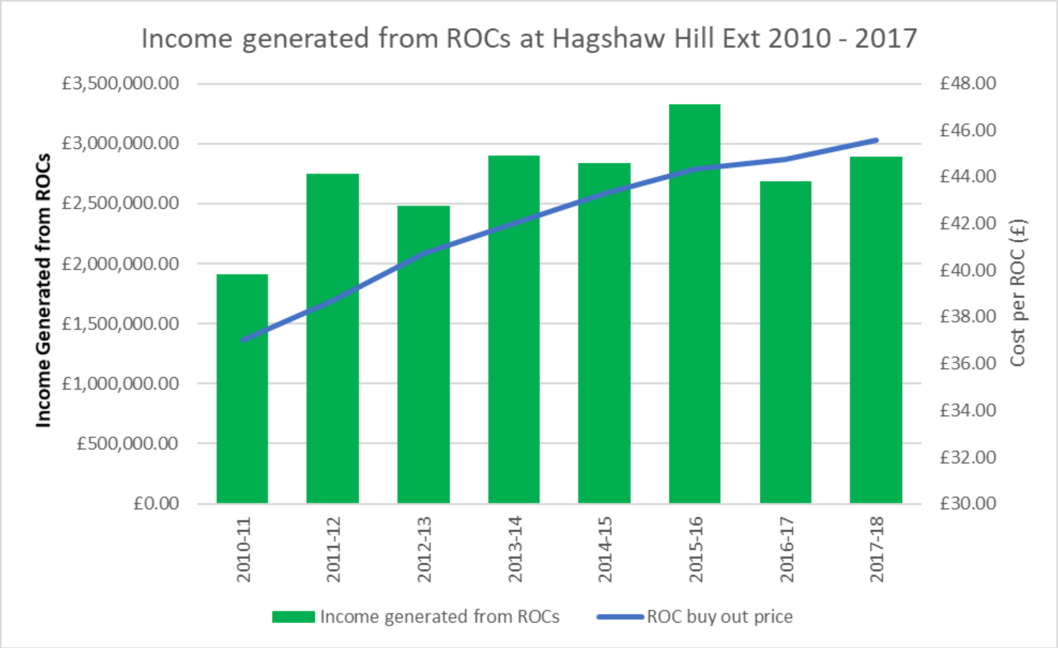


Figure 10: Income Generated From ROCs at Hagshaw Hill Extension

The graph depicts the ROC buyout price each year from 2010-11 through to 2017-18 with the blue line. The ROC value rose from £36.99 in 2010-11 to £45.58 in 2017-18. On the graph in Figure 10, the green bars indicate the total value that could have been generated from the sale of ROCs. The quantity of ROCs was taken from records generated by OFGEM. As 2015 was the year generating the highest number of ROCs, the income potential for this year was the greatest at £3,329,227. These values of income are calculated from the total recorded ROCs earned multiplied by the average ROC buy out price for the same period. Therefore the figures are purely representative and do not accurately depict the income earned by Hagshaw Hill Wind farm.

3.2.2 Whitelee Windfarm

Whitelee Windfarm is the UK’s largest windfarm with 215 Siemens and Alstom turbines with a total capacity of 539MW and can generate enough electricity to power up to 300,000 homes. Whitelee Windfarm is located near Eaglesham approximately 15km from Glasgow city centre and is connected to the national grid to support the UKs electricity network.

It was constructed in two phases, Phase 1 consisted of 140 Siemens 2.3MW turbines and was operational from February 2008, Phase 2 added an additional 75 Alstrom Power 100 3MW turbines and it became operational from April 2012.

It was constructed and owned by Scottish Power and currently has the second highest capacity of any power plant in Scotland after Peterhead Gas fired power plant.

Both phases of Whitelee were built during the Renewables Obligation period and therefore for every MWh of electricity generated Whitelee is awarded an equivalent amount of ROCs. Onshore wind was awarded one ROC per MWh in Scotland until 2013 and therefore both Phase 1 and Phase 2 of Whitelee Windfarm would have been awarded Renewable Obligation Certificates at 1ROC/MWh in 2008 and 2012 respectively and the government support for the windfarms will end in 2028 and 2032.

Whitelee Windfarm was the largest wind energy project built in Europe when it was constructed and it was representative of Scotland’s abundance of wind resource, however it also indicated a turning point for onshore wind technology in the UK. Previously, wind projects had been modest in size due to factors including capital cost and many potential construction risks and the largest wind project installed in Scotland prior to Whitelee had been Hadyard Hill Windfarm in Ayrshire. Hadyard Hill had 52 x 2.3MW turbines and a maximum capacity of 120MW.

As stated before, both stages of Whitelee Windfarm were eligible to receive ROCs for the electricity generated. The capacity of Whitelee was 322MW from 2008 until 2012 when it increased to 539MW. Below Figure 11 indicates the total quantity of ROCs earned by Whitelee from 2008 until 2017 per month and overall. The average number of ROCs generated by Whitelee over its life so far is 62864.52 certificates, indicating an average monthly generation of approximately 63,000MWh of electricity.

63,000MWh per month would equate to each turbine generating 400kW of electricity per hour, for turbines of 2.3MW would indicate a capacity factor of around 17% which may indicate that Whitelee does not operate at its full potential.

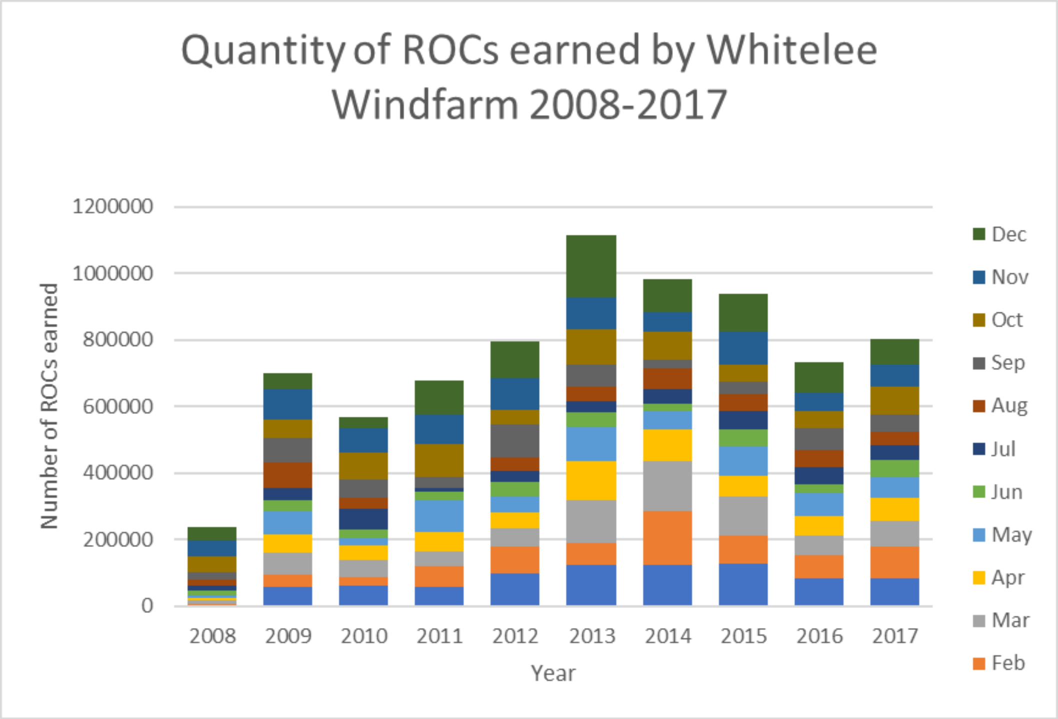


Figure 11: Quantity of ROCs earned by Whitelee Windfarm 2008 - 2017

Figure 11 shows the peak of ROC income for Whitelee was in 2013, the year after Phase 2 was completed and therefore the first whole year with 539MW capacity. It is surprising, however, that the total number of ROCs earned in 2016 and 2017 were similar to the number of ROCs earned in 2011 and 2012, shown in Table 4.

Year	**Number of ROCs earned**
2008	237,104
2009	699,488
2010	566,392
2011	677,661
2012	793,832
2013	**1,114,054**
2014	981,578
2015	937,071
2016	733,713
2017	802,849

Table 4: Total Quantity of ROCs earned at Whitelee Windfarm

Also, with 2015 being noted as the UK’s windiest year (Blog.metoffice.gov.uk, 2015) and nearby Hagshaw Hill generating the most electricity in this year, it is really very surprising that Whitelee did not generate the highest number of ROCs in this year.

3.3 Offshore Wind Technologies

The UK has become a front runner in offshore Wind technologies with a massive increase in total capacity installed from 4MW in 2000 to 7155.22MW in 2018. The UK has the greatest global offshore wind resource installed with 38% of the total worldwide capacity of 18,814MW and the future of offshore wind in Britain's shores looks very prosperous (GWEC, 2018). In addition to that, 69% of all offshore wind is harvested in the North Sea, meaning the UK is situated in an area of abundance in the natural resource but also technological expertise with Germany, Denmark, Netherlands, Belgium and Sweden all in the top 10 offshore wind generating countries.

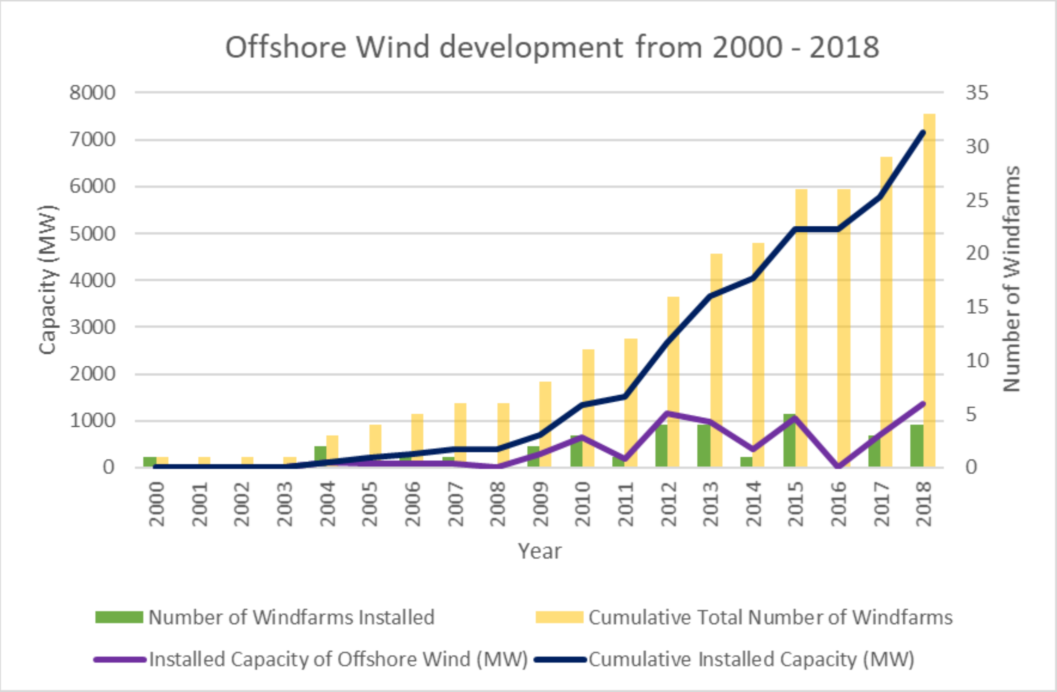


Figure 12: Development of Offshore Wind in the UK 2000 - 2018

Figure 12 shows the sharp increase in offshore wind over the past two decades and the offshore projects indicates the positive future predictions for UK offshore wind in the future. Unlike onshore wind in the UK, the majority of offshore windfarms are situated on English coast lines, as a much more densely populated country than Scotland, offshore wind has allowed England to make much greater progress in increasing the renewable energy generated south of the border.

3.3.1 Robin Rigg Windfarm

Scotland’s first offshore Windfarm was Robin Rigg Windfarm situated in the Solway Firth between Galloway and Cumbrian Coast lines within the Irish Sea. Robin Rigg Windfarm was developed by E.ON and was completed in April 2010 (BBC, 2009).

The Robin Rigg project was split into two project areas East and West, with a total capacity of 174MW with 58 x V90-3.0MW Offshore Vestas turbines (E.ON UK, 2018).

The turbines are supported by foundations that extend up to 40m deep into the sea bed and the power generated is connected to the shore via two 132kV lines which connect to the grid via a substation 2km from the shoreline. The substation is near to Seaton in Cumbria. Therefore, although being in Scottish territory waters, the substation and where the electricity is connected to the grid is in England.

The project costs were documented to be a total of £381million including all capital costs and installations (4C Offshore, 2018).

As Robin Rigg was installed in 2010, the electricity generated would be eligible to gain ROCs under the Renewable Obligation scheme, Robin Rigg would have qualified for the higher value of 1.8ROCs/MWh. It is documented by OFGEM that all of the ROCs generated by Robin Rigg Windfarm had been purchased by E.ON energy, the owner of the windfarm.

Since Robin Rigg became operational, two turbines have been decommissioned in 2015, lowering the farms capacity to 168MW. The two turbines were decommissioned due to faults in the grout of the monopile and foundation connection and the damage done to the sea bed being too much to repair (4C Offshore, 2018).

Therefore, as well as being Scotland’s first windfarm, Robin Rigg is an example of the potential damage that can be done when errors are made during the project construction and installation. Large sums of money were wasted in the purchase of the two decommissioned turbines and the repair works to the other affected foundations, but damage will also have been done to the reputation of the companies responsible for the errors.

3.3.2 Beatrice Windfarm

When Beatrice Windfarm becomes operational in 2019 it will become Scotland’s largest windfarm, taking over from Whitelee onshore Windfarm. It will have an installed capacity of 588MW over 84 turbines with 7MW capacity.

Beatrice began as a demonstrator project in 2007 with two 5MW turbines. The initial demonstrator project was used to determine if the deep-water site close by the Beatrice Oil field was a suitable location for an offshore windfarm. As the demonstrator was successful, Beatrice windfarm began construction in 2017 and is being constructed north of the original demonstrator project in the Outer Moray Firth in the North Sea and is being led by SSE, the main investor in the Beatrice Project.

Beatrice will have two dedicated substations onshore, converting power from 220kV from the OTM’s (Offshore Transformer Module) to 400kV for transmission on the national grid from the substations at Blackhillock (Modern Power Systems, 2018). The progress from Robin Rigg to Beatrice has been impressive. The capacity of Beatrice is 3.5 times larger than Robin Rigg and the turbines size is drastically bigger at 7MW vs. 3MW.

Robin Rigg was evidence that offshore wind had the potential to be successful in Scotland and pushed the development of larger projects such as Beatrice to be possible. Beatrice has required new substations to be constructed, large shipping vessels to be contracted for the construction of the farm and subsequently expert engineering design works in all engineering disciplines (McCabe, 2015).

BOWL (Beatrice Offshore Windfarm Ltd) was awarded an investment CfD contract (an early variation of Contracts for Difference) under the Government’s reform of the electricity market on 23 April 2014 (DECC, 2014). The strike price awarded to BOWL was £140/MWh, however, the adjusted strike price currently in 2018 is £155.53/MWh after inflation adjustments.

Beatrice will begin operation in 2019 and income from the CfD contracts will be known after this time. However, with a 588MW capacity operating at a potential capacity factor of 37.8% (average capacity factor for offshore wind in the UK) the windfarm could be generating income from the electricity generated, with the CfD strike price at

£155.53/MWh, of £829,000 per day. With the total project costs stated at £2600 million the Beatrice windfarm will have paid off the capital costs expended in the installation and construction in under 10 years and will be generating carbon-free electricity for over 400,000 homes per year for an expected 25 years.

3.4 Marine Energy Technologies

Marine Energy refers to both wave power which is energy captured from surface waves and tidal power which is energy extracted from the movement of water from tidal patterns.

The UK is the global leader in marine energy technologies and is home to the European Marine Energy Centre (EMEC) based in Orkney which opened in 2003.

EMEC hosted six developers in 2017: ECOG, Nautricity and Scotrenewables Tidal Power all based in the UK, OpenHydro based in Ireland, Netherlands-based Tocardo and Finnish wave developer Wello. EMEC has the capability to accommodate testing of many different tidal and wave technologies.

In 2017, 18MW of wave and tidal energy generating capacity was installed, an increase from the 13MW listed in 2016 (Waters & Spry, 2018). However, the installed capacity for wind and tidal collectively is still only a fraction of other renewable generation capacities in the UK.

Marine technologies are not new with the first large scale tidal power project being operational in 1966 in France, La Rance Tidal Power Station. La Rance has a capacity of 240MW and on average produces 500GWh of electricity per year which is a small fraction of France’s electricity usage. However, the La Rance tidal project demonstrates that not only can energy be harvested from the sea effectively, the technology will have the capability to operate for a long time. La Rance has been operational for 52 years currently with one major renovation after celebrating 30 years of generating electricity. There are currently no plans for decommissioning as it is clear that the technology has proved successful.

Tidal energy benefits from the reliability of the medium utilised to extract energy. The tides can be predicted very consistently and therefore the energy output for a tidal device can also be predicated consistently. However, as there are only two tides per day the devices can only operate during these times which may not always be valuable. Though, with the UK and Scottish Government striving to reduce the carbon content of energy generation, all renewable sources are highly valuable and sources that can be predicted can aid in the reduction of fossil fuel power station operation. The main downfall with tidal stream technologies is the location limitations due to strong tides being required in useful locations for energy extraction.

3.4.1 MeyGen Tidal Stream

The MeyGen project in Scotland's Pentland Firth between the Scottish mainland and the Island of Stroma, operated by Atlantis Resources, currently has four 1.5MW turbines installed with a total generating capacity of 6 MW (Jeffrey, H and Pennock, S., 2017). The MeyGen turbines harvest the tidal stream energy in a similar fashion to wind turbine electricity generation, with the flow of the tide turning the turbines. Currently, only 6MW of capacity has been installed but Atlantis Resources has an agreement with the Crown Estate for up to 398MW of tidal stream energy installed capacity, meaning MeyGen is the largest tidal stream project in the world.

Figure 13: MeyGen Turbine being installed in the Pentland Firth (James Fisher, 2014)

One of the major issues with any tidal installation is the difficult working conditions. High tides are often found off remote coastal areas with limited road access, with increased difficulties guaranteeing a grid connection. Therefore, the main reasons the Pentland Firth location was chosen for the MeyGen project was the high tidal flow of the area and the proximity to a grid connection with spare capacity on the main land.

In terms of the MeyGen project, David Taaffe, MeyGen's director of project delivery stated:

"The best tidal energy sites are located in areas with the highest tidal flows. By nature therefore, there are limited periods where the tide is slack and hence we must operate with small installation windows,"

The four demonstration turbines of Phase 1A completed installation in 2016 and are now being fed into the national grid via an onshore power conversion unit at Ness of Quoys distribution network centre. The cable exporting power from the turbines to the power converter is said to be one of the longest 33kV cables in delivering power to a distribution centre in the UK, which further highlights the remote project conditions that have been overcome through the MeyGen project.

Now that Phase 1A of MeyGen project has been completed, it has begun the operation of its 25-year lifespan. Phase 1B and 1C will add an additional 53 1.5MW turbines to the grid array (SIMEC ATLANTIS ENERGY, 2018). However, there is uncertainty for the future phases of the MeyGen project due to policy issues. Phase 1A was eligible to generate electricity under the Renewables Obligation due to it being completed in December 2016. Phase 1B was awarded funding from European Commission mechanisms such as NER300 and Horizon 2020 and therefore did not require additional support mechanisms. Phase 1C was not awarded a CfD contract due to the LCOE estimated and the project being grouped with offshore wind technologies.

Table 5 below displays the ROCs earned by MeyGen Project (Ness of Quoys) from its operational beginning in 2016 until the first quarter of 2018.

All ROCs generated by MeyGen were purchased by SmartestEnergy Ltd, a small energy supplier with a commitment to purchasing energy from small scale renewable generators (Smartest Energy, 2018).

Generating Station / Agent Group	Total Installed Generating Capacity	Technology Group	Output Period	No. Of Certificates	Current Holder Organisation Name
Ness of Quoys	6000	Tidal Flow	Apr-2018	4249	SmartestEnergy Ltd
Ness of Quoys	6000	Tidal Flow	Mar-2018	6725	SmartestEnergy Ltd
Ness of Quoys	6000	Tidal Flow	Feb-2018	4736	SmartestEnergy Ltd
Ness of Quoys	6000	Tidal Flow	Jan-2018	1132	SmartestEnergy Ltd
Ness of Quoys	6000	Tidal Flow	Dec-2017	604	SmartestEnergy Ltd
Ness of Quoys	6000	Tidal Flow	Nov-2017	828	SmartestEnergy Ltd
Ness of Quoys	6000	Tidal Flow	Oct-2017	1285	SmartestEnergy Ltd
Ness of Quoys	6000	Tidal Flow	Sep-2017	3897	SmartestEnergy Ltd
Ness of Quoys	6000	Tidal Flow	Aug-2017	3508	SmartestEnergy Ltd
Ness of Quoys	6000	Tidal Flow	Mar-2017	1040	SmartestEnergy Ltd
Ness of Quoys	6000	Tidal Flow	Feb-2017	583	SmartestEnergy Ltd
Ness of Quoys	6000	Tidal Flow	Dec-2016	43	SmartestEnergy Ltd

Table 5: ROCs earned by MeyGen Project/ Ness of Quoys

MeyGen Project is eligible to receive ROC payments of 5 ROCS/MWh. Marine energy technologies were eligible for the highest ROC payments more than any other renewable technology to try to encourage growth in the number of projects being installed.

In March 2018, the largest number of ROCs were awarded to MeyGen and therefore the largest amount of electricity produced. 6725 ROCs would equate to 1345MWh of electricity generated. With 6MW installed capacity, this large quantity of electricity generated, indicates that the Phase 1A demonstrator has been a success, highlighting the energy potential of the coast of the UK.

3.4.2 Swansea Tidal Lagoon

The Swansea Bay Tidal Lagoon project was a proposed tidal lagoon project in the Swansea Bay area of Wales that was rejected by the UK Government in June 2018 as it was claimed the price of £1.3billion was too expensive (Morris, S and Vaughan, A., 2018).

A tidal lagoon is an electricity generator that creates power from the natural rise and fall of the sea tides. They work similarly to tidal barrages and capture large volumes of water within a manmade structure similar to a dam to push water through a turbine which generates electricity (Tidal Lagoon Power, 2018).

The difference in height from water inside and outside of the Swansea Bay Lagoon is already 4m and the tidal flow occurs four times a day, twice in and twice out (Tidal Lagoon Power, 2018).

The Swansea Tidal Lagoon project was being developed by Tidal Lagoon Power (TLP) and was awarded a Development Consent Order in 2015. The Swansea project began development a number of years prior to that, in 2003.

The 320MW project would have comprised of 16 hydro turbines with a 9.5km breakwater wall and could have potentially have generated enough electricity to supply 155,000 homes for the next 120 years. This lifespan of 120 years is far greater than any other renewable energy generator. Wind turbines have a lifespan of approximately 25 years, and also much higher than fossil fuel and nuclear power plants, nuclear plants are expected to last approximately 40 years (Carbon Brief, 2014).

It is therefore a certainty that the £1.3 billion, initial project costs would be repaid and a healthy profit made over the lifespan of the project.

However, the UK government rejected the plans due to it not being deemed to be affordable even after the Hendry review requested by Department for Business, Energy & Industrial Strategy concluded tidal lagoons would add benefit to the electricity network in the UK.

On 12 January 2017, Charles Hendry published his final report and recommendations of the Independent Review of tidal lagoons. He stated:

“I believe that the evidence is clear that tidal lagoons can play a cost effective role in the UK’s energy mix… I conclude that tidal lagoons would help deliver security of supply; they would assist in delivering our decarbonisation commitments; and they would bring real and substantial opportunities for the UK supply chain.” (Hendry, 2016)

The decision by the UK government to not support the Swansea Tidal Lagoon project is an indication that the policies implemented are not beneficial to newer, less established technologies and that the cost of the energy produced is the major hindrance.

4 Analysis

4.1 Onshore Wind

4.1.1 Onshore Wind Growth

Onshore wind energy has grown dramatically in the UK since the early 2000's and particularly in Scotland. Figure 14 below shows the yearly installed capacity for onshore wind in Scotland.

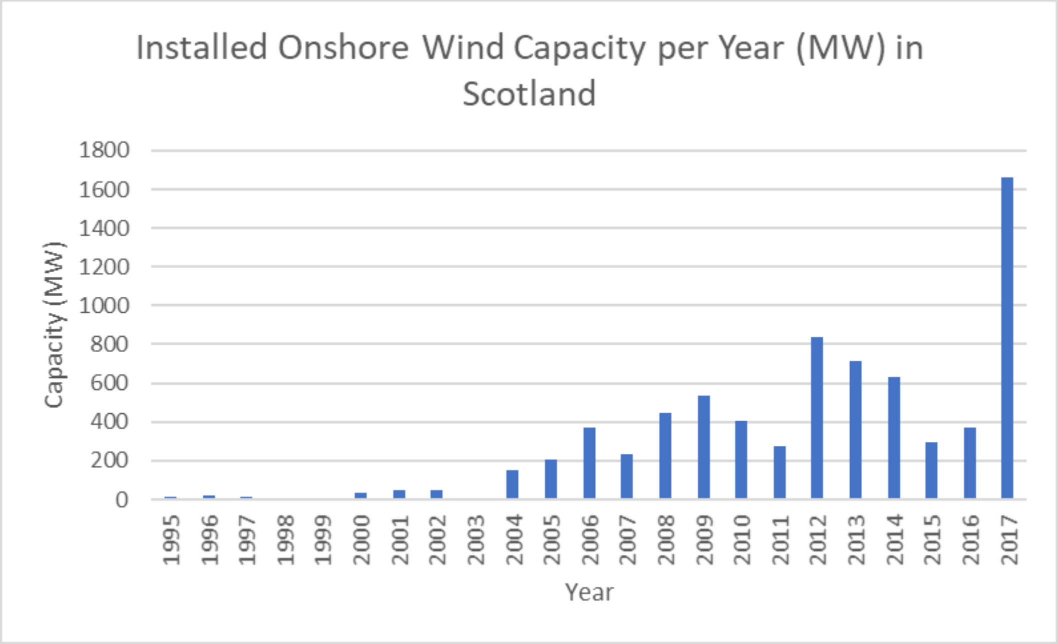


Figure 14: Installed Onshore Wind Capacity in Scotland per year from 1995

It is clear from this graph that the total capacity value installed increased greatly after 2004. It is thought that this increase would have been due to the Renewables Obligation, it was noted that it took on average two years to go through all planning processes for any size of onshore windfarm (Scottish Government, 2017a). Therefore, assuming projects began planning before the RO legislation was confirmed, and then went through construction stages, they would be generating electricity from around 2004. The renewables obligation was deemed to be responsible for the uptake of onshore wind projects and it can be validated by the figures in the graph. Also, there was a slight decline in capacity growth after 2009, this can be assumed to be due to the banding changes made to the RO, after 2009 other newer technologies were earning more

ROCs/MWh than onshore wind to increase the diversity of renewable projects in the UK. Therefore, this decline in growth may actually have been advantageous to the overall renewable energy market in the UK.

Lastly, this graph shows an abnormally large capacity being installed in 2017. Contracts for Difference scheme began around this period, with the closure of the Renewables Obligation in March 2017 and it is expected that many projects were brought to an end prematurely before the change of funding, to ensure the project would be eligible under the ROC scheme.

Figure 15 below shows the cumulative installed onshore wind capacity globally from 2001 to 2017.

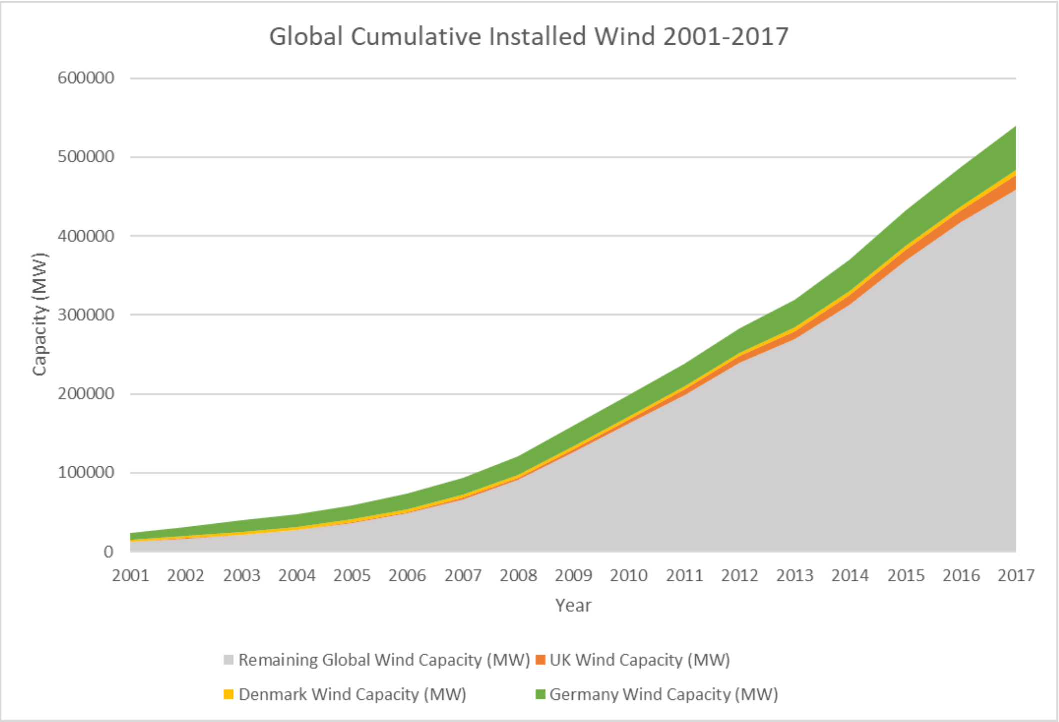


Figure 15: Global Cumulative Installed Wind 2001-2017

It is clear from the graph that the overall wind energy capacity globally has increased substantially over the past two decades. In 2001, Germany were the global leaders in onshore wind technologies in terms of capacity installed overall and in 2017 they continued to lead by growing their wind capacity in line with the global growth.

Currently, the UK has a considerable proportion of their electricity needs met through wind power. However, the level of growth seen in the UK is less than that of Germany and the percentage of electricity generated in the UK through wind is significantly less than Denmark.

Denmark produced 45% of its electricity through wind energy in 2017 and has been the highest producer of wind energy per capita for a number of years. Although they have a lower capacity of wind energy available they are actually producing a much higher proportion of their energy through wind.

Denmark only experiences relatively average wind speeds of 4.9–5.6 m/s measured at 10 m height whereas in Scotland the windspeed average is approximately 6.7-7.6m/s. Therefore, there is no reason why Scotland and the UK could not achieve similar levels of wind generation.

Country	Capacity of onshore wind turbines MW	Percentage of electricity generated through wind
UK	18872	13.5%
Germany	56132	20.8%
Denmark	5475	44.4%

Table 6: Onshore Wind Figures and Percentages per Country (European Wind Energy Association, 2018)

Table 6 indicates the capacity of onshore wind turbines in each country with Denmark reaching a much larger percentage of electricity generated through wind than the UK and Germany. Denmark has a much lower energy demand than both the UK and Germany and is able to import easily from other EU countries during times of low demand, therefore it is a simpler task for the majority of electricity to be generated through wind. The UK has the predicament of being a larger country with many demand centres far from the location of generation.

However, the UK, Germany and Denmark are key contributors to the wind generation in Europe with a total of 11.6% of total EU energy demand in 2017 being met from onshore and offshore turbines (European Wind Energy Association, 2018).

The Scottish Government has set an ambitious target to generate the equivalent of 100% of electricity consumption through wind energy by 2020, with Scotland contributing a fairly high percentage of the wind energy production of the UK, it could be possible (Scottish Government, 2017b). However, in 2016, only 42.9% of electricity generated in Scotland was through renewable sources which contributed to 24.5% of the total UK electricity. Therefore, the increase in output from wind in the period between 2016 and 2020 would have to be increased significantly (DECC, 2012).

4.1.2 Onshore Wind Cost Analysis

The cost of onshore wind has reduced over the past 30 years. Onshore wind has a number of components of cost that can be reduced over time: planning, grid costs, site optimisation and turbine optimisation.

Planning:

The costs of planning for an onshore wind generation site can be significant and can vary dependent on location. Costs include; environmental studies, wind speed assessments, engineering design, sourcing of supplies and delivery of parts, construction costs, planning permissions and ground tests.

After a new technology becomes widely installed, the planning costs can be reduced due to a greater knowledge of site requirements and being able to predict potential issues. After a developer completes one onshore wind project successfully, it is expected that the developer would be able to follow similar design and planning principles for any future projects. By simply applying the same framework for design, using all the knowledge previously gained, the planning costs can be reduced. It is expected that there would be fewer oversights and faults.

However, all projects may include unknown planning expenses, such as environmental assessments indicating any at risk species or transport costs due to remote location.

Grid Costs:

Grid costs are in relation to connecting a wind farm onto the national grid. These costs can vary greatly dependent on project location and current grid provisions. Connection costs will be higher in areas where the transmission line is a great distance from the project or in a location where the transmission line is heavily utilised, requiring upgrades. However, with experience, developers would be able to better predict the cost of grid connection and with the increase of renewable generators being connected, there is a greater pressure on the grid to have overall upgrades carried out. The Beauly-Denny line was upgraded to aid in the increase of renewable generators being connected to the grid in the North of Scotland, which were generating energy for use in the central belt (SSE Transmission, 2017).

Site Optimisation:

By selecting sites with a healthy wind energy resource, the costs of the energy generated will be reduced as cost is directly related to efficiency. Wind turbines will convert more wind energy when located at a site with a larger wind resource. Turbines are also more efficient when turning at their rated speed consistently, not having to modify their rotational speed due to a change of windspeed, therefore choosing an area which has both strong wind but also consistent wind is beneficial.

If the turbine is able to turn at a consistent rotational speed, less work will have to be done by the gearbox and power converter to improve the quality of the electricity generated.

Turbine Optimization:

Since the initial concept of generating electricity from wind was established, improvements have continued to be made to wind turbine designs.

Now turbines are bigger, more efficient, more reliable, able to harvest greater quantities of wind energy and have better conversion technologies.

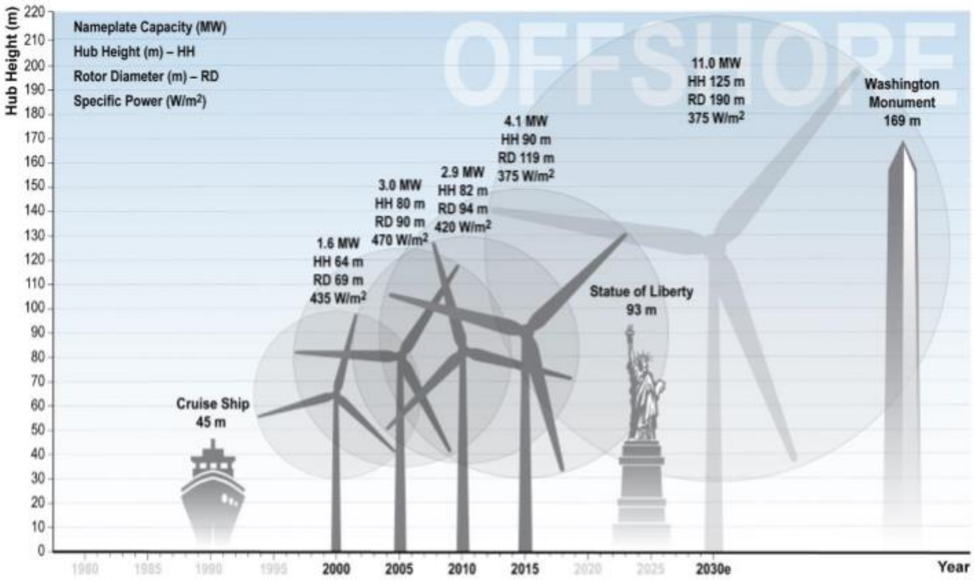


Figure 16: Prediction of Turbine Size Increases (Wiser, Hand, Seel, & Paulos, 2016)

Figure 16 above shows the growth in size both physical size and capacity of the average wind turbine installed globally from the 2000's and predicts that in 2030 we may see installations of 11MW turbines.

With greater sized turbines the quantity of potential component failures per MW can be greatly reduced. The equivalent electricity output can be generated by a small quantity of machines and therefore fewer gearboxes, blades and cables. Although larger and more difficult to install, the time taken for the overall project would be reduced. Resulting in fewer cables, foundations and environmental disruptions (Wiser et al., 2016).

<u>Levelized Cost of Energy:</u>

The Levelized Cost of Energy (LCOE) for onshore wind has been predicted at many varying values throughout the past two decades and varies considerably globally. Before Contracts for Difference, the LCOE was not as well documented as all other energy policies were dictated more by quantities of energy generated rather than costs. However, predictions were made by the Department for Business, Energy and Industrial Strategy for the future of onshore wind technologies in 2016.

The results from this prediction are shown below in Table 7.

Year	**Estimated LCOE (£/MWh)**
2016	67
2018	65
2020	63
2025	61
2030	60

Table 7: Estimation of LCOE for onshore Wind (BEIS, 2016)

The results for onshore wind LCOE are positive. It is predicted that the cost of generating electricity from wind will be reduced gradually until 2030, which indicates that onshore wind will still remain a viable alternative energy source from fossil fuel generators.

4.1.3 Onshore Wind Risks

There are a number of risks associated with the development of an onshore windfarm. Many of these risks can be reduced as the technology develops and investors begin to have more confidence in the success of projects. Risk tends to be directly related to cost and as discussed in the previous section of this report, there are many factors in relation to cost that may incite risk: technology maturity, location of development, planning approval and environmental factors.

Other risks specific to onshore windfarm developments are discussed in more detail below.

Capital Investment Risks

Large windfarms require very large upfront capital investments to fund the scoping and design stages of the project, procurement of materials and construction costs. A windfarm will not recoup initial costs until the development is operational and therefore a large upfront investment is required. With undeveloped technology, investors will be hesitant to invest large sums due to the risk of failure and therefore the interest payments on any capital loan granted will be high.

As technology is proven to be successful, the risk of investment is reduced. This is highlighted by how many large windfarms were constructed. Both Whitelee and Hagshaw Hill were constructed in two phases. The initial stage would have been the most risky in both windfarms; Hagshaw Hill, being one of the first windfarms and Whitelee due to its scale. Both windfarms would therefore have been subject to much higher interest payments on capital loans in the first phase. However, once a windfarm is successfully operating and generating electricity it is clear to investors the potential electricity that could be generated, this tends to be when a windfarm will be expanded.

Seasonal Risks

In windfarm construction the seasons can have a detrimental effect on project deadlines. Windfarms tend to be in remote, exposed, uninhabited areas and therefore any period of bad weather can result in construction being halted. In Scotland, winter periods can be very unpredictable, high windspeeds and poor visibility will stop crane operation. Therefore, projects will tend to reach construction stages during the summer months, reducing the impact of poor weather and ensuring construction is throughout months with long daylight hours.

Incentive changes

Incentive and policy changes can also be seen as a risk to a windfarm development. Many windfarms go through long periods of planning with some taking up to 10 years. Therefore, the length of time taken to be granted permission to build can have a significant effect on the policy that the windfarm will fall under. Especially in the UK where the policy has now been changed at least four times since 1990, the potential profit of the project relies heavily on how much additional income is earned from subsidies.

Operation and Maintenance

A last issue considered to be a risk, is the operation and maintenance of the windfarm. With many different components incorporated from different suppliers the operation and maintenance can be difficult. Specifically, when windfarms were fairly new electricity generating systems, it could be difficult to trouble shoot problems and determine the correct procedure to isolate faults and issues in the system. However, now that windfarms have been operating successfully for many years there are many skilled engineers and technicians who are specialists in windfarm operation and maintenance.

4.1.4 Effect of Policy on Onshore Wind

Onshore wind is one of the major renewable technologies installed to a significant scale and has experienced the effects of all the energy policies introduced by the UK Government. The UK was a relative latecomer to the onshore wind market and at the time of the first installations many other countries had made massive advances in installations. Wind power was and still is seen as an alternative to fossil fuel generation and a resource that will help to cleanse the carbon content of UK electricity generation. However, unlike fossil fuel or nuclear power generation, the planning and conception of an onshore windfarm has to face many additional barriers that are much more varied and of different scales. With any new technology the uptake of wind had to go through the technological advancement cycles to reduce the high risks and high costs associated with investing in a new system.

Now, in 2018 it is very unlikely we will see the installation and construction of a new fossil fuel power plant due to public opinion, environmental and climate change concerns, also the dependency on fickle energy markets from different countries to sell fuel to the UK. Renewable technology’s biggest competition is nuclear energy, as progress still has to be made to reach a zero-carbon national grid for Britain. Wind power is seen as a very viable energy source and it has the potential to be the largest method of producing electricity in the future.

Each energy policy had a different effect on the number of wind generators in Britain however it can’t be denied that progress has been made since 1990 with the UK having almost 19000MW capacity installed solely for onshore wind generation.

NFFO:

During the time of the NFFO and SRO onshore wind saw a rise. In 1990, the UK only awarded NFFO contracts to 12.2MW for onshore wind projects which was spread over nine different windfarms. Then in 1999, the last round of NFFO contracts were awarded seeing a total of 446MW of capacity accounted for over 97 different projects. The figures for capacity contracted for all NFFO phases are shown below in Figure 17.

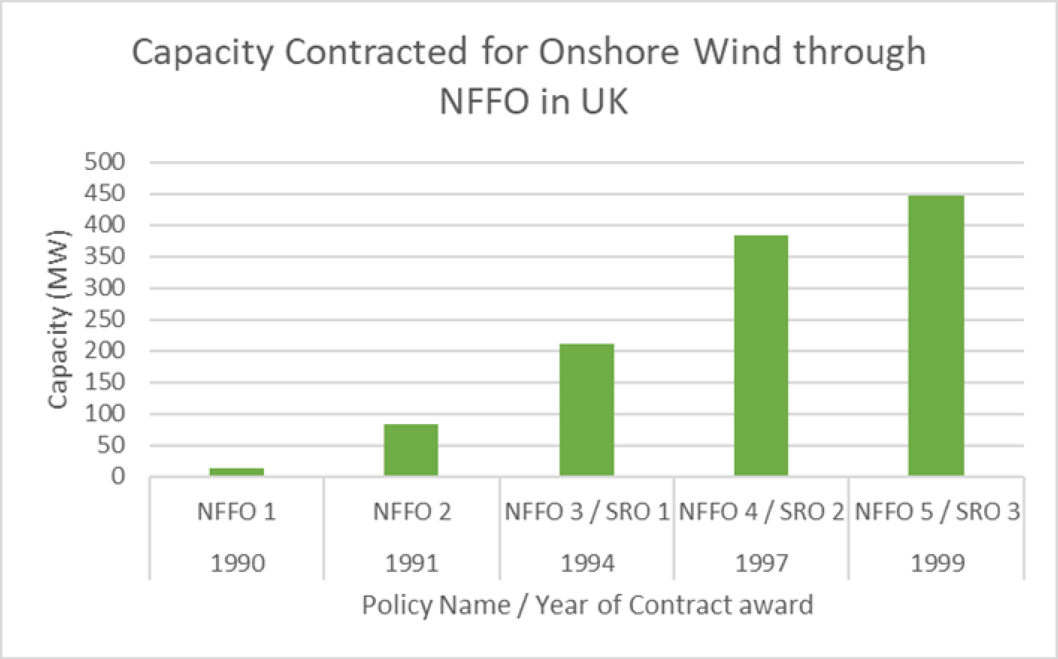


Figure 17: Capacity of NFFO Contracts for Onshore Wind Projects

From the values shown in the chart the NFFO definitely contributed to an increase of wind turbines in the UK. Also, considering the first and last contracts awarded the average size of the projects increased from approximately 1.35MW to 4.6MW, which demonstrates that the first projects installed were a successful model to follow. However, the NFFO only increased the UK's wind capacity to 474MW and in comparison to Germany's 8754MW capacity in 2001, this value is inconsequential.

The NFFO was created immediately after the privatisation of the electricity network in the UK, during the NFFO period, the opinion on climate change and emissions became more significant in dictating what the UK should be aiming to achieve in the renewables sector.

Therefore, it is understandable why the NFFO was withdrawn and replaced with a different framework to promote renewables.

To identify the progress made with the Renewables Obligation the number of ROCs issued in the UK for onshore wind was studied from the beginning – period 2002/2003 to the latest full year issue 2017/2018.

Onshore wind was awarded 1 ROC per 1 MWh of electricity produced. Therefore the total electricity generated from wind turbines on the renewable obligation scheme can be estimated through the number of ROCs issued.

Figure 18 below shows the number of ROCs issued for onshore wind from the beginning of the RO to most recently published figures.

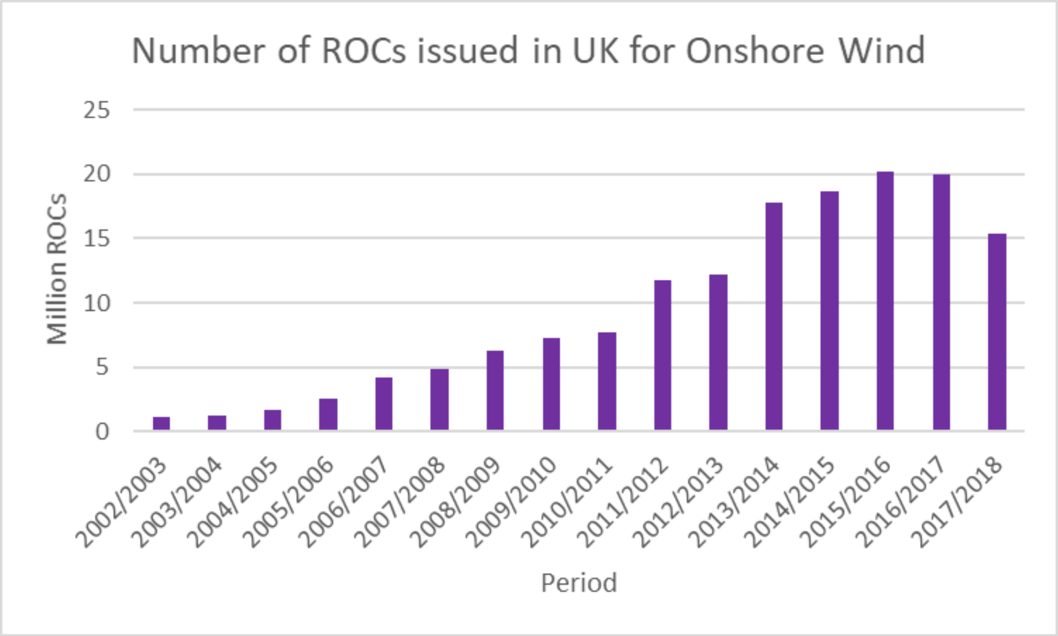


Figure 18: Number of ROCs issued for Onshore Wind Projects

The graph clearly shows that the renewable obligation certificates increased in issue every year until 2017. It is unclear as to why the number of ROCs issued in 2017/2018 was less, as it would be expected that due to the capacity of wind power continuing to increase, the quantity of electricity generated from wind would continue to increase. Also, RO contracts were for 20 years and therefore contract expiry would not explain this anomoly.

It is thought that this discrepency in wind production may be explained with wind energy curtailment, when there is a surplus of wind energy, the turbines may be controlled to stop generating. Wind curtailment was introduced due to wind energy being unpredictable and unable to control and results in windfarms being paid to stop production.

The majority of onshore wind turbines in the UK are located in Scotland, with many being in the far north or remote locations. When energy is produced from these locations and distributed over large distances, there will be losses. Therefore, if electricity can be produced closer to where the demand centres are this can be more economically viable.

By 2017 the UK had 12 offshore windfarms with capacities greater than 200MW located in England and Wales. It could be presumed that the loss in ROCs issued for onshore wind in 2017/2018 was made up by ROCs being generated for offshore windfarms. As many of the offshore windfarms were located in the South of the UK, they are far closer to many of the major demand centres such as London and Birmingham.

Also, this makes financial sense for electricity genertating companies who own both onshore and offshore windfarms as all of the major offshore windfarms in England would have been eligible for the premium ROC payment of 1.8 ROCs/ MWh.

It can be assumed that the superior income from the ROCs would be persuasive in itself to encourage generators to be more likely to utilise the offshore wind resource.

Contracts for Difference:

Onshore wind is deemed a mature technology under Contracts for Difference (CfD) and is therefore competing against Solar PV to be awarded contracts to generate electricity. Many feel that onshore wind is at a disadvantage as Solar PV projects have much less planning hurdles than onshore wind. However, 15 projects were awarded CfD approval in Round 1 with strike prices of £79.23 - £82.50. The capacity awarded was 748.55MW and therefore more onshore windfarms are now in the pipeline in the UK. No onshore windfarms were awarded contracts through Round 2 allocations of CfD, the focus of this round was primarily on offshore wind as the onshore market is viewed to be becoming a saturated market.

However, it has been rumoured that Round 3 allocations will be supportive of onshore windfarm bids from remote island locations which would aid in many small comunitites becoming less reliant on electricity transmission from distant power plants with the risk of transmission line failures.

4.2 Offshore Wind

4.2.1 Offshore Wind Growth

Offshore wind has grown in capacity in the UK greatly over the past decade. In 2007, the UK's offshore capacity was only 404MW in comparison to an onshore capacity of 2428MW. In 2017, the capacity for offshore wind had grown dramatically to 5788MW.

The UK holds the greatest proportion of offshore wind turbines globally with a share of over 30% of the total worldwide MW capacity. From the figures for the UK's offshore wind capacity, it can be ascertained that the reformation of the renewables obligation in 2009, had a great impact on the number of projects being developed. The total offshore capacity increased from 404MW in 2007 to three times that in 2011 at 1519MW. Many of the large windfarms being developed during this period had huge capacities, larger than any onshore farms, such as Great Gabbard and London Array. These large windfarms were then eligible for the increased ROC payments. Figure 19 shows the increase of UK wind from 2007 to 2017 alongside the total global increase of offshore wind (International Renewable Energy Agency (IRENA), 2018).

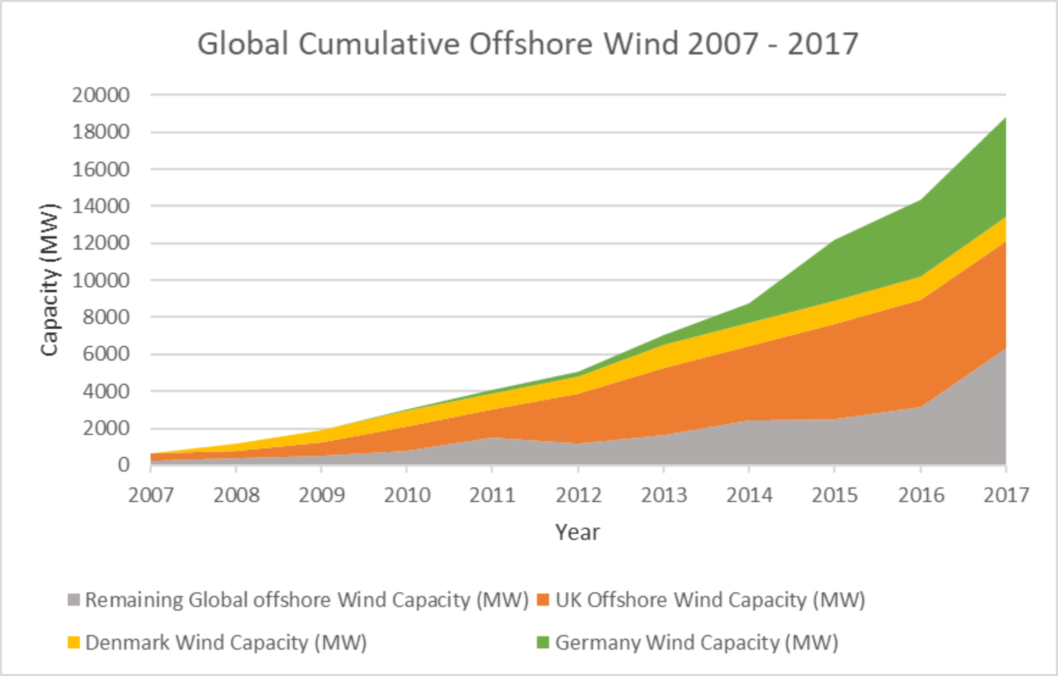


Figure 19: Global Cumulative Offshore Wind Capacity 2007- 2017

The graph indicates the massive growth in offshore wind in the past decade as well as the UK's share of the market increasing dramatically. The UK is continuing to develop windfarms on its shores and remains the leader in terms of quantity of farms and capacity. However the turbines installed are still purchased from other EU countries such as Denmark and Germany. With the progression of offshore wind in the UK it would be desirable to have more of the expertise and skills from the UK utilised in the development of the technologies.

In Figure 20, the European statistics for the year 2017 specifically relating to wind power are shown.

TOTAL EU ELECTRICITY CONSUMPTION (TWh)	ONSHORE WIND ENERGY PRODUCTION (TWh)	OFFSHORE WIND ENERGY PRODUCTION (TWh)	TOTAL WIND ENERGY PRODUCTION (TWh)	SHARE OF EU CONSUMPTION MET BY WIND ENERGY
2,906	292	43	336	11.6%

Figure 20: EU Electricity production from wind power (TWh) (Wind Europe, 2018)

These figures indicate that only 13% of the total wind generation was through offshore turbines in 2017. After all current CfD proposed projects are installed, at least 4358MW capacity to the UKs offshore wind portfolio will be added by 2023. Assuming a capacity factor of 37.8% is sustained for offshore wind in the UK, a further 14.5TWh of generation could be harvested from the UK's new windfarms which would greatly increase the offshore wind energy production in Europe by 2023.

4.2.2 Offshore Wind Cost Analysis

Similar costs are incurred in offshore windfarms as onshore windfarms such as: planning, grid costs, site optimisation and turbine optimisation. These points were discussed in section 4.1.2 on page 60 in relation to onshore turbines. However, as expected, these costs can be highly exacerbated due to the increased difficulty of installing an offshore windfarm.

Also, a high cost expenditure for offshore windfarms is the cost of operation and maintenance. In Nielsen and Sorensens paper ***"On risk-based operation and maintenance of offshore wind turbine components***", it is stated that the costs of operation and maintenance of offshore wind turbines can be up to 30% of the cost of energy generation (Nielsen & Sørensen, 2011).

Research was conducted regarding Robin Rigg windfarm in relation to total project costs. The project was estimated to have cost a total of £381 million and a breakdown showing the percentages of each element is shown below in Figure 21.

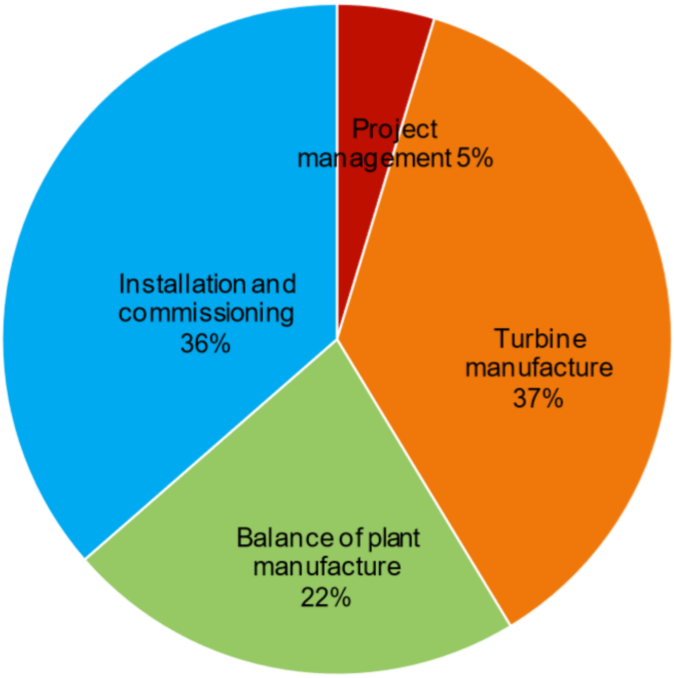


Figure 21: Breakdown of Costs for Robin Rigg Offshore Windfarm (Roberts, A., 2011)

The pie chart shows that the turbine manufacture was the costliest portion of the project outlay with installation and commissioning being almost as great. In the report by BVG Associates, it is stated that the cost breakdown for Robin Rigg was similar to other published cost analyses done for offshore windfarms.

To analyse the costs of offshore wind turbines installed in the UK, it is useful to study the LCOE's listed in relation to BEIS's predictions made in 2016 and also the strike prices listed for CfD.

Commissioning Year	**2016**	**2018**	**2020**	**2025**	**2030**
Offshore Wind Round 2	99	97	92	86	82
Offshore Wind Round 3	121	114	106	100	96

Table 8: Predictions of LCOE by BEIS for offshore wind (BEIS, 2016)

Table 8 shows the Levelised Cost Estimates for Projects Commissioning in 2016, 2018, 2020, 2025 and 2030 in £/MWh made by the Department for Business, Energy and Industrial Strategy (BEIS) in their report for electricity generation costs written in 2016.

The reference to Round 2 and Round 3 is in relation to the Crown Estate leasing of seabed for offshore windfarm projects (The Crown Estate, 2018).

It is clear that BEIS predicts that the LCOE of offshore wind will reduce by around 20% over 14 years between 2016 and 2030. However, according to at Table 7, the costs predicated by BEIS for offshore wind are still much more than the costs predicted for onshore wind in 2030, £82 vs. £60.

When studying the strike prices awarded from CfD we can understand more about the current costs of offshore windfarm development.

Strike Price refers to the guaranteed return the generator will receive for the electricity generated, regardless of the price of energy at the time of sale.

Project Name	**Allocation Round**	**Strike Price (£/MWh)**	**Delivery Year**
Neart na Gaoithe	1	114.39	2018/2019
EA 1	1	119.89	2017/2018
Hornsea Project 2	2	57.50	2022/2023
Triton Knoll Offshore Wind Farm	2	74.75	2021/2022
Moray Offshore Windfarm (East)	2	57.50	2022/2023

Table 9: CfD Strike Prices for Offshore Wind

From the prices shown in Table 9 in comparison to those listed in Table 8 above it is clear that the BEIS predictions were very pessimistic in relation to the potential reductions in LCOE overtime. The strike price for CfD also ensures that the generator has the ability to generate a profit from the electricity generated.

For the Round 1 allocated projects, the BEIS estimates were fairly accurate at £97/MWh or £114/MWh, as this price is the LCOE of offshore wind and is not accounting for a profit margin.

However, the strike price of £57.50 for generation beginning around 2023 is far lower than the predicted cost of £86/MWh or £100/MWh - predicted by BEIS for generators beginning operation in 2025.

Therefore, it can be deduced that the costs from turbine manufacture, installation and commissioning for offshore wind have seen vast reductions since the report predictions were made in 2016 and at a much faster rate than initially assumed.

4.2.3 Offshore Wind Risks

Similar to onshore wind projects, offshore wind can incur many different risks throughout the duration of the project. However, in offshore wind many of the risks encountered in onshore projects are heightened. Risks such as environmental factors, planning and technology are automatically more dangerous due to the location of the windfarm.

Environmental factors include: the effect of the concrete in the sea bed, the sea birds interaction with the turbines, impacts on fishing industry if sea traffic is heightened in other locations, pollutants from ships during construction and the overall visual impact of the windfarm.

Planning and Technology Risks

Planning risks are heightened as more costly equipment is required, also the delivery of equipment is much more difficult, logistically.

At the time of onshore wind becoming more prevalent, onshore turbines were very robust and successful technologies. However, at an additional cost, testing and trials had to be done to determine what effect sea water and the sea environment in general would have on the operation of the turbines.

Capital Investment Risks

Similarly, with onshore wind the capital investment risks for the first offshore windfarms would have been much higher than current risks in 2018. Back in 2008, it was not guaranteed that offshore wind would become an economically viable option as there were many unknown factors. Beatrice windfarm began as a test site with only two turbines and it is evident that this was to judge the achievable potential of the farm before committing to a large scale project. Now in 2018, the offshore wind projects installed are of huge capacities and it is clear that the risk seen for capital investment for offshore wind dropped dramatically over the 10 year period from 2008 to 2018.

Seasonal Risks

Again, seasonal risks affect offshore wind turbines to a massive extent as poor weather conditions can affect the project timelines. The North Sea, where the majority of the UK’s offshore wind turbines are located, is prone to storm tides and therefore installation conditions could prove difficult.

Operation and Maintenance

When offshore windfarms were first conceptualised, it was recognised that the operation and maintenance of such a system offshore would prove to be much more difficult than land based turbines.

Reducing risks developed from operation and maintenance is imperative to ensure the windfarm operates at full capacity the majority of the time.

Three different maintenance schemes can be utilised in offshore windfarm O&M strategy: Time Based Maintenance, Failure Based Maintenance and Condition Based Maintenance. To ensure a good balance of cost reduction and risk reduction a harmony between maintenance types is desired to keep maintenance costs low, whilst reducing costs incurred due to failure or down time (Nielsen & Sørensen, 2011).

FMECA (Failure Modes Effects and Critical Analysis) can be used to aid in reducing costs impaired by turbine and equipment failures. However, FMECA becomes far more effective when large quantities of data are available on similar failure types. FMECA allows easier prediction and identification of failures through certain characteristics of operation which helps to reduce the time taken to distinguish the root cause of a failure.

When offshore windfarms have been operating successfully for a number of years, the unknowns regarding maintenance are reduced and therefore the risks related to O&M also reduced (Zontangos & Anderson, 2004).

4.2.4 Effect of Policy on Offshore Wind

Renewables Obligation

Offshore wind benefitted greatly from the introduction of bands to the renewable obligation. When ROCs were first introduced offshore wind was still only a new technology and not yet implemented at any scale in the UK. However, the introduction of banding was definitely beneficial for offshore wind as it ensured a greater market value could be recuperated for the sale of the electricity generated, the sale of the electricity and the sale of the ROCs allowed offshore wind to be priced competitively.

Below, Table 10 shows the figures for the total number of windfarms installed in the UK from 2000 through to 2017 as well as the cumulative installed capacity for the same time frame.

Year	**Cumulative Total Number of Windfarms**	**Cumulative Installed Capacity (MW)**
2000	1	4
2001	1	4
2002	1	4
2003	1	4
2004	3	124
2005	4	214
2006	5	304
2007	6	404
2008	6	404
2009	8	688.4
2010	11	1335.2
2011	12	1518.8
2012	16	2673.2
2013	20	3647.3
2014	21	4036.1
2015	26	5097.6
2016	26	5097.6
2017	29	5787.52
2018	33	7155.22

Table 10: Cumulative Capacity of Offshore Wind in the UK

From Table 10, it is obvious that after 2009 a huge increase in the capacity installed in the UK was experienced. From the years 2000 to 2008, the progression of offshore wind was very slow with on average less than one windfarm site being added a year and the sites being relatively small capacity. The largest sites installed before 2009 were Kentish flats, Burbo Bank and Barrow all with a maximum capacity of 90MW.

After the alteration in RO policy to award offshore farms 1.8ROC/MWh, many more sites were developed. From 2009 to 2016, 18 windfarms became operational with approximately 4500MW of additional capacity installed. London Array was also installed during this time in 2013, adding a massive capacity of 630MW to the grid.

Therefore, we can clearly state that the RO caused significant progress for renewable generation in terms of offshore wind with the project sizes and quantities vastly increased over a short period.

Contracts for Difference

Again, by looking at Table 10 we can identify progress towards offshore wind under the CfD policy. CfD allocation for Round 1 was announced on 26 February 2015 and over 50% of the total awarded capacity for Round 1 CfD was to offshore wind with two large projects: EA1 and Neart na Gaoithe being awarded large capacities, totalling 1162MW.

On 11 September 2017, CfD Round 2 allocation was announced with a further three large offshore wind farm projects being awarded contracts.

Project Name	**Capacity (MW)**	**Strike Price (£/MWh)**	**Delivery Year**
Triton Knoll Offshore Windfarm	860	74.75	2021/2022
Hornsea Project 2	1386	57.50	2022/2023
Moray Offshore Windfarm (East)	950	57.50	2022/2023

Table 11: Contracts for Difference Round 2 Offshore Wind awards

Table 11 above shows details of the three awarded offshore windfarms through CfD Round 2 allocation. These three projects are expected to have the ability to power 3,321,210 UK homes and will add an additional 3196MW capacity of renewable energy to the UK electricity network (BEIS, 2017).

It is clear from these massive awarded projects that the UK government continues to support the development of offshore wind. Also, CfD may be having a positive effect on the offshore industry if the Strike Price reduction can be used as an indicator of the overall risks and costs being reduced.

4.3 Marine Energy

4.3.1 Marine Energy Growth

The United Kingdom was one of the first countries involved in developing marine energy projects with the first commercial wave installation, off the coast of the Isle of Islay, with the Wavegen Land Installed Marine Power Energy Transformer (LIMPET) project, installed in 2000. LIMPET was a shoreline oscillating water column and it proved that wave energy was a viable method of creating electricity, with it proving to have reliable operation throughout its lifetime. The device had an installed capacity of 500kW and was connected to the grid with the energy created converted in a turbine generator that was shore based (The Queen's University of Belfast, 1998) and (HI Energy, 2010).

However, marine technologies have not developed as fast as onshore and offshore wind. The total marine capacity in the world in 2017 was 529MW, smaller than the capacity of Whitelee Windfarm.

In the first quarter of 2016 the UK's marine energy capacity was only 9MW. Later in 2016, MeyGen would have become live and increased the capacity to 15MW. However, in 2011 DECC published an energy roadmap that indicated that the UK could increase its marine energy resources to around 300MW by 2020.

IRENA (International Renewable Energy Agency) publish statistics indicating the total global capacity of all renewable energy technologies each year per country but also IRENA publish individual technology statistics for each country. Marine technology encompasses all tidal and wave powered technologies. In this renewable sector, many countries have zero installed capacity with only a few countries having published marine capacities.

In Figure 22, the global cumulative increase in marine technologies is shown graphically, indicating Europe in orange, Asia in green and the rest of the global capacity in grey.

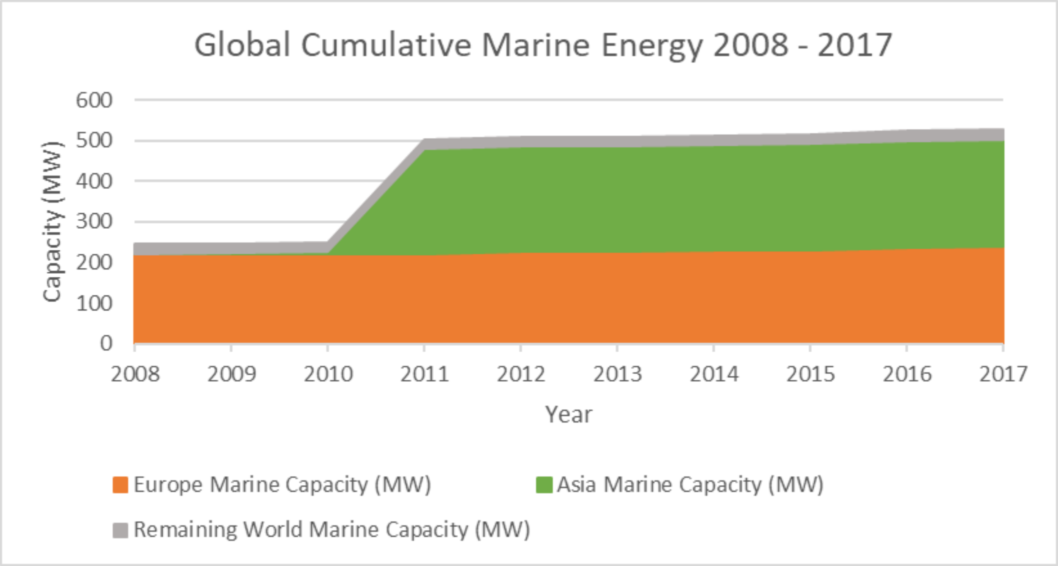


Figure 22: Global Cumulative Marine Energy Capacity 2008- 2017 (International Renewable Energy Agency (IRENA), 2018)

From the graph in Figure 22, it can be seen that in 2008 the majority of marine technologies generating electricity were installed in Europe and that between 2010 and 2011 a huge change occurred in marine energy with 250MW of capacity being installed in Asia.

Table 12 shows the capacities as of 2017 for all countries globally with marine technologies installed.

Country	Installed Capacity (MW)
Korean Republic	258
France	220
Canada	23
UK	18
China	4
Russia	2
Netherlands	2
USA	1

Table 12: Marine Energy Installed Capacities Globally

From Table 12, it can be deduced that the UK is the fourth global country in marine development in terms of installed capacity.

Also, by comparing the information displayed in Table 12 and Figure 22, it is obvious that the majority of the world's marine capacity is from France and the Korean Republic. Both of these countries have large tidal projects, France with La Rance and Korean Republic with the 254MW Sihwa Lake Tidal Project. Therefore, it is understood that the advancement in marine technologies will not occur in the same way as with wind energy.

Wind turbines were able to be installed on a very small scale to be tested, determing if the location, turbine and grid connection were suitable before scaling up. With marine technologies a large amount of work has to be carried out even for a very small test installation and therefore it is likely that if an area is deemed suitable in testing that it will be developed to a large scale quickly.

This is in accordance with how the MeyGen project was initially proposed to progress. From initial design work it was suggested that Phase 1C would commence in 2019 and soon after the Pentland Firth would be home to 57 turbines with a capacity of 85.5MW with the initial build starting in 2015.

Figure 23 below shows the data found by the World Energy Council indicates the potential developments in tidal stream globally.

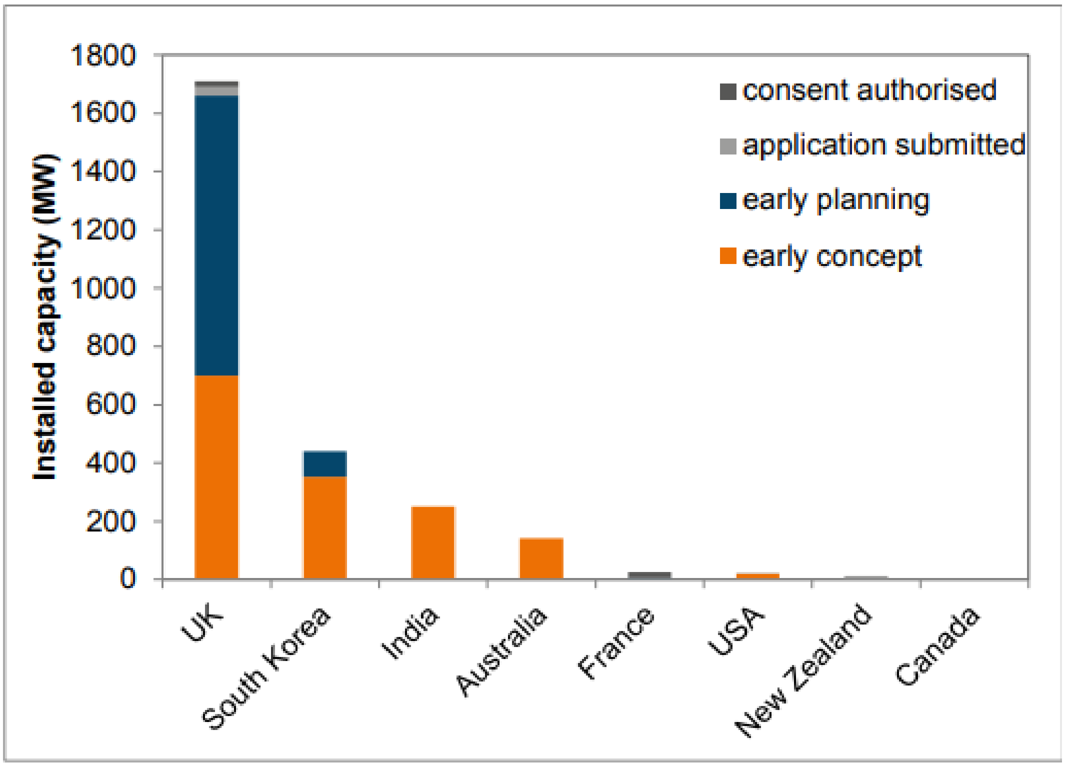


Figure 23: Future Global Tidal Stream Energy Capacities in Development (World Energy Council, 2016)

Figure 23 shows that the World Energy Council predicts the UK has the potential to increase their tidal stream installed capacity by around 1700MW if all current developments are seen through to fruition. However, this would be completely dependent on funding being available from the UK government to ensure developers can guarantee incentives or support.

4.3.2 Marine Energy Cost Analysis

When considering costs for marine energy many of the same top issues are highlighted as wind energy costs: planning, technology development, grid costs and environmental factors.

As with offshore wind in its first large scale installations, many of these costs are unknown for large tidal or wave power plants due to new practices and procedures needing to be created before major constructions and installations can be deployed.

LCOE

The World Energy Council conducted a study to determine the potential costs incurred in marine technology developments and the change in LCOE from the first project until the first commercial project. Costs were calculated using USD and the values represent the average values recorded by all developers of marine projects developed before or in 2015.

The results of the analyses show that the LCOE of wave and tidal stream are expected to fall with increased deployment, the results are shown below in Table 13.

Development Stage	**Variable**	**Wave**		**Tidal Stream**	
		Min	**Max**	**Min**	**max**
First Project	Project Capacity (MW)	1	3	0.3	10
	CAPEX ($/MWh)	4000	18100	5100	14600
	OPEX ($/MWh per year)	140	1500	160	1160
Second Project	Project Capacity (MW)	1	10	0.5	28
	CAPEX ($/MWh)	3600	15300	4300	8700
	OPEX ($/MWh per year)	100	500	150	530
First Commercial Project	Project Capacity (MW)	2	75	3	90
	CAPEX ($/MWh)	2700	9100	3300	5600
	OPEX ($/MWh per year)	70	380	90	400

Table 13: CAPEX and OPEX averages for Deployed Marine Technologies

The costs recorded indicate that project size has the potential to increase rapidly over increased deployment but also the CAPEX (capital expenditure) and OPEX (operating expenditure) costs will reduce greatly with more project development.

Development Stage	**Variable**	**Wave**		**Tidal Stream**	
		Min	**Max**	**Min**	**max**
Second Project	Project Capacity (MW)	1	10	0.5	28
	LCOE (£/MWh) *	164.30	524.21	164.30	367.73
First Commercial Project	Project Capacity (MW)	2	75	3	90
	LCOE (£/MWh) *	93.89	367.73	101.71	219.07

Table 14: LCOE averages for Deployed Marine Technologies

*Prices converted from USD to GBP using exchange rate accurate in August 2018

Table 14 shows the predicated LCOE of marine energy technologies and it is clear from these figures that the cost of energy generation greatly decreases with increased deployment. However, these cost averages and predictions are only taken from the small spectrum of currently installed projects and therefore cannot be assumed to be 100% accurate.

The LCOE of the technologies indicates that both wave and tidal projects may be competitive in future energy markets. When comparing the two technologies and offshore wind, the LCOE predictions listed in Table 8 are not widely dissimilar to the values shown above. The LCOE of offshore wind predicated made in 2016 for 2018 was a value of £114/MWh, therefore if the marine technologies follow the same optimistic pattern as offshore wind the values listed above could drop dramatically if deployment levels mirrored those of offshore wind in the past eight years.

4.3.3 Marine Energy Technology Risks

Planning and Technology Risks

The risks faced in marine energy technologies are primarily due to the optimum technology types being unknown. Many different systems are still being trialled and tested. When discussing wind turbine technologies and the risks involved the range or risks were diverse even in a robust turbine solution. Therefore, it is understandable that in marine technology projects the scope for choosing a perfect solution is very wide.

Chosen technologies can be dependent on resource availability, location and environmental factors.

The EMEC allows testing of a diverse range of marine energy devices and unlike wind power, no type technology is the market leader yet. Also, many marine devices have not been implemented on a commercial scale. Therefore, for any developer desiring to start a project, the risk of selecting a technology that is robust for their location can be high.

Capital Investment Risks

Secondly, linked with planning and technology risks and as stated previously for onshore and offshore wind, capital investment risks will be much greater for projects with no advocators or proof of previous success.

Currently, the capital investment costs for marine technologies are holding back developments. This is due to the upfront capital costs of developing a technology are not being repaid though deployment as the number of marine technologies deployed each year is so low.

Seasonal Risks

Very similar to the offshore windfarm seasonal risks, marine technologies are very dependent on weather conditions in coastal areas. Coastal areas can be very remote and subject to fierce weather conditions which can cause project delays and install issues. However, the fierce conditions are also why the potential energy within the tidal currents is worth extracting. Careful consideration has to be given to the correct season and time for marine technology installations. Good weather conditions and long daylight hours are key to successfully meeting project deadlines.

Incentive Changes

Incentive changes greatly affect marine energy projects. Due to the early stages of technology implementation, tidal and wave schemes are highly dependent on income generated from incentives. Development of new schemes is almost always determined by what government grants or policies will aid in reducing the LCOE of the energy generation. When incentives are successfully implemented, the reliability of projects being deployed increases and therefore the quantity of projects goes up. The scale of deployment of a technology is directly related to the cost of components and design of a scheme.

Therefore, it could be deemed that the uncertainty of energy policy currently for marine technologies is the highest risk factor for any new development.

4.3.4 Effect of Policy

Marine Energy Technologies have not been installed in large enough quantities in the UK to conclusively judge if any particular policy or legislation has been successful in increasing the marine energy generation proportion exporting to the national grid. However, marine technologies have been installed in the UK throughout the Renewables Obligation and now the current legislation in Contracts for Difference.

Renewables Obligation

The Renewables Obligation (RO) began in 2002 and awarded marine energy technologies 1ROC/MWh of electricity generated. The RO was reformed in 2009 to award marine technologies 5ROCs/MWh. Table 15 shows all marine generating stations that earned ROCs from their introduction until April 2018. OFGEM data is released on a quarterly basis and therefore April 2018 was the last month uploaded.

Generating Station Name	**Capacity (MW)**	**Generation Type**	**Operating Start Month**	**Operating End Month**	**Total number of ROCs earned**
Claddach Farm	169	Wave	Apr 2006	Jul 2013	413
Eday Berth 1	1138	Tidal Flow	Nov 2012	Mar 2014	5031
Eday Berth 2	1200	Tidal Flow	Oct 2010	Feb 2015	5104
EMEC Berth 5	2240	Tidal Flow	Apr 2017	Apr 2018*	10695
Ness of Quoys	6000	Tidal Flow	Dec 2016	Apr 2018*	28630
Orcadian Wave	750	Tidal Flow	Oct 2012	Jun 2014	361
S G E Tidal Array	500	Tidal Flow	Mar 2017	Apr 2018*	428
SeaGen	1200	Tidal Flow	Apr 2009	Feb 2015	18503
Vagr Atferth	750	Wave	Nov 2011	Jul 2012	218

Table 15: ROCs earned from Marine Technologies (ofgem.gov.uk, 2018c)

The banding of the RO was introduced in 2009 and from the table it is clear many more developers added marine capacity to the grid after this time, expected due to the increased revenue available from the ROC premiums. The only generator listed as earning ROCs, before the reformation of the RO was Claddach Farm, which was also a very small scale wave generator. Also noticeable for marine technologies earning ROCs is that many of the stations were based at the EMEC test area in Orkney including Eday Berth 1 & 2, EMEC Berth 5 and Orcadian Wave. It could therefore be concluded that the RO was not the instigator promoting renewable generation but that the testing available at EMEC the main promoter for marine technology uptake in the UK.

Contracts for Difference

Contracts for Difference (CfD) began around 2017 and since the introduction no new marine power plants have begun operation.

In the Round 1 auctions, no marine energy technologies were awarded a CfD contract.

The MeyGen project Phase 1C was rejected by CfD in the Round 2 allocation, awarded in September 2017 as it was not competitive enough with the lower than expected bids made by offshore wind developments. This was a major blow to the marine energy industry as previously it was alleged by the UK government that marine technologies would have a set capacity to be awarded throughout the bid process. Due to the early development of tidal stream it would never have been able to compete with the more developed and successful offshore wind technologies.

The third CfD auction is due to be held in 2019 and currently it is unknown whether marine energy technologies will be benefitting from this auction or if the majority of CfD contracts will again be awarded to offshore wind technologies.

The current consensus on CfD and marine technologies is that the policy is not aiding development to new wave or tidal projects and with MeyGen as an example CfD is currently hindering progress.

5 Discussion

5.1 Onshore Wind

Onshore wind has progressed dramatically since the UK's first large scale windfarms in the 90's. The Renewables Obligation saw the capacity of onshore wind increase by 9.3GW over 15 years which indicates the policy was successful for the increase of capacity in the onshore wind industry.

Whitelee Windfarm still remains one of the largest onshore windfarms in the world and will always be an indication of Scotland's and the UK's commitment to carbon-free electricity production. Onshore wind is now the lowest cost renewable energy at a large scale and, due to this success, the industry now faces an uncertain future. In the CfD framework, onshore wind is deemed as a mature technology and is therefore required to compete for a very low strike price. However, the cost of producing energy from onshore wind is expected to be at a similar cost as offshore wind in the near future due to heavy planning and environmental restrictions on the land suitable for onshore windfarms. Onshore developments are also fighting to justify the need for an onshore windfarm over other public or private developments, such as housing, recreational spaces or maintaining areas as green spaces (Scottish Government, 2017c).

However, the Scottish Government are keen for Scotland to develop the wind industry further without subsidies. With Scotland being the windiest country in Europe and with a thriving onshore wind industry, it could be possible to have windfarms installed without subsidies. However, with National Grid introducing the balancing mechanism and constraint payments, wind turbines with no subsidies may indeed cost the consumer far more than a subsidy or incentive framework would (Baringa LLP, 2015).

Onshore wind developers may also be less encouraged to develop onshore if they are also involved in the offshore market where there are incentives and more guarantee of generating a profit.

However, the UK overall has shown commitment to onshore wind, as the public opinion of onshore wind continues to increase in positivity with people becoming more aware of their need within the UK's electricity mix and accepting that they are a much more viable option than a new fossil fuel production plant (Norris, 2017).

However, as the offshore market continues to boom it may be some years before large-scale generation returns onshore. The main technical challenge for the future of our onshore turbines will be replacing or decommission older farms. As many of the first farms are beginning to reach the end of their lifetime they will either need to be replaced or removed from the network.

With current RO policies reaching their 20-year lifetime from 2022 and turbines installed from 2002 having a 25 year lifespan, this gives a discrepancy of five years. In this five year period, the windfarm will have to prove it is operable without any additional incentive payments. Therefore, the true success of RO policy in terms of increasing onshore wind capacity, will be known within the next five years. If the policy has been successful, the capacity of windfarms in the UK will continue to rise. If the policy is proved to be unsuccessful, we will see a fall in onshore wind capacity as the RO supported farms begin to be decommissioned.

5.2 Offshore Wind

Offshore wind has seen a massive increase in capacity with the installed capacity in the UK reaching 7514MW in 2017 (International Renewable Energy Agency (IRENA), 2018). The UK is currently the leader in offshore windfarms with almost 46% of the offshore installed capacity installed in the UK shoreline.

Before the Renewables Obligation (RO) was introduced there were no large offshore windfarms in the UK, with Blyth offshore windfarm only having a 4MW capacity. However, the RO saw the introduction of more offshore windfarms being installed with larger capacities of 90MW.

Subsequently the reformation of the renewables obligation sparked a huge increase in offshore wind development with the ROCs per MWh increasing from 1 to 1.8. 18 windfarms were installed from 2009 until 2017 with a total capacity of approximately 4500MW, with the quantity of windfarms increasing as well as the capacity increasing. This period saw the installation of the UK's largest windfarm with London Array adding 630MW capacity to the UK's renewable generation portfolio.

It can be said that offshore wind definitely thrived in the RO period but it is unknown if the same level of success would have been reached if the ROC premiums had not been increased. Also, offshore wind technologies are essentially onshore wind turbines tweaked for installation in the harsher maritime environment and therefore the technology was tried and tested thoroughly on many onshore windfarms.

In Contract for Difference times, offshore wind has continued to flourish winning contracts for the majority of the capacity in both Round 1 and Round 2. This success highlights the UK Government's continued support for offshore wind. Offshore wind will soon be a major player in the UK's generation mix with 1162MW awarded in Round 1 allocations, 3196MW awarded in Round 2 auction and 1324MW awarded in investment CfDs. These additions will see the offshore wind capacity have similar capacities to the onshore wind in the UK and hopefully continue to reduce the UK's reliance on gas fired power stations.

5.3 Marine Energy Technologies

Marine Energy Technology development has remained almost stagnant in the UK throughout all policy changes.

The Renewables Obligation only supported one wave energy project and no tidal projects before it was reformed in 2009. Even after the reformation, the main projects supported were test projects at the EMEC in Orkney and it can be established that very few major players in the electricity market were keen to invest in the marine energy market even with the 5ROCs/MWh incentive.

The lack in project investment highlights that the technologies were not advanced enough to succeed during the RO period and that further investment in test projects on larger scales was potentially required within the years of 2002 to 2017.

The most successful UK marine project to date is the MeyGen project. MeyGen is a worldwide example of the potential energy in the tidal streams that could be extracted and converted into electricity. MeyGen was going to be the UK's flagship tidal stream project with a grid capacity for up to 252MW of tidal stream generation. MeyGen remains the largest planned tidal stream project in the world. However, with the lack of a CfD award the projects future is uncertain.

If Phase 1C of MeyGen does not see realisation it would be a great failure of UK energy policy and a huge disappointment to the future potential of marine energy worldwide.

Secondly, the failure of support for Swansea Bay Tidal Lagoon highlights the Governments control on the success or failure of the marine technology industry. The project was stalled with BEIS stating:

"As the business secretary told MPs recently, while we have quadrupled the proportion of our electricity that comes from renewable sources since 2010, we have a responsibility to minimise the impact on consumer bills and the Swansea proposal is more than twice as expensive as the Hinkley power station." (BBC, 2018)

This statement highlights that the Government's priority is reducing initial capital cost with a lack of foresight over the longevity of the power industry in the UK. If carbon reductions were the priority rather than costs, there would be no opposition to the Swansea Tidal Lagoon project.

With EMEC investment currently totally £34million from: The Scottish Government, Highlands and Islands Enterprise, The Carbon Trust, UK Government, Scottish Enterprise, the European Union and Orkney Islands Council, it would be a huge frustration if progress in this industry is not made (EMEC, 2018).

6 Conclusions

In conclusion, it can be stated that policy and incentives play a huge role in increasing the renewable generation proportion of the UK's electricity mix. When policies are implemented successfully, the benefits for developers far outweighs the potential risks and mitigates the pressure of the initial capital cost expenditure of a new project.

The NFFO policy was introduced too quickly and, without prior knowledge or experience of the renewable market, as a method to ensure the new electricity supply companies paid for the electricity generated from the nuclear power plants, which were too expensive for any supplier to be willing to purchase outright. Due to the mixed ambitions of the obligation, the renewables market did not see a sharp rise in uptake as seen in other EU countries such as Denmark and Germany.

The RO policy could be deemed fairly successful as it increased the percentage of renewable generation massively. However, before the reformation of the policy it did not effectively diversify the renewables mix with mature technologies, such as onshore wind and landfill gas, therefore benefitting the most, and newer technologies adding a very limited capacity. The reformation of the RO brought a huge amount of offshore wind development, as offshore wind became far more economically viable than before, but also was potentially a better investment than onshore wind with larger capacity farms being able to be installed and 1.8ROCs/MWh being able to be received for electricity generated.

However, the RO was closed in 2017 to new generation with the introduction of Contracts for Difference.

Since the introduction of CfD the capacity added to the renewable mix has dropped significantly. The CfD awards contracts at a strike price through auctions. There have been two auctions since the introduction of the scheme with a total of 5484.8MW capacity awarded for install from 2016 until 2023.

	Year									
	2008	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**
Total Renewable Capacity Installed (MW)	7093	8280	9673	12845	15933	20042	24894	30734	35505	40789
Percentage increase from previous Year (%)	n/a	16.7	16.8	32.8	24	25.8	24	23.5	15.5	14.9

Table 16:Renewable Capacity Increases UK 2008 – 2017(International Renewable Energy Agency (IRENA), 2018)

Table 16 shows the total renewable energy capacities in the UK from 2008 and 2017. Percentage increase was calculated to indicate the years with the greatest increase showing 2011 to be a peak year for additional renewable generators.

If in 2023 only the 5484.8MW of CfD scheduled renewables are installed, the percentage renewable energy installed will reduce to about a 2% increase of capacity per year. Contracts for Difference allows developers much more certainty of income than the RO, however it is preventing new generator’s funding projects before guaranteeing they will be awarded a CfD.

In comparison to Germany and Denmark’s stable Feed in Tariff type policies, the UK has implemented a variety of different energy policies with different success rates. From the research undertaken for this thesis, it is unclear why the UK Government did not see the value in using a feed in tariff type method and why they did not follow the successful model already utilised in Germany and Denmark.

In my view, the multiple changes of policy in the UK has been disruptive to developers and put pressure onto the energy suppliers as well adding strain to the national grid. The selection process of the CfD scheme looks as if it will cause obstacles to any technology that is not mature in development enough, to be deployed in a large scale and seems to be putting a halt to any major increase in capacity that is not offshore wind.

With the Scottish Government hoping to be able to generate the equivalent to 100% electricity through renewable energy by 2020 and the UK government's 2050 emissions targets it seems odd that the current government are putting the brakes on renewable electricity so prematurely.

Lastly, the UK has been succeeding in the offshore wind industry since 2011 due to the massive scale of installations being made around our coastlines. It is obvious that the support for offshore wind from government incentives has supported this achievement. However, with wind turbine manufacture still being primarily in Denmark and Germany, the UK is still not the only benefactor. Therefore, with the UK being the current lead in marine energy technology research and development and home to the EMEC, it would be wonderful if the UK could benefit from the labour of their work. The UK has the potential to be the leader in terms of installed capacity of both tidal and wave generation projects if the correct support mechanisms are implemented.

7 Recommendations and Future Work

7.1 Recommendations

From the work carried out in this thesis a clear consensus is made that the rate of renewable development is beginning to slow with the introduction of Contracts for Difference. However, the UK has yet to reach their targets for renewable generation and carbon emissions. Therefore, recommendations to ensure a positive future for renewable energy were determined from the knowledge gained in this thesis study.

1. The UK government should continue to fund investment into renewable technologies through the deployment of the CfD scheme as the scheme does have the potential to be successfully implemented and ensure profitability for renewable developers. However, it would be beneficial if contracts were awarded with a more diverse approach, both in terms of location and in technology type. Large offshore wind projects are great for increasing the overall capacity of renewables feeding the grid, but large scale wind projects cannot be reliant for the production of all of the UK's energy needs. A range of technologies such as biomass, solar, tidal stream, wave and hydro power can offer the UK grid more stability in instances with low wind. The peak capacity of the national grid is becoming more reliant on non-despatchable sources of energy and having very large quantities of wind power will eventually have a negative effect on the availability of power.
2. The BEIS should allow Contracts for Difference to focus a proportion of the funds to developing technologies such as wave and tidal and not have immature technologies competing for contracts that they cannot hope to gain. With the investments already made in the marine energy industry the tidal stream industry is ready to boom if the full MeyGen project is implemented successfully within the next 5 years. MeyGen also has the added benefit of being British developed technology, (Scotrenewables has developed the SR2000 turbine successfully installed at MeyGen site) and therefore there is potential to bring back manufacturing industry to the UK.

3. The UK government would benefit from investing funds into developing the electricity storage capabilities of the country. Moving focus from primarily awarding contracts to offshore wind developments to a wider range of electricity generation options will help to reduce overall reliance on gas power plants. Also, with the level of wind energy curtailment being increased year on year by National Grid, the UK could benefit greatly from having large scale storage systems deployed and operating as both a consumer and generator to the National Grid.

4. Lastly, the increase of scale of the onshore wind industry and the fast deployment of the offshore wind industry is undoubtedly down to large developers getting on board with the technology. Without the "big 6", large windfarms would not have developed as quickly. Therefore, it would be of great benefit if the big players in the electricity market were encouraged to invest funds into marine technologies. With a large investment, the UK could become a worldwide example of successfully extracting energy from the sea.

7.2 Future Work

Looking to the future, with CfD Round 3 scheduled for May 2019 it would be worth studying the results of this auction alongside the outcomes of this study. It would be useful to identify if the results of the auction follow the pattern of the previous two or if the outcomes are swayed towards a different technology.

It would also be useful to study the windfarms reaching potential decommissioning status in the 2020's. This study would be to identify the impact on the UK's wind energy capacity with large quantities of turbines reaching the end of their lifespans. Alongside this, it would be valuable to investigate how windfarms operate after their RO funding runs out. With five years of lifetime left after the 20 year funding expires, farms will be operating with old turbines and no funding and this may affect the price of electricity to the consumer.

Lastly for future work, the UK has major future political uncertainty in terms of Brexit. The UK is due to leave the EU on 29th March 2019 and with this departure it is unclear how the UK electricity market will be affected. With no guarantee of whether electricity will still be imported and exported at the same rate, the UK may become much more reliant on the assets within their borders. Therefore, it would be beneficial to conduct research into the area of renewable energy developments and policies after Brexit has been finalised. It will be interesting to determine the impact of Brexit on the UK's renewable energy goals and the EU's climate change ambitions.

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