Department of Mechanical and Aerospace Engineering

Frameworks to Aid New Renewable Energy Technology Development to Successfully and Speedily Traverse Technology Readiness Levels

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Abstract

As the UK Government works towards net-zero targets there is an overwhelming demand from consumers for their energy to be supplied from a renewable or low-carbon source. However, development of innovative renewable technologies is facing a substantial funding gap. For many years, investment in renewable energy technologies has been aided by government policy and legislation. The aim of this thesis points to where support is inadequate and what adjustments could be made to redirect funding to areas of development. It provides a framework to drive the adoption of alternative technologies ahead of the target emission levels by building on previous and existing policy frameworks. The thesis presents a mixed method approach, analysing data sets and past literature from industry and government reports. The main findings suggest that government support is an effective driver for advancement and deployment of innovative renewable technologies; however, the design of current frameworks is leaving less mature technologies with no path to market. A five-step strategy is put-forward to incorporate the beneficial aspects from past mechanisms and provide a reduced capacity banding to target small generation. Conclusions reveal that installed capacities will rise with an injection of funding, however the uptake will be slower than wind energy and solar PV. The levelised cost of electricity will fall to ultimately compete with established technologies currently on the market.

Acknowledgements

I would first like to thank my supervisor Cameron Johnstone for discussing a topic that I find extremely interesting and important. For being available to review ideas and supporting and guiding me with his knowledge.

I would like to thank all my friends for encouraging me and listening to endless monologs about renewable energy policy and climate change, and for providing a space to work when a change of scenery was needed.

Finally, a special thanks to my parents. To my mum for providing a sympathetic ear and always being there when I needed to talk ideas through. To my dad for continuously sharing his wisdom, guidance, and knowledge with me throughout my five years at university. I could not have done it without you.

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Abbreviations

BEIS	Department for Business, Energy & Industrial Strategy
CfD	Contracts for Difference
E.ON	Energy On
EDF Energy	Electricite de France Energy
FIT	Feed in Tariffs
GWh	Gigawatt hour
IEA	International Energy Agency
kWh	Kilowatt hour
LCCC	Low Carbon Contracts Company
LCOE	Levelised Cost of Electricity
MWh	Megawatt hour
NFFO	Non-fossil Fuel Obligation
NI-NFFO	Northern Ireland Non-Fossil Fuel Obligation
OFGEM	Office of Gas & Electricity Markets
RO	Renewable Obligation
ROC	Renewable Obligation Certificate
RE	Renewable Energy
SRO	Scottish Renewables Obligation
SSE	Scottish Southern Energy
TRL	Technology Readiness Level
TWh	Terawatt hours

1.0. Introduction

1.1. Motivation

There is a global movement of transitioning from fossil fuels to renewable and low-carbon energy sources. Over the past 20 years, the contribution that wind power makes to the UK energy market has seen extraordinary growth, with greater than 20GW of capacity installed over the past ten years alone. The UKs location makes it one of the best for generating wind power in the world, and public opinion polls suggest that 80% of respondents now support onshore wind developments (The Scottish Government, 2017). The UK has harnessed wind energy for over 40 years, opening the first commercial-scale onshore wind farm in 1991. Since that time, onshore wind has become a the most cost-effective form of energy generation, cheaper to supply than any fossil fuel or renewable alternative.

Recent advancements in offshore deployment have lowered the price of generation considerably, making it cheaper than new nuclear power. Global expenditure on offshore wind projects is expected to reach £210 billion within ten years (The Scottish Government, 2017). The UK boasts over 7500 miles of coastline and offers a huge potential for offshore wind resource. Offshore locations offer many advantages including stronger, more constant winds, making them a more reliable source (Lamy and Azevedo, 2018). These benefits are projected to cause offshore wind capacity to exceed onshore wind.

Renewable energy typically used for generation of electricity, rather than in the form of heating and transport, from and wind energy makes up the largest portion of the electricity mix in Scotland. The current installed capacity of wind power equates to over 78% of the total capacity, with the next most significant contributor being hydro at just under 14% (Figure 1) (Scottish Renewables, 2020).

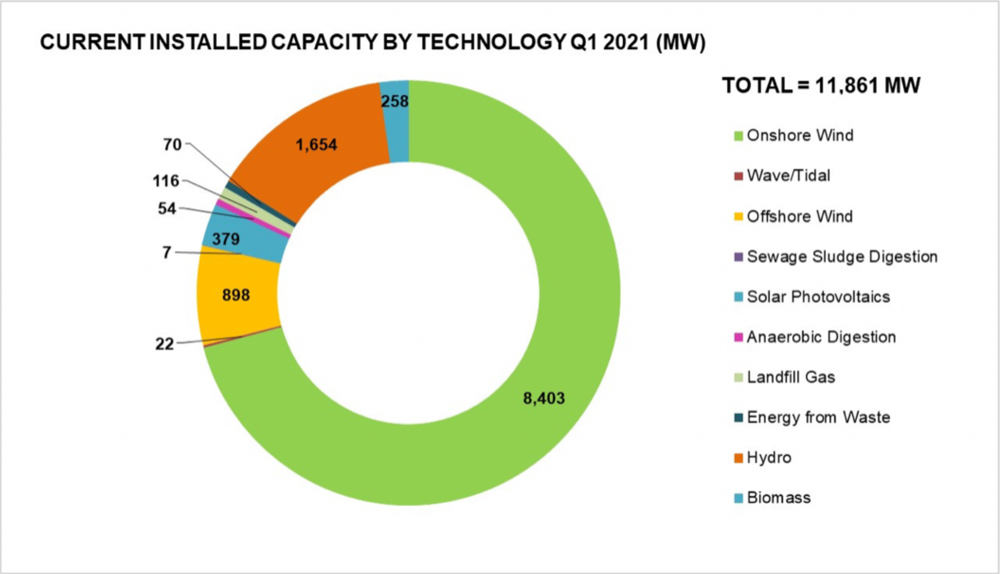


Figure 1: Total installed capacity of renewable electricity in Scotland (Scottish Renewables, 2020).

The motivation for this thesis was to investigate what has propelled the dominance of wind energy in the UK market while other technologies have stalled and how might this be rebalanced in terms of the contribution of less established technologies.

It is argued that policy mechanisms introduced to support wind projects have underlined the successes and competitiveness of the newly installed capacity. However, where this legislative support has incentivised more mature, low-carbon technologies, the less developed forms have seen far slower progress.

A suitable support mechanism would appear desirable to achieve a more diverse and reliable future energy sector with a diverse set of technologies. To expand available and cheap low-carbon technologies, it is critical that the uncertainty surrounding the innovation process be strengthened and supported through financial investments. Therefore, this thesis will explore past policies and analyse their outputs to investigate how a new policy framework could provide support where it is currently lacking.

1.2. Aims

The initial aim of this thesis was to understand the technology readiness levels (TRL) scale and its duration with renewable technologies. In addition, investigate how financial support affects the duration of the TRL journey and where support is absent.

The second aim was to examine past UK government policies implemented to incentivise the uptake of renewable generation. Research of past policies included: the Non-Fossil Fuel Obligation (NFFO), Renewables Obligations (RO), Feed-in Tariffs (FIT), and Contracts for Difference (CfD). This research included the year each policy got introduced (and closed), the basic framework structure, what they aimed to achieve, which technologies did they benefit/support, and the outcomes, successes, and criticism.

The third aim was to identify a potential new framework that would allow a safe and speedy traverse of the TRL journey. Aiming also to distinguish weighting and capacity factors that would best support small-scale generation and use the levelised cost of electricity (LCOE) to forecast how this new policy support mechanism could change over time.

Finally, provide an analysis of projected LCOEs over time for less developed technologies and a discussion on the future energy system in the UK.

1.3. Objectives

The method adopted to achieve these aims was primarily research and investigation of online journal papers, articles, and books that focused on past policies' structure and outcomes. The annual summary reports of the RO scheme, provided by OFGEM, from 2008/09 - 2019/20 acted as the main reference for this research.

The objectives included:

1. Quantify how the installation capacity of wind generation has increased over the past twenty years in the UK.

2. Identify the role that support mechanisms played in the growth of wind generation, and at which point on the TRL scale this support was aimed to help. To what degree what this helped the overall target towards net zero.

3. Model past LCOE for onshore and offshore wind for a ** given period and use the outcomes to hindcast the predicted effect for technologies in their innovation stage.

4. Ascertain any limitations and assumptions that hindcasting would produce and to what extent

5. Investigate a future police support mechanism that would assist technologies that are not yet mature or ready for deployment in the commercial energy market.

6. Identify what types of renewable technologies would benefit from the proposed support, remarking on the potential in the UK. Produce models for the predicted change in LCOE for each technology and analyse results to determine their reliability.

7. Conclude on whether the energy market would benefit from the diversity of renewable technologies and if so, which ones.

2.0. Literature Review

2.1. Background

In 2019, the UK became the first major economy pledging to achieve net-zero greenhouse gas emissions by 2050 to address climate change (O'Beirne et al., 2020). Following recommendations from the independent Climate Change Committee, the UK government is now working towards a goal of decreasing emissions by 68% - compared to 1990 levels - by 2030.

Although the capacity of renewable energy has more than tripled worldwide over the past 20 years (IRENA, 2021), challenges arise as the demand for electricity from renewable sources increases. The latest reports by the Department of Climate Change (DECC) suggest that around a quarter of the UK's existing capacity for carbon-intensive generation plants will be closed in the next decade (DECC, 2020). Ambitious goals set by the Government have achieved an increase in the deployment of renewable sources for electricity; however, if targets of net zero are going to be reached, renewable energy must start to replace natural gas and oil within heating and transport sectors. In achieving this, it is essential that supply continues to be available and reliable, creating the need for resource diversity.

Renewable energy makes up roughly 14% of the UK's total energy mix while natural gas and oil accounted for roughly 80% of the remaining (Armstrong, 2020). On the other hand, renewable sources account for almost 45% of the electricity supply, surpassing natural gas and showing a move away from fossil fuels (Alves, 2021) (Figure 2). Wind energy was the largest contributor and solar photovoltaic and hydro schemes made up much of the remaining capacity (IEA, 2021). Forecasts predict that wind energy's share will continue to accelerate as installation and manufacturing costs fall, widening the gap between wind and other sources. Figure 3 shows the installed capacity in the UK of onshore- and offshore wind as of 2020 with the greatest onshore capacity is in Scotland.

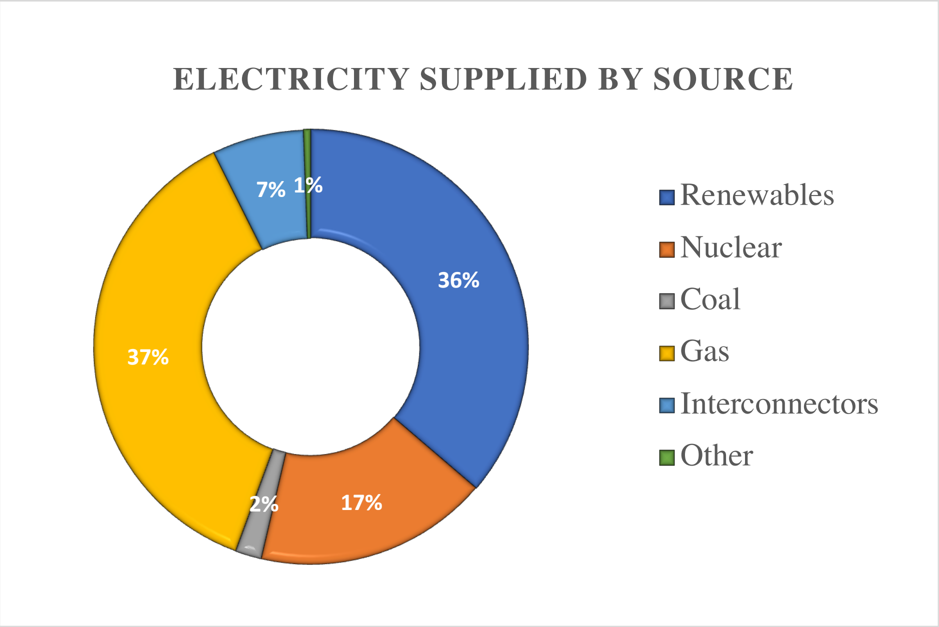


Figure 2 UK electricity supply by source, 2021. Adapted from (Alves, 2021)

The need to diversify the energy market is mainly due to concerns over energy security and fuel prices. If the UK is to move into a fully renewable market reflecting the current source share, the intermit nature of wind power will produce challenges for the operators (Lamy and Azevedo, 2018). Energy security is the continuity of supply to meet demand at a given, affordable price (IEA, 2019). As the UK transitions into a low-carbon electricity network, challenges of energy security heighten as renewables require a greater degree of network flexibility to compensate for their intermittent nature (IEA, 2019). As a result, governments are becoming increasingly concerned about the ability of existing markets and regulatory frameworks to continue supplying a reliable, affordable, and efficient supply of energy.

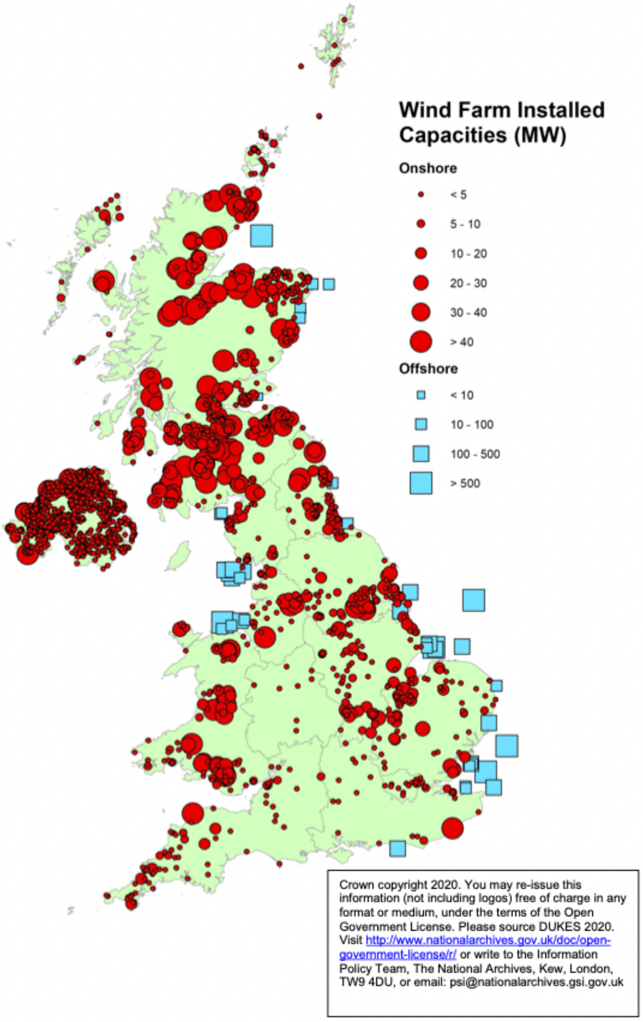


Figure 3: Installed capacities of onshore and offshore wind farms in the UK. (BEIS, 2020)

Two of the key instruments that promote renewable energy are market push and market pull mechanisms. Market push mechanisms provide initial support to technologies in the early stages of their development. Typically, grant support or private investors provide the funding for projects in their early stages which are less capital intensive (Hogg and O'Regan, 2010). An example of grant support that the Scottish Government provide is the Community and Renewable Energy Scheme (CARES), designed to help with start-up costs, feasibility studies, and other preliminary costs. Returns on these grants are typically not expected so long as the money is spent effectively according to the grant scheme rules (Hogg and O'Regan, 2010).

In 2015, the Scottish Government also introduced the Low Carbon Infrastructure Transition Programme (LCITP). The LCITP provides financial support to assist the development and delivery of low-carbon and renewable projects (www.gov.scot, n.d.). This mechanism drives the attraction of commercial investment in infrastructure projects, contributing to the lowering of Scotland's greenhouse gas emissions. For example, Nova Innovation, who led the Shetland Tidal Array project, was awarded £268,606 in funding. This was the world’s first offshore tidal energy array, installed in 2016 with a capacity of 600kW (Nova Innovation, n.d.). The project integrated Shetlands tidal energy with battery storage to provide grid-connected 'baseload' tidal power (Nova Innovation, n.d.); however, this was the lone tidal project supported by the LCITP scheme.

Market pull mechanisms are designed to support mature technologies through the end of their development and into commercialisation (IEA, 2020). This thesis will first look in more detail at the TRL scale and then investigate the past market pull mechanisms implemented in the UK.

2.2. Technology Readiness Levels

The National Aeronautics and Space Administration (NASA) created the TRL scale in the 1970s as a standardised technological maturity evaluation tool (Olechowski et al., 2020). It provides a framework for assessing and comparing the maturity of technologies across industries (IEA, 2020). This scale was first employed outside of the aerospace industry in 2014 as part of the Horizon 2020 framework, introduced by the European Union, which aimed to designed to assist new innovative solutions from the lab to the market (Moedas and Smits, 2018). This plan was the most significant EU Research and Innovation programme with almost 80 billion euros of funding accessible over seven years (2014 – 2020) (McIntyre, 2014).

The first published version of the TRL scale had seven stages; however, Figure 4 outlines the most up-to-date version of this scale used by the International Energy Agency (IEA) – mentions of TRL scale throughout this thesis refers to the IEA version (Figure 4). The journey begins by defining a concept and basic principles - TRL 1. As the concept develops, the technology will move through to TRL 3, by which time initial testing will have been carried out. Research and development grants support this stage of the technologies journey to commercialisation. At this point, financial requirements are at their lowest, so the associated risks are also low.

A small, laboratory-sized prototype will allow the technology to move into TRL 4. Further developments using a larger prototype in deployment conditions will bring the technology through to TRL 6 (IEA, 2020). They must be subsequently tested in real-world environments to achieve TRL 7. During these stages, as testing progresses and prototypes reach full scale, there is a significant increase in the amount of money required for development. If these costs cannot be covered by the developer, the technology will not be able to progress and finish its development into the commercial market to start to generate revenue. These stages (TRL 4 – 7) are often referred to as the "valley of death" (IEA, 2020).

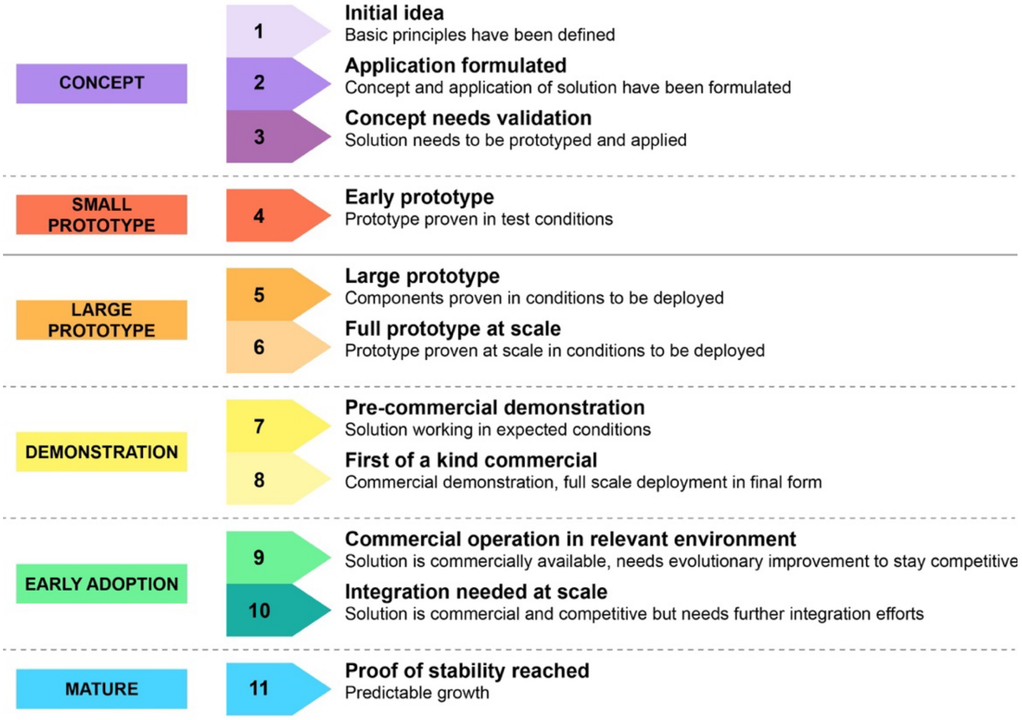


Figure 4: Technology readiness level scale applied by IEA (IEA, 2020).

When the technology has performed a commercial demonstration, which can run for several years, the project can be expanded to full scale capacity – TRL 8. Once the technology is fully operational and commercially available, it is in its ‘Early Adoption’ stage – TRL 9 (IEA, 2020). Market pull mechanisms will come into play at this stage, and technologies will begin to be eligible for longer-term financial support. As previously mentioned, the IEA extended the TRL scale by two levels, and this was to represent technologies readiness to meet energy public policy - TRLs 10 and 11. These levels recognise the need to integrate technology into the existing energy system and demonstrate its potential to develop (IEA, 2020). The risks associated with technological performance decrease as the technologies reach a higher level of maturity; however, the overall risk increases as financial obligations grow (IEA, 2020).

Innovation will rarely follow a linear progression due to unforeseen delays owing to cost and technology concerns. The technology designs that make it from concept to market will undergo multiple modifications; however, not all designs will make it to market. The inability to finance the TRL journey is one of the critical reasons that cause ventures to fail, and this failure rate is the reason that investment risk is so high in the "valley of death" (Mcintyre, 2014).

2.2.1. Valley of Death

The "valley of death" refers to the gap between academic research and industrial commercialisation (Figure 5). This stage describes a point where the technology has a working prototype but is still in its innovation phase and has not yet been developed for commercial sales (McIntyre, 2014). Developers design prototypes to assess the technologies' operation from laboratory to deployment conditions and confirm an outline of the costs, equipment, and processes required for manufacturing (McIntyre, 2014).

Sufficient financial support is required to aid the development of the prototype towards reaching commercialisation and generating revenue; however, investments are typically based on a comparison between benefits and risks, which is a complex subject. Due to the nature of prototypes not being thoroughly tested, the risk of failure is highest at this stage in development. Therefore, significant investment is required to move from a test series of products to the production of commercial volumes (McIntyre, 2014).

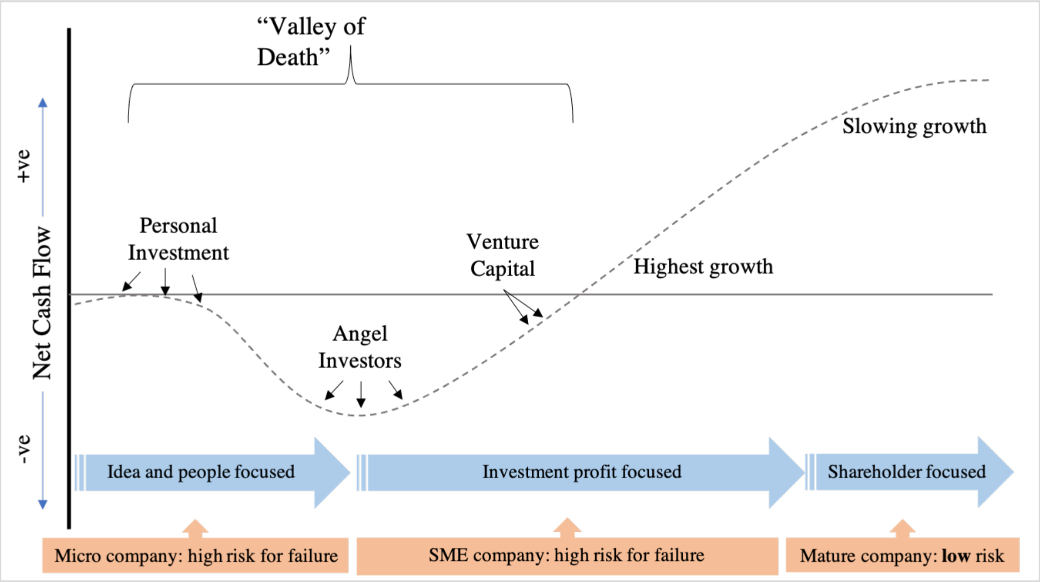


Figure 5: Valley of death with cash flow and associated risk. Adapted from Mcintyre, (2014)

At the start of the TRL scale, research and innovation makes up most of the work, and these processes are mainly public funded as costs are at their lowest (Figure 6). At this stage, developers will create a portfolio of innovations ready to test, however translating these ideas into practical products to test costs money (Herbert, 2016). It's clear that a lack of funding within the innovation stages will slow or stop development. As the Government has the responsibility for policy mechanisms to promote innovation, this support must first come from them so as Government, to ultimately attract more private investments.

2.2.2. Risks

As technologies move up the TRL scale from laboratory prototypes to scaled demonstrations, challenging technological developments are required and this generates higher financial risks. Risk can be analysed through several concepts, including the likelihood, consequence, and impact (Chin, 2019). A combination of these factors will give a determination of the overall risk, whether it be financial or technical. As the innovation is complex, the approach to managing risks is also complex. Experts recognise that physical sciences – such as renewable technologies - experiences uniquely large associated risks, and costs (Windheim and Myers, 2014). Investors will therefore be less incline to buy into ventures within this sector as they have not been validated in market, so choosing other, safer options.

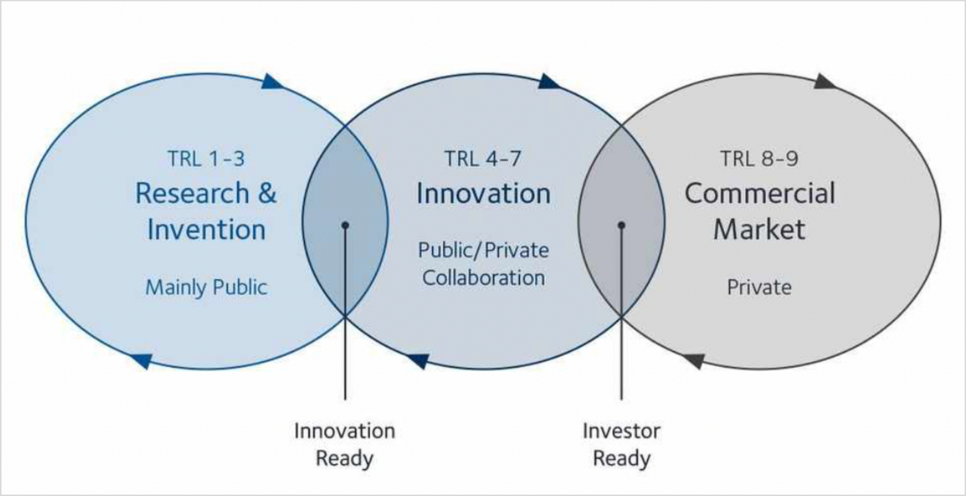


Figure 6: Sources of capital along the TRL scale. Source (Herbert, 2016)

2.2.3. Timeline

The timescale for new technologies to reach the market from the original concept typically takes between 20 and 70 years (IEA, 2020). As technologies mature and deployment increases, shared learning will reduce this timescale and costs. The stages taking the greatest lengths occur at the beginning of the development journey, where concepts and fundamental research are realised (Table 1). The time to complete technology developments and initiate the first tests is also a lengthy process, adding on years to the process. These stages are typically more chaotic and poorly funded which is the primary reason for the increase in the timeline (Windheim and Myers, 2014).

Table 1: Technology timeline. Adapted from Windheim and Myers (2014).

Technology Stage	**Increasing Value**	**Timing**	**Company building**
Theory	↓	Decades	
Fundamental research		Decades	Concept
Technology development		5-10 years	
Proof of concept		1-2 years	
Prototype		6 months	Seed
Alpha produce		6-12 months	Start-up
Qualification and manufacturing		12 months	
Product extensions		2 years +	

Considering this timescale and the net-zero target for 2050, technologies in their very early stages of development are unlikely to provide any significant contribution to the renewable energy mix before this date. Despite the ambition of targets set by the Government, greenhouse gas emissions are still rising, and current policy drivers are failing to adequately address this issue. The International Environmental Agency, along with many experts in the field, maintain that a huge surge in innovation and their deployment is required if countries are to meet their targets (IEA, 2020). The IEA state:

> *Reaching net zero by 2050 requires further rapid deployment of available technologies as well as widespread use of technologies that are not on the market yet. Major innovation efforts must occur over this decade in order to bring these new technologies to market in time.*

Nearly half of the reductions in 2050 will come from technologies that are still in the demonstration or prototype stage (IEA, 2020). Therefore, this historic timescale must be shortened for a higher diversity of renewable technologies to reach the market.

2.3. Policy Matters

The implementation of government policies, subsequent legislation and associated support mechanisms has long been shown to elicit change. In the book 'How to Avoid a Climate Disaster' written by Bill Gates (2021), he describes the how policy has been implemented to address environmental concerns in the past. For example, when the UK government enacted the Clean Air Act in 1956 to reduce air pollution in response to harmful smog, it was a defining moment in creating an environmental legal framework as it generated a decrease in numerous air pollutants, including a reduction in greenhouse gasses (Legislation.gov.uk, 2014; Gates, 2021). Government policies can regulate and limit the amount of carbon that cars, factories, and power stations emit, shaping financial markets and emphasising the risks of climate change to the public and private sectors (Gates, 2021). Moreover, as these policies drive clean energy generation, they can also determine the speed at which specific products can get to market - typically through investment. Gates makes a critical point when mentioning the control government has over the time that it can take to get a concept to commercialisation.

The cost of producing electricity through renewable sources is more expensive than through fossil fuels and suppliers are less likely to voluntarily chose to get their supply from a renewable resource if it costs more. Thus, if there is to be an increase in the uptake of renewables, they must be at a competitive price. Despite dropping prices for certain technologies, such as offshore wind and solar PV, other, less established technologies still have a long way to go before they can compete with the price of fossil fuels. (IRENA, 2020).

Financial support for renewable technologies generally comes from increased customer energy bills rather than taxes (IRENA, 2012). Government subsidisation for the energy generation comes from within the energy sector, therefore for companies to maintain a profit they will increase energy prices to compensate. Figure 7 illustrates the different support mechanisms investigated in this thesis. The introduction and closure of each scheme is signified with a dashed line. The CfD are ongoing and have not got a closure date.

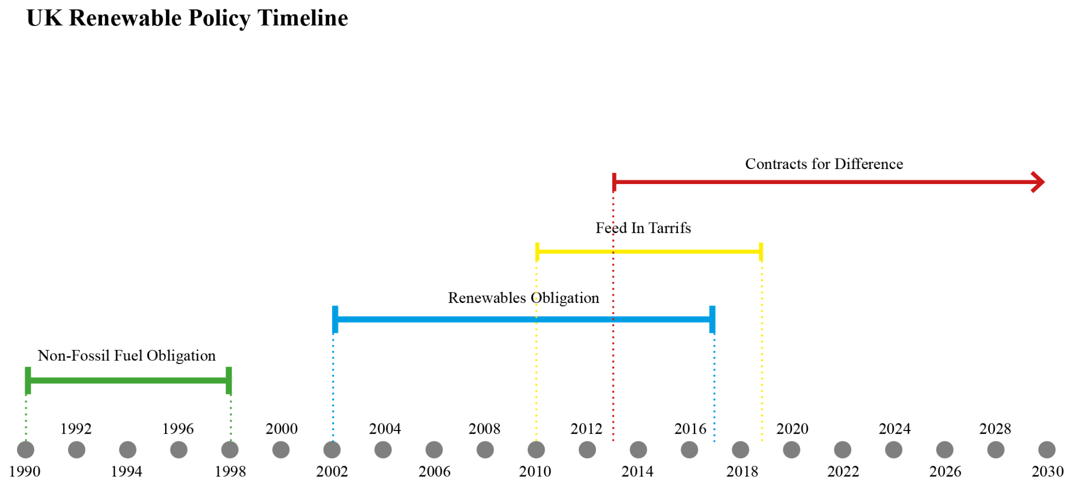


Figure 7: Timeline of NFFO, RO, FIT and CfD

2.4. Non-Fossil Fuel Obligation

The privatised UK's electricity system allowed the promotion and the introduction of the Non-Fossil Fuel Obligation (NFFO) (Mitchell, 2000) – for Scotland this was the Scottish Renewables Obligation (SRO), and in Northern Ireland the Northern Ireland Non-Fossil Fuel Obligation (NI-NFFO) but for brevity this thesis will refer to all as the NFFO. These voluntary schemes were the primary renewable energy policy instruments in the 1990s and were part of the 1989 Electricity Act - supported by the Fossil Fuel Levy imposed on consumers (Gross and Heptonstall, 2010). They permitted the various licenced electricity suppliers to acquire electricity from low-carbon generators – generators of nuclear or renewable energy (Mitchell, 2000; IRENA, 2012). The NFFO was in place from 1990 and the final contracts expired in 2019. It offered the first real opportunity to utilise renewable energy in the UK (IRENA, 2012).

Competitive bidding within a technology band determines the granting of NFFO contracts and the price paid for renewable energy (Mitchell, 2000). Wind energy projects competed with other wind energy projects, but not with tidal or solar initiatives, prices from each NFFO year are listed in Appendix 1. Within each technological band, the lowest bids per kWh were granted a contract (Mitchell, 2000). The largest capacity award was to 600kW projects. capacity being approximately 600MW. This approach aimed to keep prices down and prevent fixed prices; however, criticism arose as the rounds progressed. As there was no 'obligation' to supply or a penalty imposed if not delivered under the NFFO, developers submitted unrealistically low bids (Table 2) (IRENA, 2012; Mitchell, 2000). The total projects awarded over the five periods was 794, however 43% of these did not progress. The average price for the NFFO rounds decreased from £0.065/kWh in 1990 to £0.027/kWh in 1998 (Wiser, 2002), where the majority of the Scottish 1998 bids did deliver wind energy projects.

Although other shortcomings of the NFFO occurred, relating to planning and delivery problems, the reason for their ultimate demise came down to (i) the disproportionately low bids and (ii) lack of participation in the voluntary scheme be the major fossil fuel electricity generators. This caused projects to make no progress and fail to ever be commissioned as manufacturing and operational costs outweighed bids, this failure is reinforced by Gross and Heptonstall's (2010) and Mitchell's (2000) analysis on the NFFO scheme. The NFFO served as the initial stimulant for renewable energy in the UK and operated for over a decade to later be replaced in 2002 by the Renewables Obligation (RO).

Table 2: Status of NFFO 1 – 5 (Mitchell, 2000).

Projects contracted			**Projects generating**		**No progress projects**			
	Date	**Number**	**MW DNC**	**Number**	**MW DNC**	**Number**	**MW DNC**	**%**
NFFO1	1990	75	152.12	61	144.53	14	7.58	93
NFFO2	1991	122	472.23	82	173.73	40	298.49	37
NFFO3	1994	141	626.91	75	254.47	38	234.4	40.6
NFFO4	1997	195	842.72	56	132.62	90	494.66	15.74
NFFO5	1998	261	1177	17	24.31	159	960.43	2.07
TOTAL		794	3270.98	291	729.66	341	1995.3	

2.5. Renewables Obligation

In 2002 the UK government introduced the Renewables Obligation (RO) to provide a mechanism that overcame the limitations of the NFFO and greater develop continued to support renewable energy on the broader energy market (Gross and Heptonstall, 2010). The RO was a market-based support mechanism designed to 'obligate' licensed electricity suppliers to source alternative energy as well as incentivise and stimulate large- and small-scale renewable generation at a competitive cost.

The RO required all registered suppliers to provide a specific percentage of their energy to their customers from renewable sources. This percentage increased annually to reflect the growing market (Appendix 2). The Office of Gas and Electricity Markets (Ofgem) issued Renewable Obligation Certificates (ROCs) to electricity generators based on the amount of renewable electricity they produced (Fan et al., 2018). ROCs were traded as a commodity between suppliers at a market price to manage their obligation on required mix of renewable energy to fossil fuel. This allowed the ROC price to adjust to market conditions and directly affected renewable targets (Zhou, 2012).

Suppliers, particularly the smaller, newer companies that developed out of the deregulation of the electricity market in the 1980's were often not able to comply with the obligation and not present ROCs to meet their target obligation. So, they either purchased surplus certificates off generators or they paid into a 'buy-out' fund, the price of which varied annually (Figure 8) (see Appendix 2 for table of values); however, this would mean suppliers miss out on any non-compliance money redistributed through the ROC recycle mechanism (Bryan et al., 2013). The amount paid into this fund is related to the MWh's shortfall on an annual basis (Ofgem, 2020). Redistribution of payments received into the buy-out fund is done so on a single recycling mechanism - redistributed proportionally back to the suppliers who hold ROCs (Figure 9) (Fan et al., 2018). This system is unique to RO and provided an escape for suppliers who could not meet the high prices of ROCs.

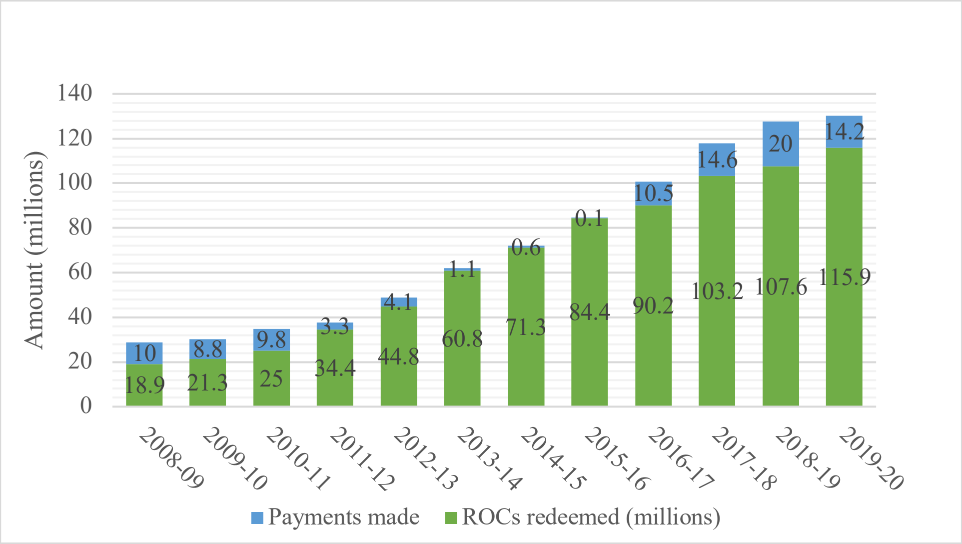


Figure 8: Number of ROCs redeemed annually, and payments made into the buy-out fund.

The recycle value of a ROC is the amount that suppliers will receive back for each ROC they present. For example, in 2019-20, suppliers presented a total of 115.9 million ROCs, and the recycle value was £5.65; however, for the 2015-16 obligation period, the recycle value was £0 as all targets were met so there was no redistribution. Zhou (2012) presents interesting findings concerning the RO buy-out fund and redistribution payments, commenting on the potential of ROC pricing to provide feedback to policymakers when deciding whether to raise or lower the penalty rate or speed up or slow down target implementation. There is value in providing instant feedback, however the variable price is a more significant hinderance to smaller generators than benefit.

Annual reports for each RO allocation round were published by Ofgem and provide information on how the scheme has performed. The quantity of generating stations accredited each year and their aggregate capacity shows to what extent the RO scheme is driving renewable installation. In the 2019-20 annual report, the number of stations and accredited capacity was highest for offshore wind projects (Figure 10). Appendix 3 includes the total accredited stations and capacities for offshore and onshore wind, solar PV and tidal.

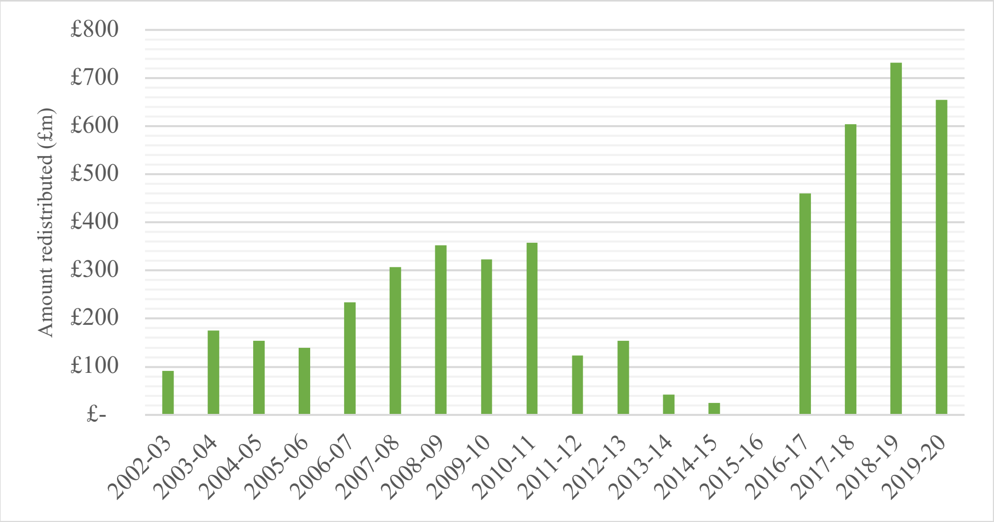


Figure 9: Redistribution values of RO scheme. (Ofgem, 2020)

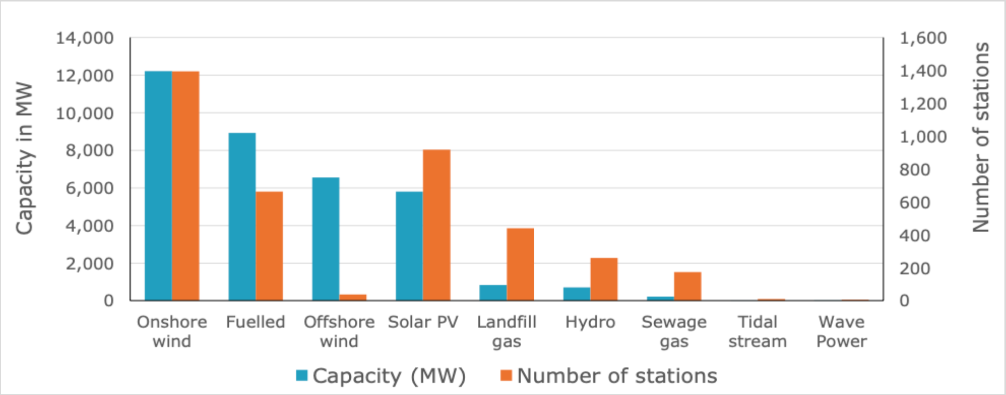


Figure 10: Installed capacity and number of stations accredited to the scheme in 2019-20 (Ofgem, 2020).

Onshore wind accredited the most stations and gained the largest installed capacity. The difference in number of stations and capacity for offshore wind is attributed to the greater capacity per station. Tidal stream and wave power results were negligible.

Where suppliers do not meet their obligation and are unable to pay into the buy-out fund, it triggers mutualisation. Mutualisation has occurred for three years running from 2017-18. When mutualisation is triggered, all suppliers must make up for the shortfall with additional payments - except Northern Ireland, where this does not apply. These payments are capped at a predetermined amount each year and redistributed to suppliers on the same single recycling mechanism as the buy-out and late payments fund (OFGEM, 2016). Mutualisation was amended in 2016 to ensure it reflected the growth of the scheme value (Figure 11).

2.5.1. Banding

On introducing the RO scheme in 2002, each renewable energy technology received one ROC/MWh guaranteed. This equal level of support received aimed to promote a market-led strategy and not favour particular technologies and risk distorting the market (Wood and Dow, 2011) (see Appendix 4). By remaining technology-neutral, more established technologies near commercialisation ultimately got favoured.

Following criticism, the Government received for supporting technologies nearer commercial viability, there was a review and subsequent reforming of the RO. As a result, banding came into place in 2009 to give different degrees of support to different technologies based on their technology costs and market readiness (Table 3) (Ofgem, 2007). The introduction of banding was to provide more cost-effective support for more expensive technologies. Banding groups incorporated emerging technologies - such as tidal stream, wave, and microgeneration – and established ones – such as landfill gas, onshore wind, and offshore wind (IRENA, 2012).

The RO also implemented project capacity limits to avoid overcompensating technologies. For example, less developed technologies that received more ROCs per MWh were subject to capacity limits of 30MW (Ofgem, 2007). Combining realistic deployment capacities for each technology with the expected revenues and introducing the banding produced a mechanism that supported a more comprehensive range of technologies while not increasing the subsidisation.

Table 3: Number of ROCs awarded per MWh 2013 – 2017.

Technology	**ROCs/MWh**			
	2013-14	**2014-15**	**2015-16**	**2016-17**
Landfill gas heat recovery	0.1	0.1	0.1	0.1
Onshore wind	0.9	0.9	0.9	0.9
Offshore wind	2	2	0.9	0.8
Solar PV – building mounted	1.7	1.6	1.5	1.3
Solar PV – ground mounted	1.6	1.4	1.3	1.2
Tidal lagoon	2	2	1.9	1.8
Tidal Stream*	5	5	5	5
Wave *	5	5	5	5

*5 ROCs subject to capacity limits of 30MW per generating station

2.5.2. Outcomes of ROs

In 2006, a public consultation recommended modifying the RO to reflect the reality that some technologies will no longer require full support. Instead, support for emerging mature technologies, for example, offshore wind projects required additional funding. The restructure gave rise to wind energy overtaking hydropower as the UK's largest low-carbon generation source just one year later (IRENA, 2012). This success was the catalyst for wind powers dominance in the UK. The RO scheme had some additional success. The UK increased electricity generation from renewable sources by over 10% between 2002 – 2016, accounting for 22.2% of the UK electricity market (Ofgem, 2017). The total installed capacity from renewable technologies had almost reached 30GW, and wind accounted for just over 50%. The value of the scheme rose to £6.3 billion and because a significant instrument for renewable energy development (Figure 11).

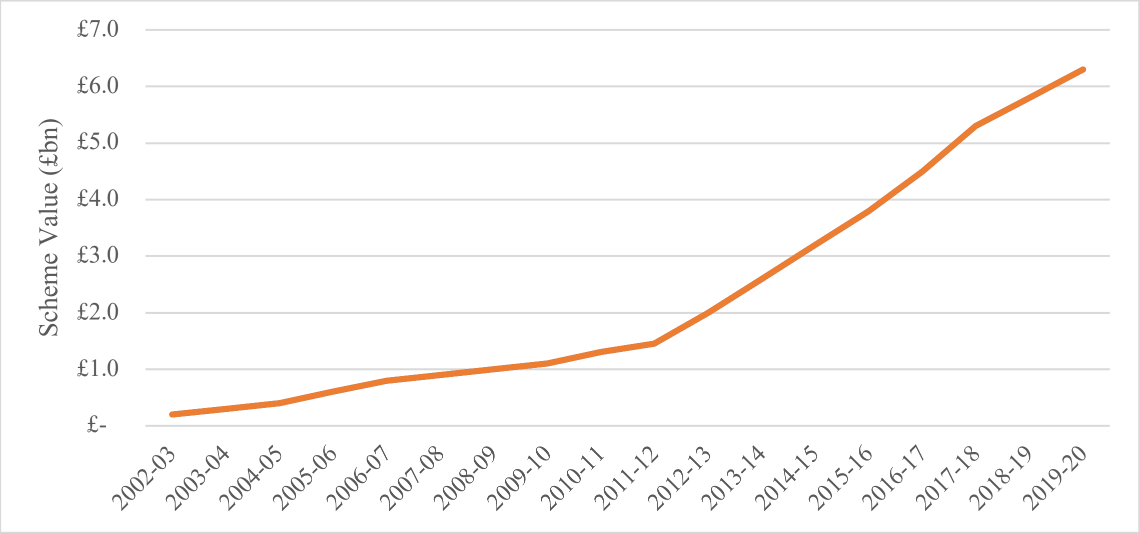


Figure 11: Increase in value of the RO scheme 2002-2020 (Ofgem, 2020).

However, the RO did not provide the generator with a guaranteed electricity price, so they were exposed to the unpredictability of the market prices. This exposure created uncertainty in costs for the supplier, increasing the risk associated with the scheme and causing a volatile electricity price (Fan et al., 2018; Zhou, 2012). As there was no certainty to investors in less mature technologies, the developers required a mechanism of support that would have an increased contract length. The RO scheme closed to any new applicants in 2017, however, support (20-year contract) will continue for all 2017 entrants until 2037.

2.6. Feed-in Tariffs

The Government introduced Feed-in tariffs (FITs) in April 2010 as an additional support mechanism to promote the uptake of small-scale renewable generation technologies (Ofgem, 2020). FITs were eligible for developers installing capacities of 5MW or less in solar photovoltaic (solar PV), wind, hydro, and anaerobic digestion, and up to 2kW for micro combined heat and power (CHP) (Ofgem, 2020). In addition, it provided a flexible price that varied depending on the technology and installation capacities (IRENA, 2012). The FIT rates, set by the Department of Business, Energy and Industrial Strategy (BEIS), are illustrated in Figure 12. This market pull mechanism aimed to advance technologies to the point where they can function independently in the marketplace, however, as the FIT scheme targeted small-scale generation, the impact on the overall contribution to the renewable energy sector is considerably lesser than legislation extending to larger renewable generators.

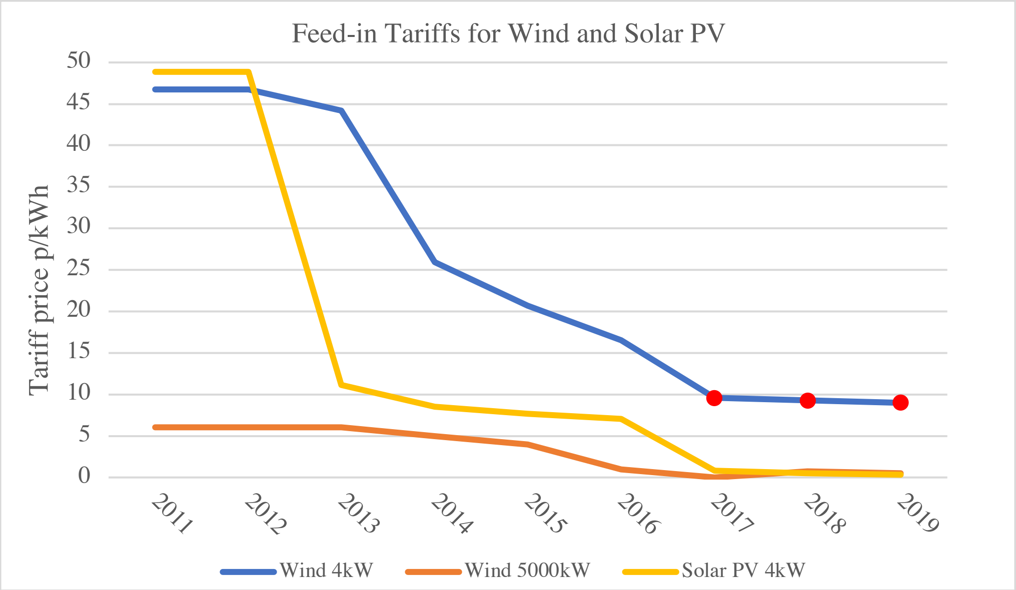


Figure 12: Feed-in tariff rates for wind and solar PV installations. FIT rates are determined by Ofgem and were published on 28/01/2021.

The blue line indicates ≤ 4kW onshore wind capacity, and red markers signify an increase to 50kW after amendments were made. The orange line indicates the capacity of onshore wind installations ranging from 15000 – 5000 kW and the yellow line indicates solar PV capacity of ≤ 4kW, which is the average capacity of a domestic solar panel.

The rapid decrease in tariff price for solar PV installations from 2011 – 2013 resulted from the plummeting solar installation costs (Figure 12). In 2011, the Government cut the rate for small solar photovoltaic installations by more than 50% and set a new capacity limit, keeping the scheme from becoming overwhelmed. Cuts were a consequence of an increasing number of applications to the scheme that exceeded forecasts from the DECC and risked surpassing the allocated funding. PV owners profited financially from this scheme in two ways: firstly, the FIT is given to PV owners, which means they are paid for each kWh of PV energy produced, whether or not they use it; and secondly, any extra electricity could be exported and sold at the export tariff (Castaneda et al., 2020).

Figure 13 shows the distribution of installations from 2010-2015 and total cumulative installations. Domestic solar PV installations grew tremendously with support from the FIT, and as installation numbers grew, the price of the tariff fell. As the tariff price dropped, the incentive to install domestic solar PV panels fell. The total installed capacity has since generally flattened off (Ofgem, 2020).

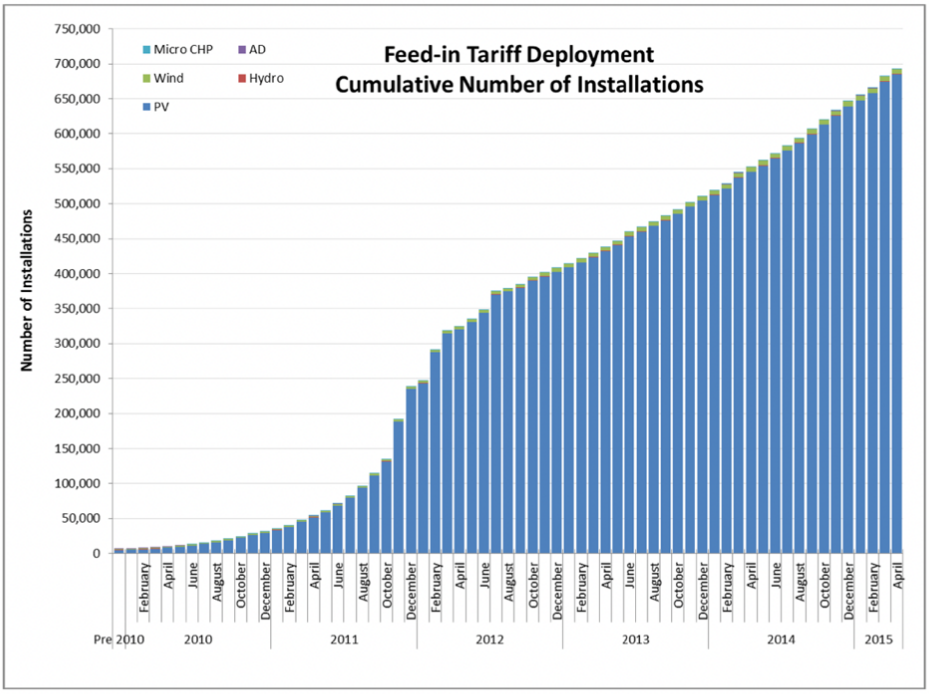


Figure 13: Installation growth of solar PV from 2010 to 2015 (DECC, 2015)

Criticism of the FIT scheme surrounds the inconsistent tariffs rates (see Appendix 5). It also relied on customers to pay any up-front costs by themselves, limiting the number of people benefiting. Those who were able to install and benefit from solar panels would typically be paid a small amount for their electricity or not pay anything at all. However, for suppliers to maintain a profit, they would put this loss onto other customers through increased bills.

The FIT scheme did not limit the number of projects is supported and ultimately collapsed backfired when tariff prices crashed. This poorly designed scheme then caused the solar PV industry to suffer as the uptake of solar panels became far less attractive. FIT schemes were an effective way of jumpstarting innovations to penetrate the market; however, they must be designed with limits to remain competitive and not negatively influenced. In 2019, BEIS announced the closure of the FIT scheme (subsequently amended to 2020.

2.7. Contracts for Difference

In 2013, under an Act of Parliament Contracts for Difference (CfD) legislation was introduced under the Electricity Market Reform (EMR) to work alongside the FIT scheme and replace the RO. The first Round One bidding was announced in 2016 for contract commencing in 2017 to dovetail with the end of the RO programme. The UK government introduced the EMR as a series of continuing reforms to ensure affordable, secure, and increasing low-carbon electricity supply.

CfDs are a long-term agreement between the Low Carbon Contracts Company LCCC and renewable energy generators to promote low-carbon electricity generation and remove the price risk. The LCCC is a BEIS-owned private company that manages contracts awarded to CfD generators. These contracts work by paying the difference between the Reference Price (RP) – an average market price for electricity in the UK market, and a Strike Price (SP) - set out in the contract (Figure 14) (Fan et al., 2018). When the RP is above the SP, for example, when electricity demand is high, the generator will pay the difference back via the LCCC to reduce excess funds getting transferred to consumers. Thus, traders and investors are both able to profit from the flexibility in price over the 15-year CfD term. In addition, payments collected from electricity suppliers are made to the LCCC by generators. These funds are returned to the suppliers and will likely get passed on to consumers as higher electricity prices.

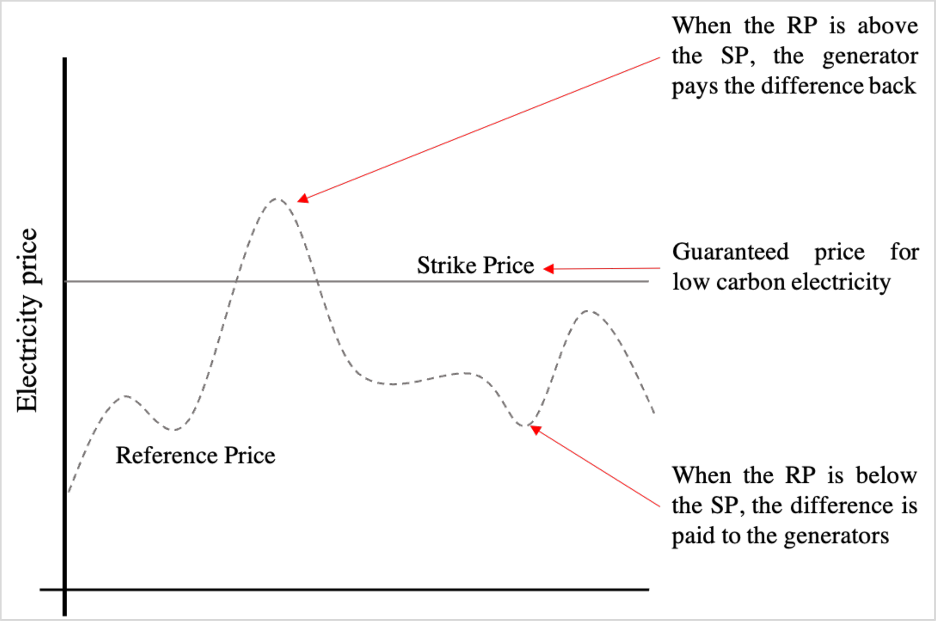


Figure 14:CfD mechanism. Adapted from Fan et al.,(2018).

According to results posted by the Government, the most successful allocation of CfDs was in Round 3 in 2019 (Figure 15). As a result, the CfD scheme awarded 5800 MW of new renewable capacity contracts, which has prompted the plans to have another round of allocations in late 2021. The installed capacity awarded to different technologies for each allocation round is displayed in Figure 15. The scheme favoured offshore wind projects granting them 88% of the total capacity over the three rounds. ‘Other’ includes Advanced Conversion Technologies; Dedicated Biomass with CHP; Energy from Waste with CHP; and Solar PV

A principal focus of the CfD scheme is to lower the risk of investing in low-carbon energy by reducing the risk associated with market volatility. If the generator fails to meet the contracted obligation, energy can be bought from the market to compensate. However, if the RP exceeds the SP, electricity may be more cost-effective to buy energy from a coal plant, essentially subsidising carbon production (Newbery, 2013). This mechanism can also create a market where larger companies, such as those in the Big Six, dominate because they can adjust better with their mix of generating technologies.

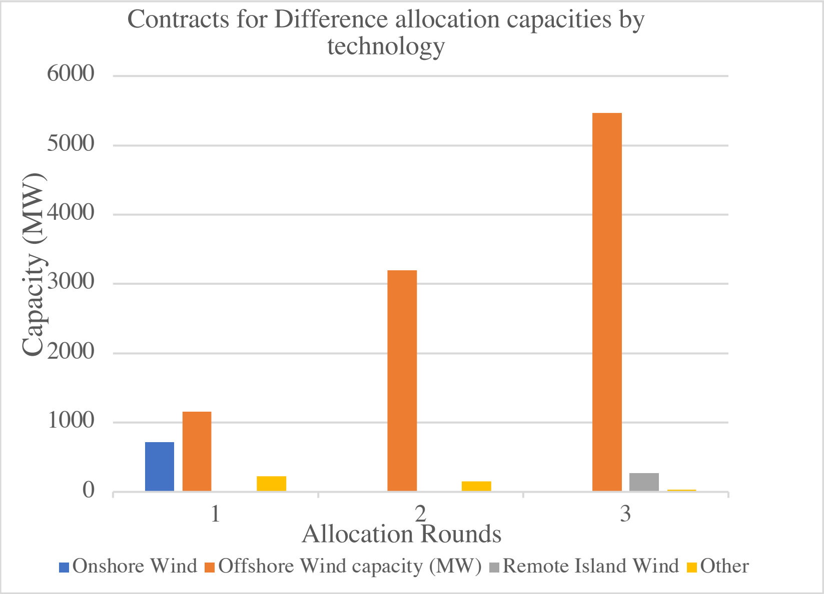


Figure 15: Install capacity awarded through CfD scheme. Rounds 1, 2 and 3 were awarded in 2015, 2017 and 2019, respectively (www.gov.uk, 2019).

2.7.1. Outcomes of CfDs

The CfD scheme effectively removes the generator's exposure to wholesale electricity prices, which removed the risks associated with a volatile market. However, it does not guarantee the generator an income. In addition, solar PV has suffered due to the lowering strike prices; for a solar park to become economical, it is acknowledged at this time that they require a SP of at least £80/MWh, £30 higher than the bids.

Although CfDs have been a critical mechanism in reducing the cost of offshore wind over the last ten years, it has resulted in a "winner-takes-all" market where winning projects are constructed, leaving other, smaller developers without a path to market. Ultimately, there had been less support and financing of innovation in this sector because of the absence of risk-taking possibilities. Ultimately, the CfD scheme was aimed at mature technologies that could deliver large capacity against the government targets, namely offshore wind, and created barriers for underdeveloped technologies, discouraging investments in innovation.

3.0. Research

3.1. Methodology

A mixed-method approach was applied to meet the aims of this thesis and ensure the accuracy and reliability of results. Research and analysis of past and present funding opportunities was principally carried out via government websites and supporting documents, the Ofgem website, annual reports, and relevant journal papers.

The following flow diagram illustrates the method that this thesis followed:

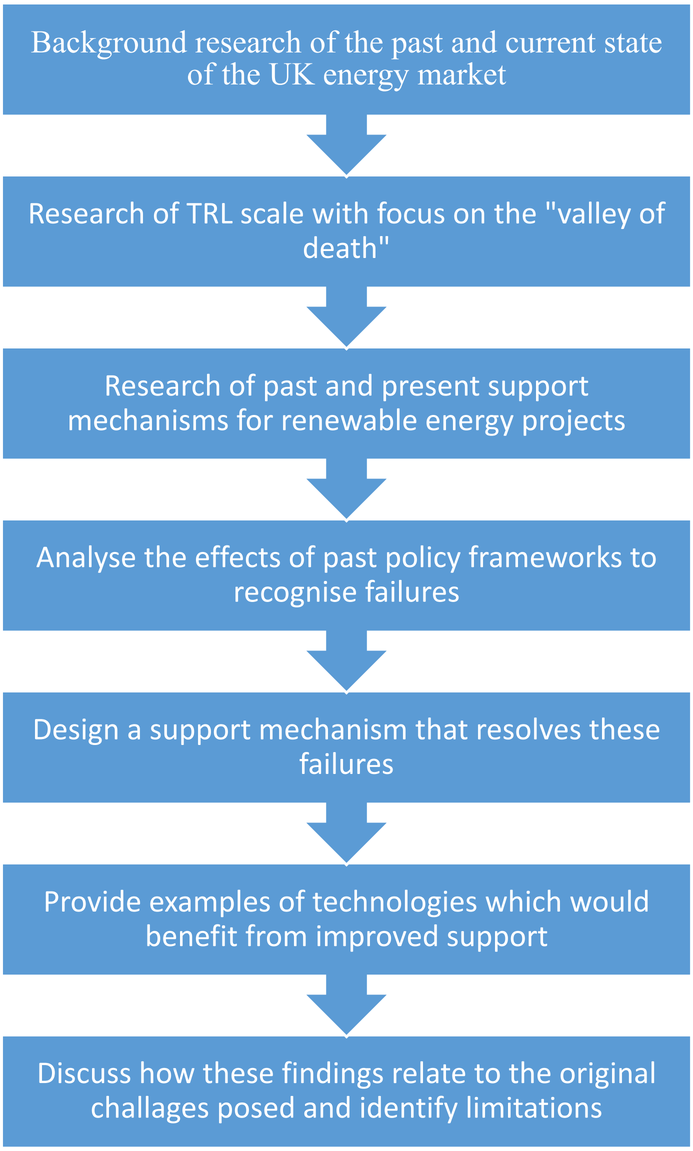


Figure 16: Methodology structure for analysis and discussion

The initial focus of research was to gain a greater insight into the possibilities of improved framework and a framework structure. Further research was conducted on critical reviews of past policies to improve the validity of recognised failures, acting as an additional source of confirmation that existing policies have not adequately facilitated the deployment of new renewable technologies.

Then, research into promising technologies that require funding to penetrate the energy market. The UK and Scottish Government websites provided the source of information and data on past policies. Annual reviews, budget reports, and supporting documents were analysed and extracted data compiled to produce summaries. Journal and news articles provided up-to-date information on relevant case studies. These studies were selected based on their suitability to demonstrate areas that are not meeting their predicted potential and showcase current projects that have verified the potential.

Lastly, using information from recent progress of onshore and offshore wind should hopefully produce a reasonable forecast of how a new policy framework will affect the cost and installation capacity of new, innovative renewable energy technologies. This approach is called hindcasting.

3.2. Proposed Policy Framework

As discussed in the literature review, introducing a legislative obligation helps to increase the installed capacity of a targeted technology. The Government must re-evaluate existing policies to appropriately target the innovation stage of the TRL scale as current estimations suggest that current technological progress is insufficient to reach the net-zero target (Hart, 2020). Evidence also suggests that if the UK is to reach the target of net-zero emissions within an 'acceptable' time, then innovation should be one of the top priorities of the UK Government.

3.2.1. Overview

Until 2000, the NFFO schemes were the Governments primary instruments of renewable energy policy prior to the introduction of the RO. These schemes required electricity supplies to acquire a certain portion of their electricity from a renewable source, however difficulties in planning meant that only a quarter of the NFFO contracted electricity was delivered (Renewable Energy, 2001). These difficulties lead to the Government reforming the scheme and implementing an enhanced obligation on suppliers.

The RO scheme redirected funding from within the energy sector towards ‘eligible’ renewable generators. Obligations not only required energy suppliers to obtain a given portion of their electricity from renewable generation but had penalties for non-compliance. A number of issues with the RO were recognised and outlined in a report issued from the Parliamentary Office of Science and Technology (POST) (Renewable Energy, 2001). One of the most significant initial failings of the RO was that there was no disparity between different technologies, leading to a market dominated by more developed technologies and leaving less mature technologies to fall into the shadows (Renewable Energy, 2001). For example, wind power became increasingly competitive in the market whereas tidal was still not commercially viable. There were many debates surrounding the success and long-term viability of the RO, which led to multiple reformations and restructurings of the scheme.

The introduction of FIT was a result of one of the RO reformations and was aimed at providing specific support to smaller generators. This scheme significantly increased the uptake of domestic solar PV panels and helped support small wind projects. Many wider benefits were identified, including the creation of jobs and economic growth of companies who were eligible for the scheme (DECC, 2015). However, the tariff prices declined rapidly as costs reduced and the scheme struggled to maintain any valuable support. As a result, the scheme came to its closure just shy of ten years later.

RO or FIT schemes did not manage to adequately fund the less mature technologies that require an injection of capital to help get them to commercialisation. The CfD scheme promised to be the new mechanism to bridge this gap between innovation and the market and boost renewable capacity in the UK. However, onshore and offshore wind projects were awarded the majority of the contracts, reflected in the falling costs and increased installed capacities. As CfDs were allocated through bidding, and the highest bids with largest capacities won, technologies in the 'valley of death' were again left with no path to market.

The Government have since released cost estimates for offshore-, onshore- and large-scale solar projects from 2025 - 2040 (Figure 17). The estimates place these technologies at 57, 46 and 44 £/MWh in 2025 and 40, 44 and 33 £/MWh in 2040 (BEIS, 2020). These figures represent the levelised cost of electricity (LCOE). LCOE is the amount that the generator must earn throughout the life of its assets in order to pay its capital and operating costs.

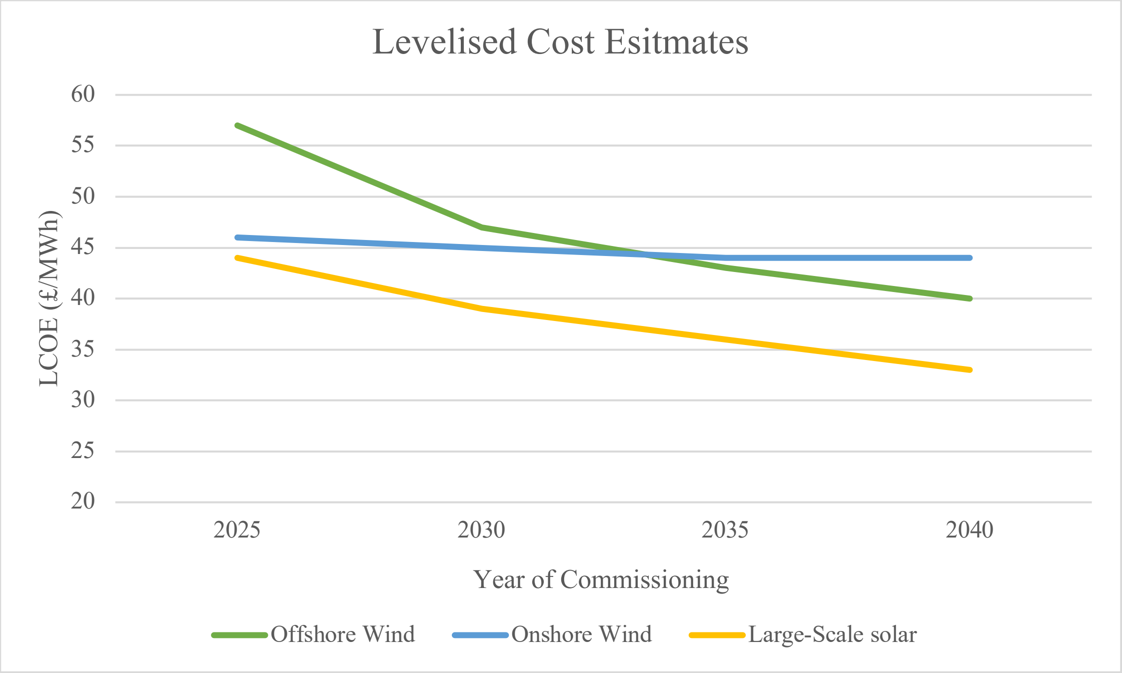


Figure 17: Levelised cost estimates from 2025 – 2040 for offshore-, onshore- and large-scale solar projects.

From the introduction of these renewable energy policies, there has been a notable decline in costs, and as can be seen from Figure 17, this is projected to continue. This decline has been particularly sharp in offshore wind, due to the support it receives from the government, helping to produce significant technological advancement and driving down costs. Using this information, projections for less mature technologies are likely to follow the same path as they make their way through development to commercially viable projects. It is important to note that the decline in costs will vary from technology to technology but will still reflect the amount of support received.

3.2.2. Innovation Tariff

As a project enters its demonstration phase, after an original prototype has been passed initial testing, an innovation tariff could provide long-term support for the project and entice investment opportunities.

As the project has passed initial testing, the risk of failure reduces - thus, investment becomes a more attractive prospect. Private investments will provide capital costs for the project; these are the upfront costs paid for the main construction and maintenance works. As previously discussed, projects' overall capital costs increase with increasing project size; however, as learning and the economies of volume come into play, the cost per unit decreases. A targeted market pull mechanism could facilitate the journey to commercialisation and expand the number of technologies available to consumers.

3.2.3. Policy Structure

Figure 18 illustrates the TRL levels within the 'valley of death', where a funding mechanism is required.

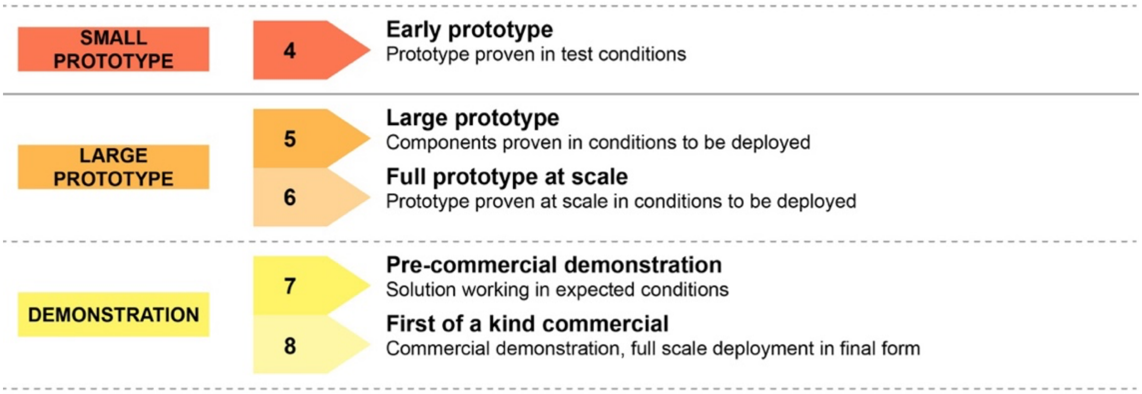


Figure 18: TRL levels within the 'valley of death'.

The proposed tariff should exhibit five key components:

1. Fixed/strike price for electricity generation/suppliers
2. Weighting technologies based on maturity level
3. Capacity limits per project
4. Capacity limits for awarded contracts
5. Long-term contract that exceeds the pay-back time

The combination of these components is what makes this proposed structure different from past mechanisms. The inclusion of each component reflects the changing requirements technologies have as they develop through the TRL scale. Each component is expanded on below:

1. Fixed price for suppliers

A strike price is a guaranteed price paid to the wholesale generators – for renewables, the strike price will be higher than the wholesale price on the market. Like the CfD scheme, rates will reflect the LCOE for each technology. Having a fixed price will incentivise investments because if a project succeeds, it will eventually generate revenue, and investors will receive a profit. By removing the exposure to volatile market prices, the scheme reduces the associated risk. The Government absorbs any fluctuations in price, benefiting both supplier and generator.

2. Weighting technologies based on maturity level

The tariff price must incorporate a weighting system to reflect the maturity level of the technology. A tariff multiplier will be given to each technology, creating a non-discriminatory system that gives less developed - or more expensive - generators a fairer chance. For example, tidal stream projects will receive a higher weighting than hydro schemes, whereas wave would receive a greater weighting than tidal.

In addition, as a particular technology matures, the multiplier will reduce through contingent degression. For example, as tidal stream projects develop and prices fall, the tariff multiplier will reduce. Incorporating a contingent degression* mechanism will account for the lowering unit costs as project capacities increase is recommended. Once a project reaches a deployment capacity boundary, there will be a reduction in the tariff they receive - dropping by a predetermined percentage. Table 4 outlines the suggested capacity limits. A 10% degression is suggested as is recommended in the FIT scheme. For example, if a project is developed and exceeds the 5MW limit, the project would enter Band 2, decreasing the tariff by 10%.

*Contingent degression is the periodic reduction of payments on reaching agreed boundaries

3. Capacity limits per project

The capacity of the project must also be reflected in the tariff price. A banding system that places capacity limits on individual projects will ensure that the targeted demonstration projects benefit. The maximum capacity that any project can have is 30MW as after this, a project is considered commercially viable and will no longer need the support of an innovation tariff. Table 4 outlines these project capacities.

The initial capacity of projects can differ depending on the technology, for example, a demonstration project for a wave farm may begin with a 3MW capacity, while a hydrogen power plant may have an initial capacity of 10MW. Having a weighted tariff for different capacities will remove unfair advantages of larger capacity technologies.

Table 4: Banding for project capacity

Band	**Project Capacity (MW)**	Award Capacity (MW)
1.	≥1 - <5	20
2.	≥5 - <10	100
3.	≥10 - ≤30	500

4. Capacity limits for awarded contracts

The scheme must also include a limit on each band's total capacity ("award capacity") - a limit on the number of projects awarded a given tariff. This limit will safeguard against excess spending. For example, Band 1 has a maximum project capacity of 5MW; however, the capacity of this band is 20MW, so a maximum of four projects - each with a capacity of 5MW, can receive this tariff. On reaching this limit, no further contracts are eligible for this tariff. Table 5 outlines the award capacities.

A periodic review of the capacity for each band limit will recommend whether this could increase and accommodate a greater number of projects. For example, when a project reaches the limit for Band 1, but costs for the projects are reducing as the operation progresses, the government could increase the award capacity to 30MW and allocate more contracts.

Table 5: Award capacities for each band.

Band	Project Capacity (MW)	**Award Capacity (MW)**
1.	≥1 - <5	20
2.	≥5 - <10	100
3.	≥10 - ≤30	500

5. Long-term contract that exceeds the pay-back time

The length of the tariff contract is important as it will determine the feasibility of a project and influence potential investment. If the contract is too short, then developers may struggle to pay back investors. However, if the contract is too long, the subsidized amount increases and puts pressure on funding budgets. In the renewable and low-carbon energy sector, government support is required over a more extended period due to the time-consuming and expensive nature of the work involved (Gates, 2021).

For example, a project costs £10 million to develop, and private investments provide the capital costs. However, after considering the capacity factor and annual operational costs, the project returns a £2 million profit. Therefore, the project would take five years to pay back money for the original investment, and any time after that would be a profit that would go to investors and back to the developers.

This time scale will depend on the size of a project, the type of technology, and the capital investment value. Less mature technologies with higher capital costs will typically have a longer payback period. Increasing the tariff value for less developed technologies will help to level the investment opportunity.

3.3. Examples of targeted technologies

Decarbonising the energy sector will require accelerated improvements in a number of different technologies. Technologies currently in their innovation stage include any that are not commercially available on the mark or cost competitive with current forms of generation. These technologies will be required for industry, transport, heating and electricity. Two examples of technologies which exhibit promise but require innovation to reduce costs are tidal stream and green hydrogen.

3.3.1. Tidal

The UK boasts 7500 miles of coastline, offering a significant tidal resource with a potential market price of £76 billion (BEIS, 2020). The crown estate - who own the seafloor - state that the UK could provide up to 30% of the electricity demand (Smart and Noonan, 2018). However, Government estimates suggest that tidal could deliver up to 12% of the UK's electricity needs, with an installed capacity up to 30GW (gov.uk, 2013). This analysis will consider this government estimation of 30GW.

There are three different methods of harnessing tidal energy: tidal barrages, tidal lagoons, and tidal streams. Tidal barrages involve constructing a dam-like structure with turbines placed at the bottom. These structures generate a significantly larger capacity than the other methods; however, the potential impact the environment can be considerable, so no tidal barrage projects have been commissioned in the UK (Hooper and Austen, 2013). Results from Hooper and Austen's review of tidal barrages suggest that this form of generation may become an attractive proposition if there was available funding for research of the ecology and mitigation involved in these projects (Hooper and Austen, 2013). Tidal lagoons are made by constructing sea barriers, which may then be utilised as artificial estuaries with larger tidal lagoons producing less power than small ones, owing to economies of scale (MacKay, 2015). Lastly, Tidal Stream Energy (TSE) captures kinetic energy from tidal currents that flow during the transition between high and low tide, occurring twice per lunar day (24 h and 50 min). In David MacKay's book 'Sustainable Energy – without the hot air', he discusses the prospect of tidal stream farms. Built like a wind farm, tide farms would be built in an area with strong tidal currents and connect to the grid (MacKay, 2015). This method of tidal stream has not been employed in the UK yet, however it provides an insight into how tidal stream could advance and progress. This thesis, however, will consider tidal energy potential in terms of small-scale generation of TSE, not as a TSE farm.

One of the key benefits of tidal energy is the higher degree of predictability, allowing it to be more accurately forecast than intermittent wind and solar (Klaus, 2020). Furthermore, unlike offshore wind, there are minimal visual impacts on ocean landscapes as the turbine is typically fully submerged after installation (MacKay, 2015). Nevertheless, challenges remain with the deployment of tidal projects. As there are so few TSE projects in operation, the ecological and environmental impacts remain somewhat unknown. However, the turbines get secured to the ocean floor similarly to offshore wind projects; thus, expected impacts will be comparable. As the number of tidal projects increases and learning increases, significant impacts will be more predictable, and mitigation improved.

The Marine Energy Programme Board (MEPB) conducted a report on wave and tidal energy in the UK and found that the closure of the RO scheme and subsequent replacement with CfDs made it more difficult for developers to secure financial support. It found that it was particularly difficult for small generators, test projects and pilot arrays and recommended that policy must be flexible enough to support these projects (MEPB, 2015). They find that as deployment has increased over the past, the LCOE has progressively fallen, and both these trends should continue into the future until tidal becomes cost competitive with established forms of electricity generation.

3.3.2. Case Study: MeyGen

The current installed capacity of tidal in the UK is 14MW, roughly 0.05% of its estimated potential. However, in 2010 The Crown Estate awarded SIMEC Atlantis Energy ("Atlantis") a lease that would allow a project capacity of 398MW. Atlantis is a sustainable energy company with an established reputation in Tidal Energy projects aiming to reduce the LCOE over the coming years.

Project MeyGen was awarded a lease in 2010 and in 2013, received consent to commence the first phase of their project, installing 86MW of capacity. Onshore construction works began in 2015, and offshore works one year later (SIMEC Atlantis Energy, 2016). The project began its operation phase in 2018 as the largest planned tidal project in the world.

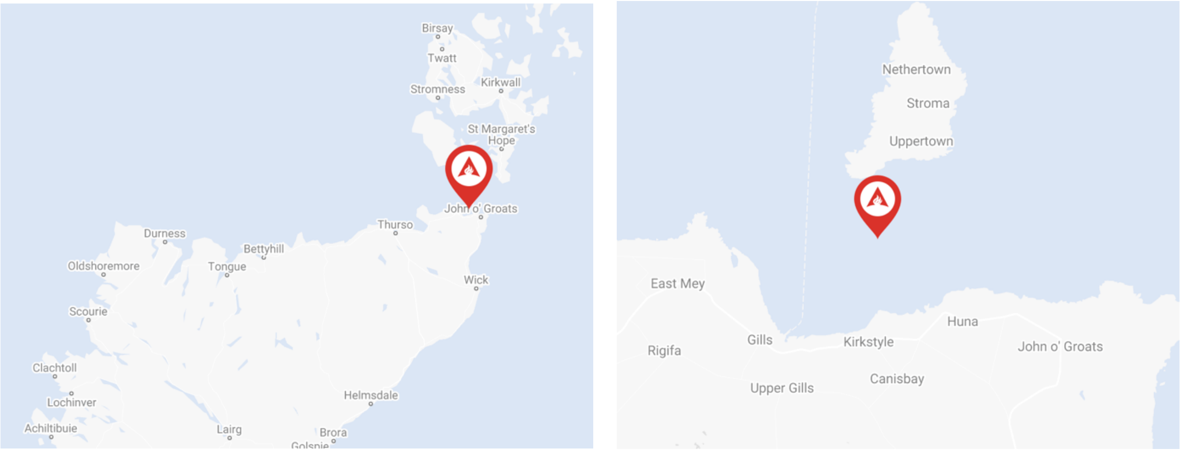


Figure 19: Location of MeyGen project in North-East of Scotland (SIMEC Atlantis Energy, 2016).

The current grid capacity for the site is 252MW, however the site can expand to a total 398MW capacity (SIMEC Atlantis Energy, 2016). Located 2km off the northeast coast of Scotland, the site covers a 3.5km area (Figure 19). The site lies between mainland and island of Stroma in a natural 2.5km channel of flowing water with water depths between 31-38m. This project provides serval advantages, including attracting investment opportunities into tidal projects and creating thousands of jobs. Crucially, the project aims to reduce the LCOE significantly.

A new turbine design, the AR2000, has increased each unit capacity to 2MW has also increased the system's optimization (Figure 20) (SIMEC Atlantis Energy, 2018). This next-generation turbine was developed over two years and will further drive down the LCOE while increasing reliability. This new innovative design is an example of the great progress that is being made within tidal arrays.

While in operation, Atlantis partnered with several academics and researchers to monitor and analyse the system process. As a result, a combination of experts working on the project allowed the innovation process to speed up and drive up the working capacity of this site. With additional financial support from the government, progress could be further accelerated (NS Energy, 2019). The MeyGen project provides an example of the potential that tidal holds for expansion in the UK.

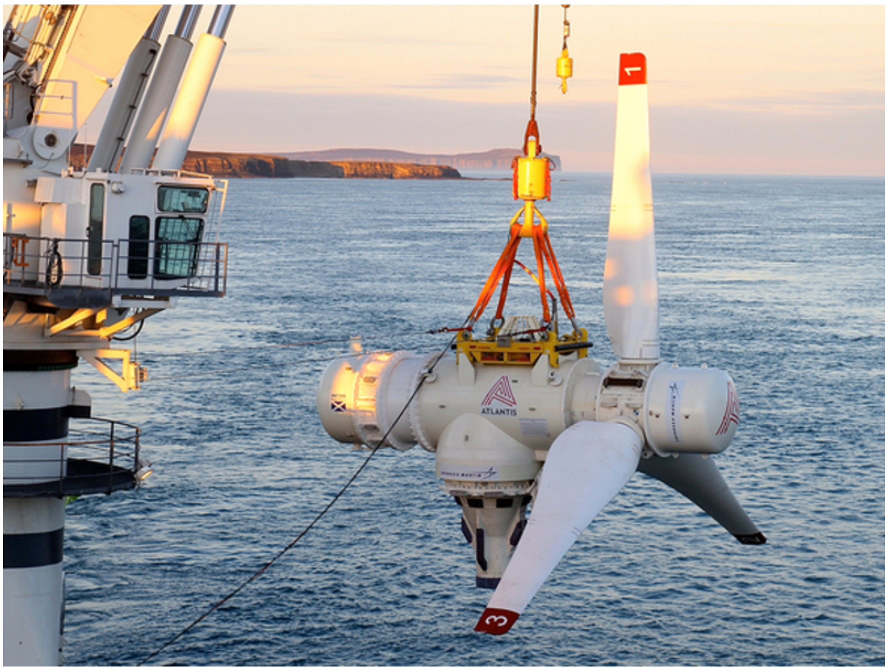


Figure 20: AR2000 turbine. 20-24m diameter rotor with a rated capacity of 2MW at 3.05 m/s (NS Energy, 2019).

3.3.3. LCOE

Lamy and Azevedo (2018) find that a significant challenge facing TSE projects is the initial capital outlay. Allan et al. (2011) suggests that TSE is somewhat comparable to offshore wind, with much of the costs coming from the construction phase (Allan et al., 2011). The majority of funding available for tidal projects in Scotland aims at more mature projects nearing deployment. The Saltire Tidal Energy Challenge Fund is an example of available funding which excludes projects still in their innovation stages (Gov.scot, n.d). Smart and Noonan's analysis on Tidal Stream and wave energy (Smart and Noonan, 2018) predicts the LCOE of tidal could drastically reduce by focusing on support at the innovation stage

The UK government has received criticism from experts from within the field (such as members of the Environmental Audit Committee (EAC)) that there is not enough funding support for tidal projects to pass the concept stage. However, the Department for Business, Energy & Industrial Strategy (2019) has outlined key innovation areas within TSE that would benefit from financial support. The current LCOE is approximately £300/MWh, compared to £55/MWh for offshore wind (Smart and Noonan, 2018). Tidal has the potential to reduce this figure to £150/MWh at 100 MW deployment and £80/MWh at 2 GW (Figure 21) (BEIS, 2020). Providing a support mechanism to help drive innovation in this field could allow tidal to be competitive with alternative renewable energy sources.

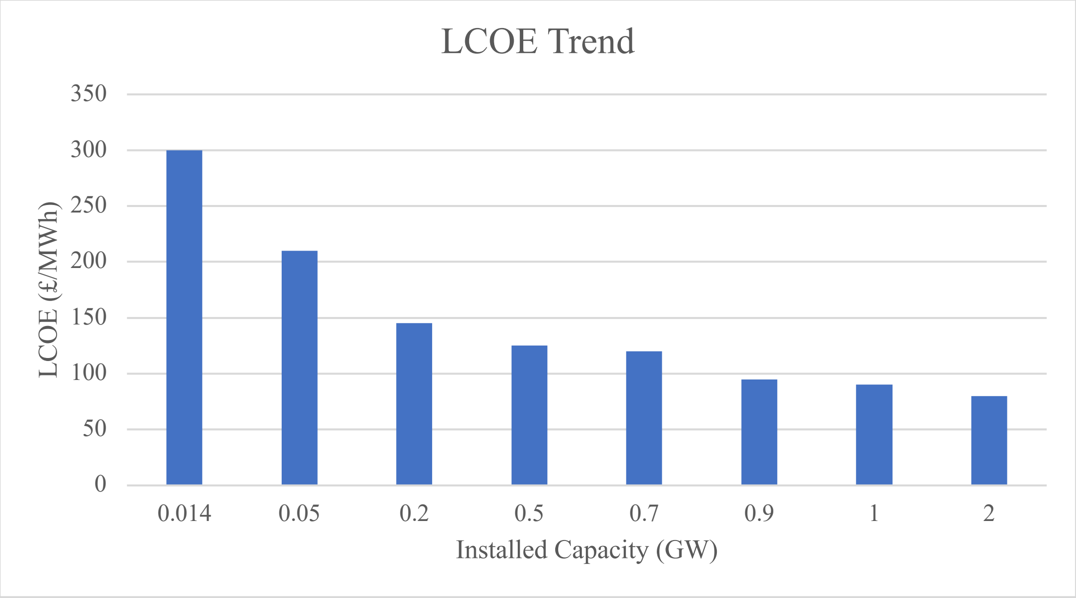


Figure 21: LCOE reduction of Tidal energy. LCOE figures are taken from 2012. Adapted from, Smart and Noonan (2018)

The estimations presented in Figure 21 are subject to assumptions and variables. For example, the construction and fuel costs will vary depending on the state of the market. Cost reductions are principally reduced through learning and economies of volume – manufacturing and purchasing multiple units (Smart and Noonan, 2018). As the number of installations increase and time goes on, processes will be optimised – like those in the MeyGen project. Transitioning from the prototype stage to early adoption will result in initial accelerated cost reductions and costs will exhibit a steadier decline. Estimating a time scale of the advances is challenging due to the unpredictability of market prices. However, if the UK is working towards 2050 targets, it is reasonable to suggest that substantial improvements will occur within this time period.

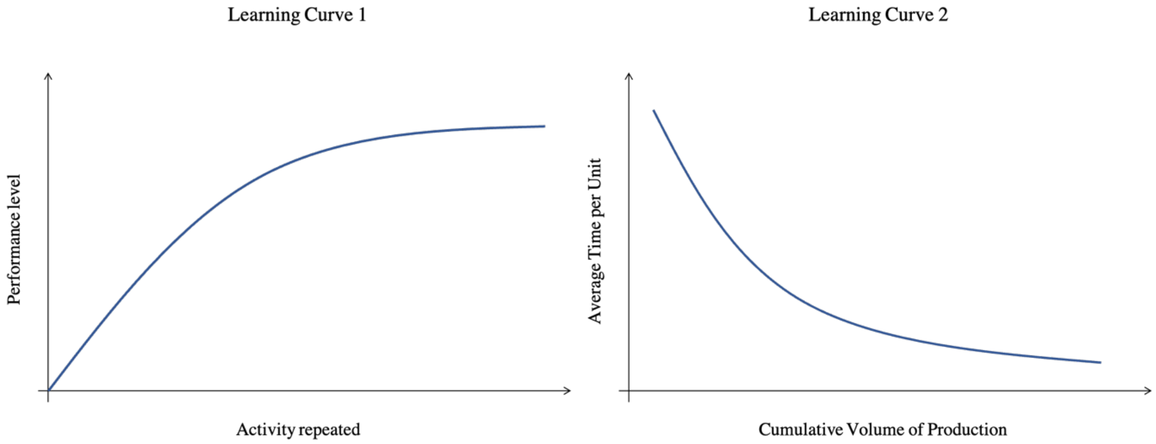


Figure 22: Learning curves 1 & 2. Repeated activity and economies of volume

A concept that has long proven to decrease costs and time scales is 'learning by doing', exhibited in Learning Curve 1 (

Figure 22). Processes become better understood, methods optimised, and operations completed more rapidly when developers open additional sites and repeat activities (

Figure 22) (Smart and Noonan, 2018). As capacity can increase fast during the start of an industry's development, the cost savings that the industry achieves in the short term are considerable. However, to fully benefit from the learning possibilities presented by increased capacity, the industry must work together collaboratively.

Volume economies also work to reduce the cost over time, illustrated in 'Learning Curve 2' (

Figure 22). Bulk purchase discounts, lower production costs per unit, and standardisation of standard components have all ultimately reduced the LCOE of new technologies (Smart and Noonan, 2018). As design optimisation and serial manufacturing take place, the long-term impacts will be significant. In the UK, tidal has not yet reached a great capacity, with the MeyGen project as the largest, so the optimisation of manufacturing and operational processes are likely going to get much better with continued deployment. As developers continue to deploy turbines with 1-2MW capacities, the plant and fixed costs will further decrease (Smart and Noonan, 2018).

3.3.4. Tidal Tariff Example

Figure 23 illustrates how a tidal stream tariff price could change over a 15-year contract. This example assumes that the LCOE progressively falls from £300/MWh to £80/MWh in accordance with projections in Figure 21and Figure 24. The price per MWh reduces by 10% going up each band. The tariff is set to ensure the difference between the guaranteed price for electricity and the LCOE is subsidised.

Each line follows a technology which is within a band group. A project is unlikely to remain in one group and not increase its capacity over the 15 years, so it will move up a band, and the tariff will reduce. In addition, the tariff is reduced every five years in the contract to reflect reductions in costs attributed to learning and economies of volume.

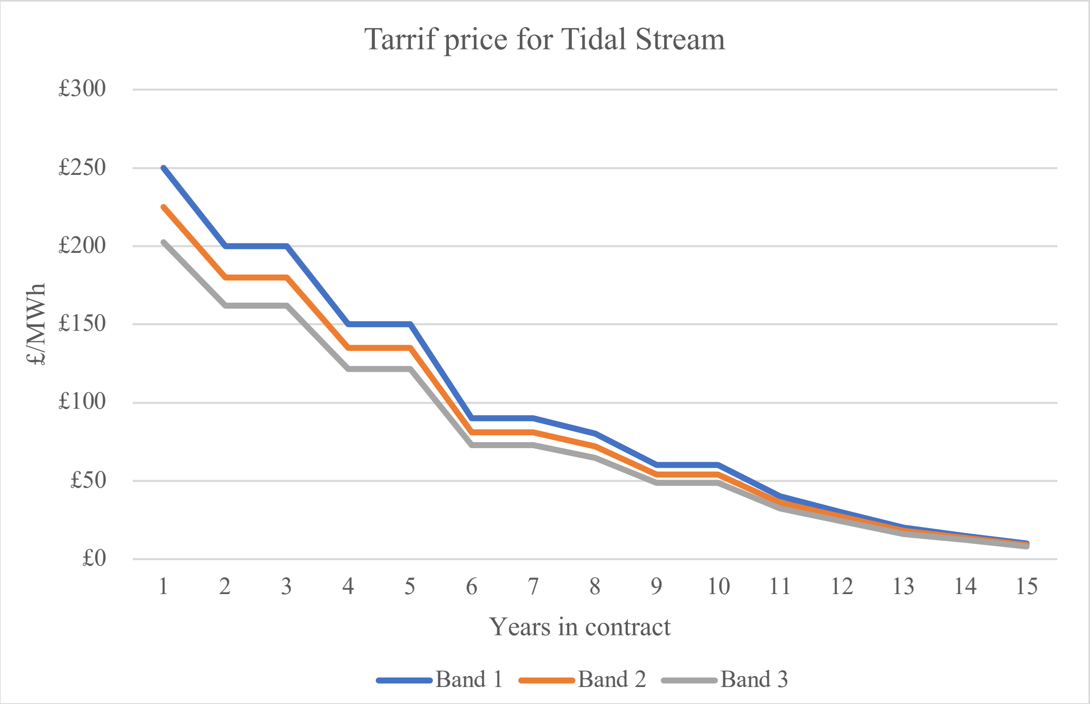


Figure 23: Example tariff over different bands for tidal projects.

The initial ten years will likely be the pay-back period and revenue will be recycled directly back to the project for operation and maintenance costs, as well and paying back investors. Although the tariff price reduces from £36.00/MWh to £8.10/MWh in the last five years; the project is still guaranteed the fixed price agreed in beginning of the project. It is expected that costs will have substantially reduced by this point and the project will be able to retain a profit.

As previously stated, this example is to provide a sense of how a tariff may change over time. There are serval assumptions and estimations involved as this technology has been readily deployed, thus statistics on costs and projected capacities are limited.

Figure 24 shows what could happen if the UK government established an aim of reaching 7% of the total potential capacity (2GW) by 2030. Considering the projected LCOE for 2GW capacity, the cost of tidal could reach £80/MWh by this point (Figure 24). This reduction would drive tidal energy to be as cost competitive as current offshore wind prices. Beyond this point, support will reduce substantially, and tidal project will then be eligible for alternative support which is targeted towards more mature technologies, such as the CfD scheme.

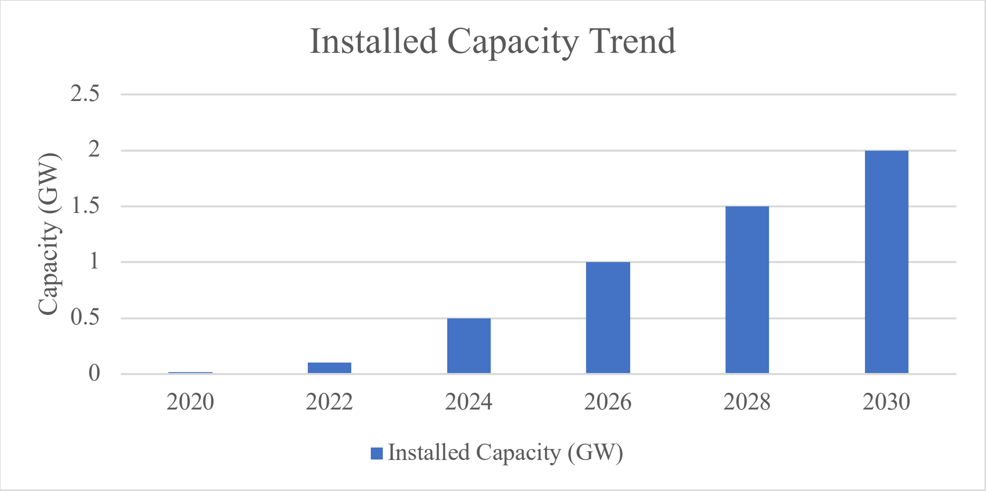


Figure 24: Capacity increase to 2GW by 2030

3.4. Hydrogen

Green hydrogen presents long-term economic opportunities for the future of the UK energy market. The term 'green hydrogen' refers to hydrogen made from renewable energy via electrolysis – which uses electricity to split water into hydrogen and oxygen. The only by-products from this process are heat and water; thus, it produces no emissions. Hydrogen is then transported, stored, and used when supply is low from intermittent sources like wind and solar.

The Case for Green Hydrogen, a paper written by the UK Hydrogen and Full Call Association (UKHFCA), provides a detailed road map for the deployment of green hydrogen. It recognises that green hydrogen is a key component of the UK's journey towards net-zero, and policy and investment support is critical to its success (UKHFCA, 2021). Global demand for hydrogen is increasing, and 90% of its current use is for industrial processes, however hydrogen begins to be utilised in the energy sector, this demand will accelerate. The UK government has set a target of reaching 10GW capacity of green hydrogen by 2035. With increasing onshore and offshore wind capacities, where the production of most hydrogen is, this target is becoming more attainable (Scottish Power, 2021).

Hydrogen demand projections created by the Scottish Government give an idea of the expected increase over three scenarios (Figure 25). The business-as-usual scenario shows an increase of under 20TWh/year over the 20 years. The most optimistic assumptions of Scotland's hydrogen deployment over all sectors have created the ambitious scenario. In this scenario, hydrogen would play an essential role in the efforts to reach net zero. Hydrogen would act as the primary method to decarbonise the transport sector and supply half of Scotland's total energy (www.gov.scot, 2019). All three scenarios will require sufficient financial support to help them reach targets, however it is not as simple as developing the technology required to produce hydrogen. For example, transportation and storage units are still being developed, along with existing infrastructure for distribution.

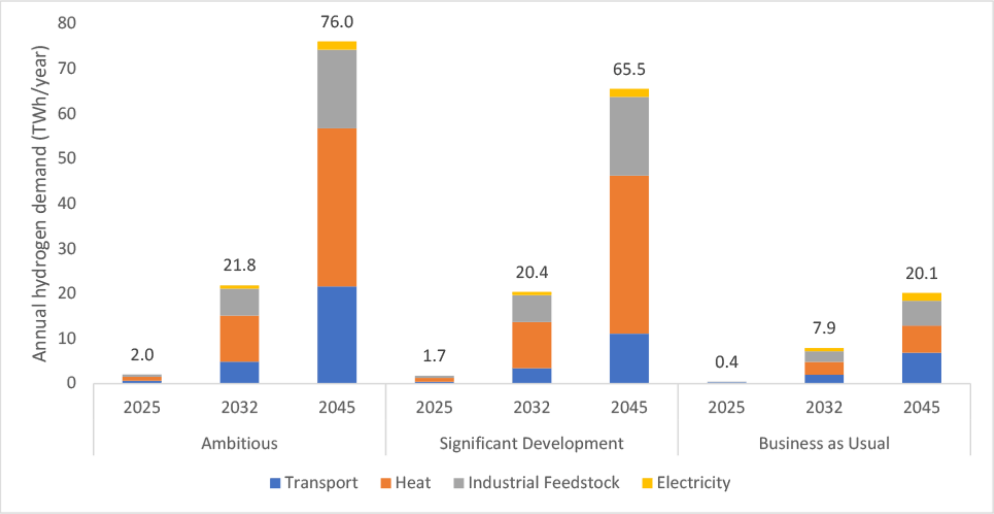


Figure 25: Scotland's hydrogen demand projections for three given scenarios (Scottish Power, 2021)

3.4.1. Case Study: Whitelee windfarm

Whitelee windfarm, located southwest of Glasgow, is the UK's largest onshore windfarm, with 215 turbines totalling 539MW. To assist the generation of green hydrogen, the UK's biggest electrolyser is now being built near this site. This site will be the first facility developed as part of the 'Green Hydrogen for Scotland' collaboration between Scottish Power, BOC, and ITM Power (Scottish Power, 2021). The electrolyser will have a capacity of 20MW, powered through a combined solar and battery storage scheme with up to 90MW.

The purpose of this scheme is to provide carbon-free transport, creating a zero-emission vehicle fleet alongside the current electric vehicles. It hopes to supply hydrogen at commercial use before 2023 – a key milestone for hydrogen in the UK. Hydrogen schemes like these are important as they tackle decarbonisation of different sectors other than electricity, which is essential to reach net-zero emissions.

3.4.2. LCOE

To achieve green hydrogen deployment at scale and, support from government mechanisms is crucial. Providing financial investments into the early stages of innovation is crucial to speed up the process of getting these technologies to market at a lower price (UKHFCA, 2021). Energy Networks also anticipate that net-zero will not be achievable without the inclusion of hydrogen (Energy Networks Association, 2020). Hydrogen is not yet readily deployed in the UK and has not scratched the surface of its potential. Energy Networks has calculated and predicted the levelised cost of hydrogen (Figure 26).

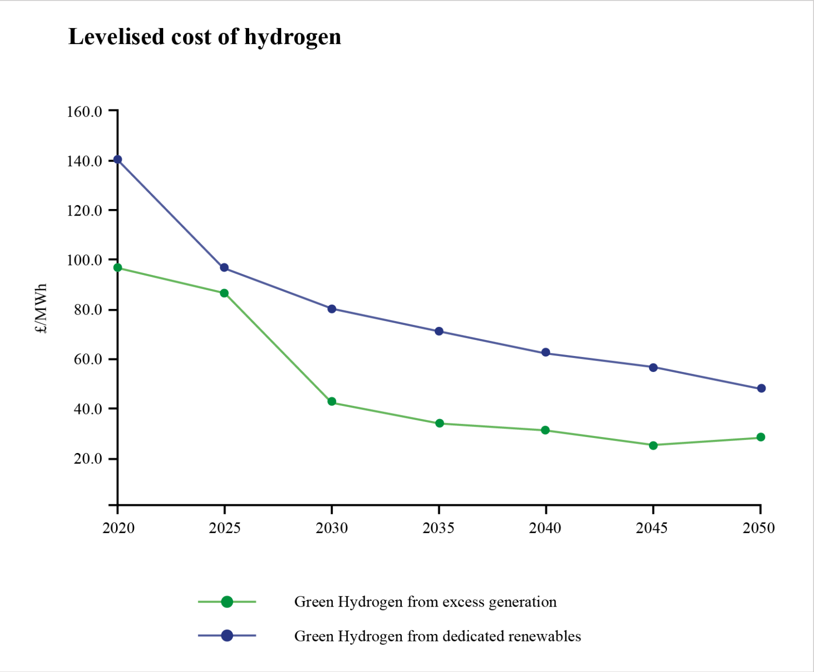


Figure 26: LCOE of green hydrogen Source: ENA, 2020

Like tidal, the expected trajectory of the LCOE of hydrogen is down as the installed capacity increases (Energy Networks Association, 2020). Green hydrogen is steadily becoming cheaper as the manufacturing costs of electrolysers fall and installation increases. Green hydrogen from excess generation has a lower rate £/MWh as installation costs are already covered by the existing renewable energy plant. The only costs associated with these projects are the electrolyser side of the project. It is widely accepted that the potential for green hydrogen to lower its costs to the wholesale market price relies heavily on the presence of Government support.

4.0. Discussion

As targets of net-zero emissions near and the requirement for renewable energy generation increases, there is a call to direct government support towards innovation (Fan et al., 2018). It is widely accepted that diversifying the energy mix with promising but underdeveloped technologies is crucial to meet targets and on time. Several channels can provide financial support for technologies in their early stages, but the higher risks lead to less attractive investment opportunities. Implementing obligations on energy supplies helps aim financial support towards these areas, however it can create a "winner takes all" market, leaving less developed, more expensive technologies without support (Fan et al., 2018; Gates, 2021). Implementing tariffs has proven to assist the uptake of specific technologies and lower prices, however a poorly designed scheme can lead to a collapse in prices and the eventual scheme failure.

Wind power is dominant in the UK's renewable energy sector and has received substantial support to drive deployment. Over the past decade alone, there has been a 715% increase in generation (Figure 27), and the current capacity is approximately 24GW, accounting for one-quarter of the total electricity generation (Hogg and O’Regan, 2010). Legislative and government support have undoubtedly helped drive down costs and increase the installed capacity through advancements in technology and manufacturing processes. However, as the cost of producing energy form wind power becomes more competitive with fossil fuels, the same level of support is no longer justifiable, and funding should be redistributed to different technologies to help diversify the energy market and ensure energy security.

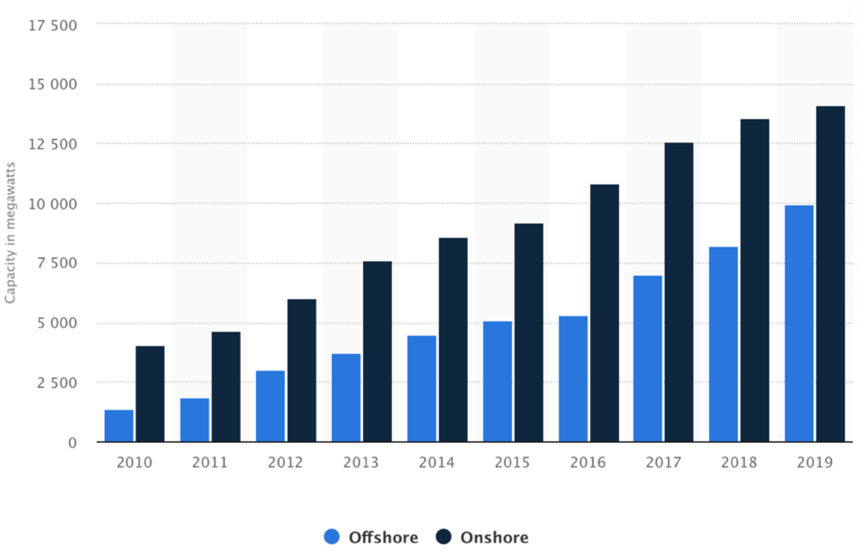


Figure 27: Wind power capacity increase from 2010 – 2019.

Analysis of past and current policies highlighted the gap in funding within the TRL scale. Market push mechanisms, such as local or government grant support, effectively provide small, early-stage prototypes capital costs. The financial requirements for projects in this stage are lower, reflecting the smaller scale of the prototypes, so available funding can support initial capital costs. However, market push mechanisms are designed to "push" the technology into or towards the market but not provide long-term support. Examination of these mechanisms shows that unless technology already displays cost-competitiveness with available alternatives, it will not sustain itself for a significant period.

Once a project has tested the initial prototype and proven its success, it will look to develop further to a full-scale demonstration. The installed capacity of this next stage will still be relatively small; however, the increase in costs is substantial. These costs are attributed to the increase in the unit sizes and the number of units (Klaus, 2020). Installation periods will be longer, and operational costs are also likely to increase. Market pull mechanisms provide support for a more extended period by contributing subsidies to allow new technologies to survive in the market until they are cost-competitive.

The research and analysis into the different market push and pull mechanisms indicate a gap in the funding, where technologies between their early-stage prototypes and commercial deployment are unsupported. This gap slows the progression of promising technologies such as tidal and hydrogen towards commercialisation. As a result, capacity levels are far lower, and costs have remained substantially high. Nevertheless, the analysis shows increasing deployment levels, such as tidal energy projects across the UK. A few larger tidal projects, such as MeyGen, are operational and hope to reduce the LCOE as installed capacity increases; reducing the costs associated with technologies will create a competitive market and drive further advancements. For these reasons, adequate early support must be available for technologies not yet ready to operate in the market.

Designing a support mechanism that encapsulates the fundamental principles that innovations require to succeed will help drive installation capacities effectively. The five components identified for an improved support mechanism are:

1. Fixed tariff price
2. Maturity level banding
3. Project capacity limits
4. Award capacity limits
5. Long-term contracts

Combining these components into a policy framework is predicted to mend the failures of past police designs and target the funding gap. Research and understanding of how each element affects the successes of policy mechanisms demonstrate that it is relatively complex to ensure the support is designated to the targeted sector.

These findings build on the evidence presented from reviews of policy frameworks; however, they provide new insights into a framework structure that would provide more focused support. The more money put into this scheme will inevitably produce a greater chance of success. With that in mind, as the scheme progresses, it will begin to generate revenue for the generators and investors. Technologies will move towards commercialisation and require a smaller tariff, opening back up funding for new projects. As costs fall across each technology type, the money invested will stretch further, and the speed of deployment is predicted to follow.

4.1. Importance

There are two fundamental points to make regarding the importance of these findings. Firstly, net-zero targets are approaching while the uptake rate of new renewable technologies lags. Second, diversifying the energy system is crucial in providing energy security and reliability.

Energy security is crucial, and it must be prioritised while transitioning into a new renewable energy system. There are a number of reasons why the UK will be unable to reach net-zero emissions solely on wind power. The intermittent nature of wind creates unreliability in supply and demand matching. Fossil fuels burning follows demand patterns, unlike wind and solar energy, which only generates when the wind blows, or the sun shines. Changing demand habits to account for this intermittency is not realistic, especially when considering businesses and services that rely on supply to be readily available. Therefore, we require other energy sources and available storage mechanisms to retain the energy until it is required. Although results cannot provide a definitive timeline of cost reductions, considering wind energy's growth over recent years, it is fair to assume that a similar trajectory is possible.

Financial investments are known to advance the innovation process, aiding both development and deployment. Therefore, targeting support to get technologies through the "valley of death" successfully and speedily is crucial in aiding new renewable energy development. In 2019, the UK Government committed to achieving net-zero carbon emissions by 2050. Initial targets have also been set to reach 68% by 2030 and 78% by 2035 (Badshah, 2021). However, these ambitious targets are not achievable at the current rate of deployment. Therefore, innovation and development must be financially supported to accelerate the time that technologies currently take to reach the market.

4.2. Implications

Original research suggested that the current support mechanisms for renewable energy development are unsuitable for small-scale innovation projects. Although results show that installed capacities are rising across technology types, they establish that this growth is far less than in wind or solar PV. Positive trends observed in the uptake of onshore wind, offshore wind, domestic solar PV projects over the past ten years are most likely due to substantial, targeted support from the Government. Redirecting money now towards the less developed technologies will produce a similar outcome, albeit with a slight lag to begin with due to initial high installation costs.

5.0. Conclusions

As the global energy market phases out from fossil fuels and into a renewable and low-carbon energy system, there is an increasing need for innovation and development. This thesis aims to identify a funding mechanism for under-developed technologies to speed up the timescale of prototype to deployment.

Policy frameworks have successfully boosted the adoption of mature renewable technologies, such as wind and solar power, exhibited by the growing rates of installed capacity and the declining cost of generation. However, analysis of the outcomes of these policies highlighted the fact that less developed technologies were falling through a funding gap, delaying progression to market. If this slow rate of development continues, the United Kingdom may fail to meet net-zero targets.

Energy demand has increased exponentially since the Industrial Revolution. As demand rises and the use of fossil fuels declines, there is a margin that renewable and low-carbon sources must fill. Wind power has proven to be a substantial player in the renewable energy mix, offering large capacities at competitive prices. The fundamental driver of this transition was government support mechanisms and legislation, which quickly made wind the most prevalent renewable energy source. A diverse energy mix creates a competitive market, lowering the costs associated with energy generation and assisting the continued development of technologies. In addition, diversity ensures energy security, as alternative sources generate over different times and storage technologies emerge.

Unfortunately, current policy frameworks in place for renewable generation are not adequately supporting innovation and development. As a result, the time that technologies are taking to move from prototype to deployment is too long and has too many risks for private investment. Therefore, this thesis reviews a new support mechanism design that would provide an innovation tariff to targeted technologies that fall into this funding gap. The design includes a guaranteed price for a tariff rate over a long-term contract, capacity limits on projects and awarded tariffs, and weighting to reflect market readiness of the technology. Hindcasting the effect past policies had on promoting the uptake of wind and solar PV was conducted and results revealed that the policies would be successful in driving up deployment, however the time scale of this is challenging to determine.

5.1. Limitations

The reliability of the data used to predict future costs and installation capacities are impacted by the uncertainty surrounding current costs. Innovations, in their nature, are not well established, so project cost predictions result from some degree of hypothetical data. The volatile price of energy also creates problems when trying to outline a sufficient budget for policy frameworks. Like past policies, prices are used from past years and adjust with time.

Project failure rates are also assumed, and this adds another limitation to the reliability of results. The rate of failure typically decreases as technology advances, however this is neither linear nor foreseen, so assumptions are made. The volatile price of energy also creates problems when trying to outline a sufficient budget for policy frameworks. Similar to past policies, prices are used from past years and adjust with time.

It was beyond the thesis scope to include exact weighting factors, capacity limits, and distribution payments. However, as these factors vary considerably annually, values from past years provided reliable predictions.

5.2. Future work

Therefore, further research is needed to establish more accurate predictions of tariff rates. The results provide an understanding of the trajectory of the renewable sector; however, as advancements continue in deployment and technology, updated data sets will provide more precise predictions.

Additionally, further studies should consider grid connection challenges associated with an increase in small-scale generation.

Appendix 1

Table 1: Strike prices for NFFO rounds 1 -5

	NFFO1	NFFO2	NFFO3	NFFO4	NFFO5
Technology band	**Cost-justification**	**Strike Price (p/kWh)**	**Average Price (p/kWh)**	**Average Price (p/kWh)**	**Average Price (p/kWh)**
Wind	10.0	11.0	4.43	3.56	2.88
Wind sub-band	—	—	5.29	4.57	4.18
Hydro	7.5	6.0	4.46	4.25	4.08
Landfill Gas	6.4	5.7	3.76	3.01	2.73
M&IW[a]	6.0	6.55	3.89	—	—
M&IW[b]	—	—	—	2.75	2.43
Sewage Gas	6.0	5.9	—	—	—
EC&A&FW[c]	—	—	8.65	5.51	—
EC&A&FW[d]	—	5.9	5.07	—	—
EC&A&FW[e]	6.0	—	—	—	—
M&IW/CHP[f]	—	—	—	3.23	2.63
TOTAL	7.0	7.2	4.35	3.46	2.71

[a] Municipal and industrial waste with mass burn technology.
[b] Municipal and industrial waste with fluidised bed technology.
[c] Energy crops and agricultural and forestry waste with gasification technology.
[d] Energy crops and agricultural and forestry waste with residual technologies.
[e] Energy crops and agricultural and forestry waste with anaerobic digestion.
[f] Municipal and industrial waste with combined heat and power.

Table 2: Percentage commissioned in NFFO3 by technology. Source Mitchell, 2000.

		Commissioned				
Technology	**Number of contracts**	**Capacity (MW DNC)**	**Number**	**Percentage (%)**	**Capacity MW DNC**	**Proportion of capacity**
ECAFW[a]	3	19.1	0	0	0	0
ECAFW[b]	6	103.8	1	16.7	38.5	37.1
Hydro	15	14.5	8	40	11.74	81
Landfill Gas	42	82.07	42	100	82.07	100
MIW[c]	20	241.9	6	30	77.4	32
Wind Large	31	145.9	8	25.8	34.77	2.38
Wind Small	24	19.7	10	41.7	9.973	50.6

[a] Energy crops and agricultural and forestry waste with gasification technology.
[b] Energy crops and agricultural and forestry waste with other technology.
[c] Municipal and industrial waste.

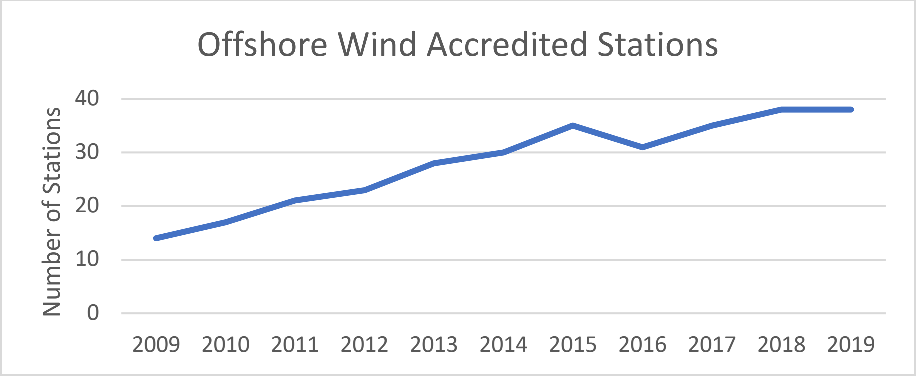
Appendix 2

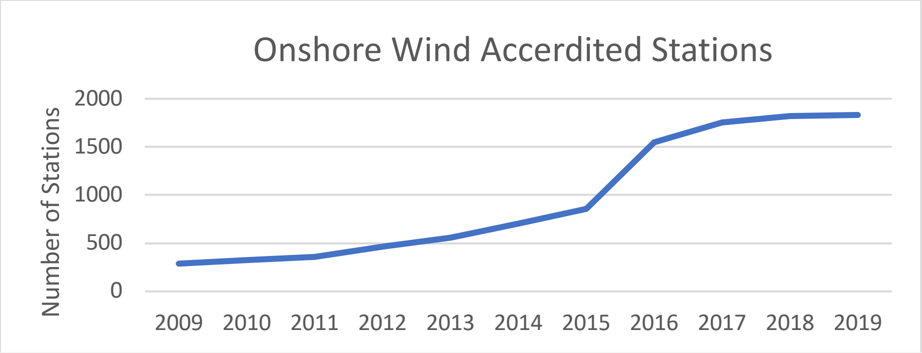
Table adapted from Wikipedia, (2020) and Ofgem reports:

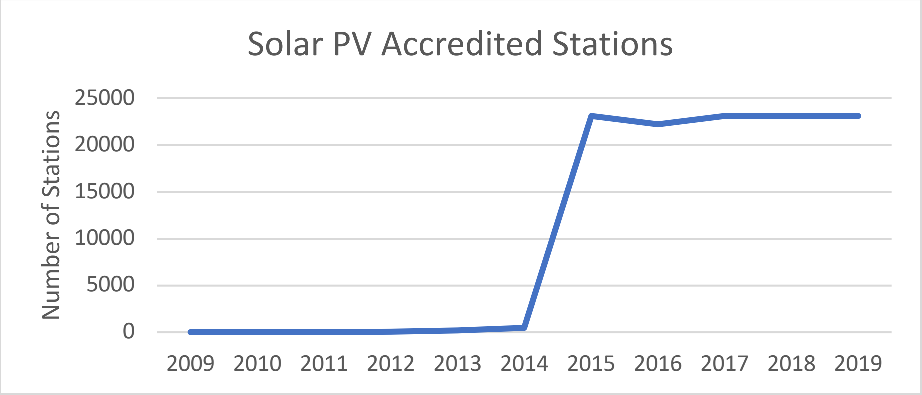
Obligation Period (1st April – 31st March)	% of supply	Buy-out price (£)	Obligation for England, Wales, and Scotland (ROCs/MWh)
2002-03	3	30.00	1
2003-04	4.3	30.51	1
2004-05	4.9	31.39	1
2005-06	5.5	32.33	1
2006-07	6.7	33.24	1
2007-08	7.9	34.30	1
2008-09	9.1	35.76	1
2009-10	9.7	37.19	0.097
2010-11	11.1	36.99	0.111
2011-12	12.4	38.69	0.124
2012-13	15.8	40.71	0.158
2013-14	20.6	42.02	0.206
2014-15	24.4	43.30	0.244
2015-16	29.0	44.33	0.290
2016-17	34.8	44.77	0.348
2017-18	40.9	45.58	0.409
2018-19	-	47.22	0.468
2019-20	-	48.48	0.484
2020-21	-	50.05	0.471
2021-22	-	50.80	0.492

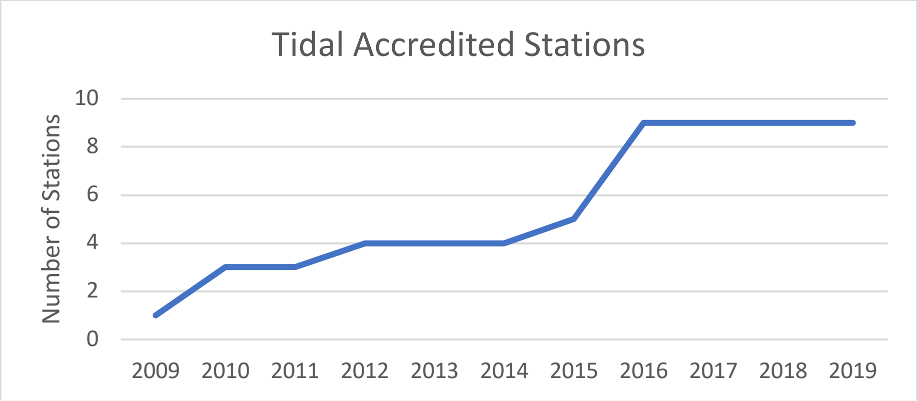
Appendix 3

Accredited Stations for Renewables Obligation scheme from 2009 – 2019. Source: Ofgem Annual reports on Renewables Obligation 2009-2019

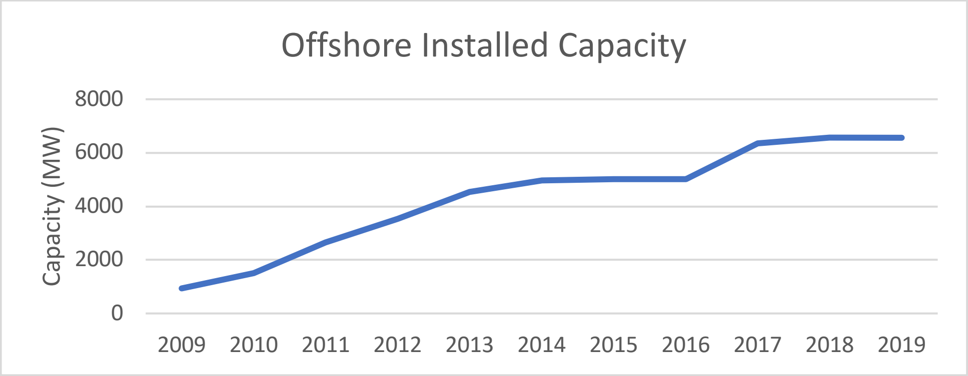


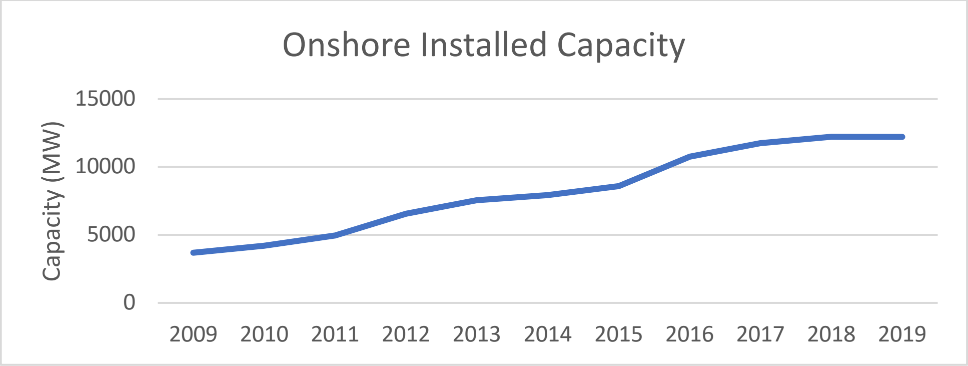


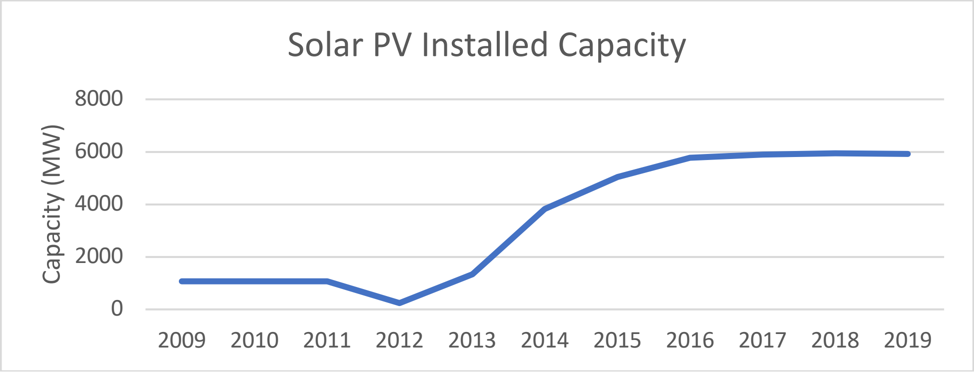


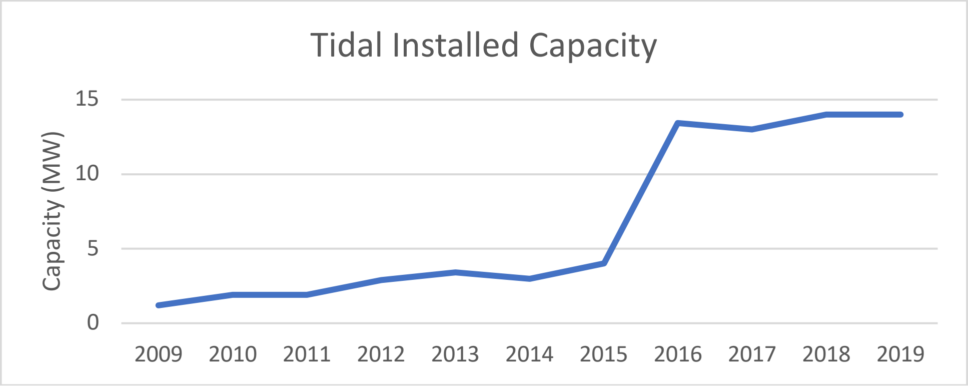


Installed Capacity for Renewables Obligation scheme from 2009 – 2019. Source: Ofgem Annual reports on Renewables Obligation 2009-2019









Appendix 4

Table listing of all Generation Tariff levels based on the accredited installation date

Energy Source	**Scale**	**Type / Rate**	**Tariff (p/kWh)**	
		Installed:	< 31/12/16	< 31/3/17
Anaerobic digestion	≤250kW		6.65	6.65*
Anaerobic digestion	>250kW – 500kW		6.14	6.14*
Anaerobic digestion	>500kW		6.33	6.33*
Hydro	>100kW		7.65	7.63
Hydro	>100kW – 2MW		6.12	6.11
Hydro	>2MW – 5MW		4.43	4.43
Micro-CHP	<2 kW	(limited)	13.45	13.45
Solar PV	=10 kW	Higher rate	4.18	4.11
Solar PV	=10 kW	Medium rate	3.76	3.7
Solar PV	>10 – 50kW	Higher rate	4.39	4.32
Solar PV	>10 – 50kW	Medium rate	3.95	3.89
Solar PV	>50 – 250kW	Higher rate	2.03	1.99
Solar PV	>50 – 250kW	Medium rate	1.83	1.79
Solar PV	=250kW	Lower rate	0.57	0.52
Solar PV	>250kW – 1MW		1.69	1.65
Solar PV	>1MW – 5MW and	Standalone	0.51	0.47
Wind	=50kW		8.33	8.26
Wind	>50 – 100kW		6.08	6.02

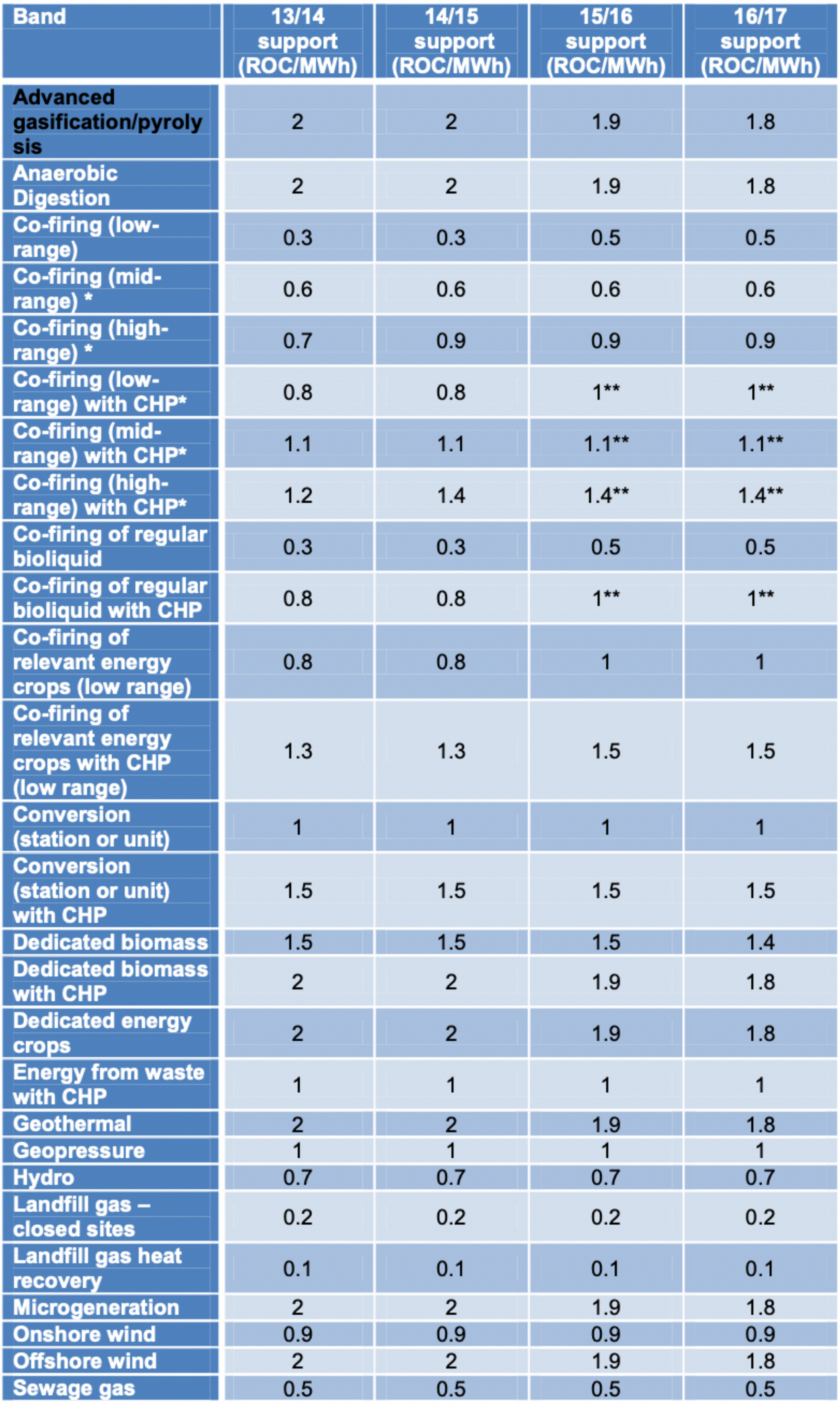
Wind	>100kW – 1.5MW		3.92	3.9
Wind	>1.5MW – 5MW		0.83	0.82
Any	existing systems transferred from RO		10.66	

* rates currently under review

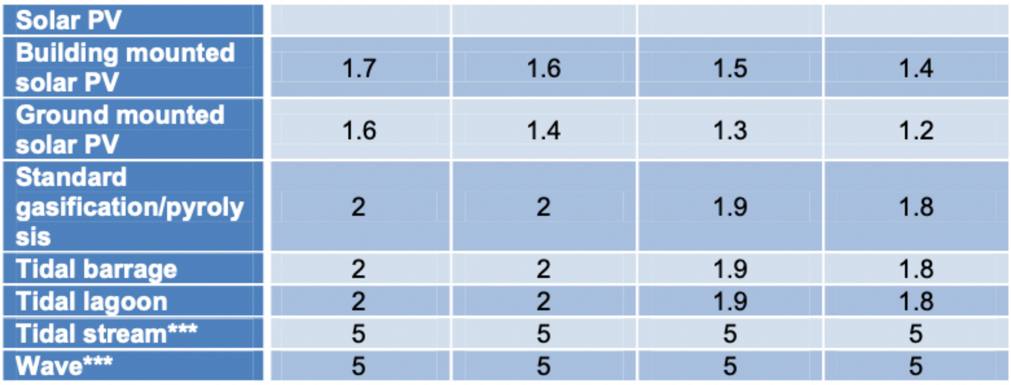
Source: (FI Tarrifs | Feed-In Tariffs, 2016).

Appendix 5

Table summarising the banding levels for the banding review period (2013-17) in England and Wales:



Band	13/14 support (ROC/MWh)	14/15 support (ROC/MWh)	15/16 support (ROC/MWh)	16/17 support (ROC/MWh)
Advanced gasification/pyrolysis	2	2	1.9	1.8
Anaerobic Digestion	2	2	1.9	1.8
Co-firing (low-range)	0.3	0.3	0.5	0.5
Co-firing (mid-range) *	0.6	0.6	0.6	0.6
Co-firing (high-range) *	0.7	0.9	0.9	0.9
Co-firing (low-range) with CHP*	0.8	0.8	1**	1**
Co-firing (mid-range) with CHP*	1.1	1.1	1.1**	1.1**
Co-firing (high-range) with CHP*	1.2	1.4	1.4**	1.4**
Co-firing of regular bioliquid	0.3	0.3	0.5	0.5
Co-firing of regular bioliquid with CHP	0.8	0.8	1**	1**
Co-firing of relevant energy crops (low range)	0.8	0.8	1	1
Co-firing of relevant energy crops with CHP (low range)	1.3	1.3	1.5	1.5
Conversion (station or unit)	1	1	1	1
Conversion (station or unit) with CHP	1.5	1.5	1.5	1.5
Dedicated biomass	1.5	1.5	1.5	1.4
Dedicated biomass with CHP	2	2	1.9	1.8
Dedicated energy crops	2	2	1.9	1.8
Energy from waste with CHP	1	1	1	1
Geothermal	2	2	1.9	1.8
Geopressure	1	1	1	1
Hydro	0.7	0.7	0.7	0.7
Landfill gas – closed sites	0.2	0.2	0.2	0.2
Landfill gas heat recovery	0.1	0.1	0.1	0.1
Microgeneration	2	2	1.9	1.8
Onshore wind	0.9	0.9	0.9	0.9
Offshore wind	2	2	1.9	1.8
Sewage gas	0.5	0.5	0.5	0.5



Solar PV				
Building mounted solar PV	1.7	1.6	1.5	1.4
Ground mounted solar PV	1.6	1.4	1.3	1.2
Standard gasification/pyrolysis	2	2	1.9	1.8
Tidal barrage	2	2	1.9	1.8
Tidal lagoon	2	2	1.9	1.8
Tidal stream* **	5	5	5	5
Wave* **	5	5	5	5

*Includes solid and gaseous biomass and energy crops
**These support levels are only available in circumstances where support under the RHI is not available
*** 5 ROCs subject to 30 MW cap at each generating station. 2 ROCs for any additional capacity added above 30 MW cap.

Source: (GOV.UK, n.d.)

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