Support scheme options to incentivise renewables investment in Northern Ireland: Report for the Department for the Economy as evidence for the Northern Ireland Energy Strategy 2021

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Executive Summary

This research report reviews and assesses the suitability of possible support scheme options to incentivise renewable investment in Northern Ireland for power generation. It was prepared between July and September 2021. It was commissioned by the Renewable Electricity Branch at the Northern Ireland Department for the Economy. This research report complements other work being undertaken as part of Northern Ireland's new Energy Strategy and contributes to the evidence base. The overarching reason for this work is the United Kingdom's (UK) Climate Act 2008 and the Climate Change legislation currently under consideration in the Northern Ireland Assembly. This work has been informed by this national policy, the work done by the Committee on Climate Change as part of the UK by 2050 roadmap and reflects the UK's emissions reduction and net zero targets by 2050. The study focuses on power generation specifically, other energy sources, vectors and sectors such as hydrogen, ammonia, biogas for transport and heating were not included.

The research involved three main elements. Element one, was a review of the suitability of renewable power generation technologies for Northern Ireland as support schemes options are integrally linked to technology readiness levels and maturity in order to benchmark impact against net zero target deadlines (i.e., 2030, 2040 and 2050). Element two, was an appraisal of historical and existing support scheme options in Great Britain, the European Union (EU) and some high gross domestic product countries in order to assess if there are other approaches that could be employed in Northern Ireland. Element three was a Delphi study to capture the expert views and opinions of decision-makers in the different organisations in industry, government and non-government organisations in order to understand the power system need into the future. Three analytical methods were used to inform the research work, 1) a strength, weaknesses, opportunities and threats (SWOT) analysis, 2) a Pugh matrix analysis and 3) a levelised cost of energy (LCOE) financial model to assess the feasibility of implementing the power generating technologies and support scheme options in Northern Ireland. The LCOE financial model compares the economic competitiveness of the different power generating technologies and associated support scheme options into the future.

The technologies examined will support renewable power generation in Northern Ireland. These technologies were agreed with the Renewable Electricity Branch. They included Anaerobic Digestion (AD), Combined Cycle Gas Turbine (CCGT), Open Gas Cycle Turbine (OGCT), Carbon Capture, Utilisation and Storage (CCUS), energy storage (i.e., batteries, and compressed air energy storage), geothermal, hydropower, nuclear power, solar photovoltaic (PV), onshore and offshore wind, as well as tidal and wave energy. Four groups of incentives schemes were examined in the analyses. These schemes were identified based on the best available published information as part of the state-of-the-art desktop study. These in alphabetical order were 1) Capacity Payment Mechanisms (CPM), Export Guarantee and Power Purchase Agreement (PPA), 2) Contract for Differences, (CfD), 3) Feed-in Tariffs (FiT) and Feed-in Premiums (FiP), 4) Green Certificates and Renewables Obligation Certificates (ROC), 5) Investment Bonds, Loans, Grants and Tax Incentives.

The five key findings of the research study are summarised as follows:

- Technologies were quantitatively assessed utilising a Pugh matrix analysis. The Pugh matrix results ranked onshore wind with the highest score, and CCGT, energy storage, hydro and OCGT in joint second.
- Support scheme options were quantitatively assessed using a Pugh matrix, which was informed by the qualitative SWOT analysis. The results of the Pugh matrix rated the schemes as follows; CfD scheme (Northern Ireland Pot), CfD (Separate Northern Ireland based scheme), FiP, FiT, GC and investment loans and grants all had the joint highest score, whereas CfD (i.e., GB scheme) and export guarantees came in joint second. Overall CPM had the lowest score, and tax incentives had the second lowest score.
- It is important to consider the power system landscape when selecting the optimum support scheme to incentivise and support renewable power generation investment in Northern Ireland. The power system landscape is being challenged by many 'known knowns' and 'unknown knowns' that are impacting the interaction of the wholesale and the retail electricity markets, and the decentralisation of transport and heating loads as industry and policy makers strive to reduce emissions.
- A total of 150 experts were invited to be part of a Delphi study at the end of August, and 27 responded and provided their insights on the electricity market, technologies, and support scheme options needed to reach the net zero targets by 2050. Overall, they recognised that there is no silver bullet solution to reach net zero targets by 2050.

- An LCOE financial model was built to assess the various support scheme options in Northern Ireland. The results show that between 2030 and 2040 the average LCOE for the generation portfolio rises but then falls from 2040 to 2050. A ‘do-nothing’ is the lowest cost scenario, but it will lead to increased market volatility, and huge uncertainty in achieving net zero targets and a knock-on impact across other sectors in terms of carbon costs.

The five key recommendations are summarised as follows;

- Energy system security is driven by the generation portfolio and reserve generation, and this impacts market dynamics. The way to address this cost and security challenge is to undertake an in-depth analysis in the form of cost benefit analysis (COBA) at least every five years to track progress to 2050.
- A PESTEL analysis (i.e., political, economic, social, technological, environmental, legal) in tandem with the COBA of the whole energy system across the different energy sectors is required to compare savings and efficiencies across the three pillars of sustainability (i.e., social equity, environment and economics).
- The generation portfolio mix has been in essence decided, namely wind, and solar with storage, but gas needs to play a significant role during the transition period. The only way to address this is by being pragmatic during the transition period and agreeing that new gas generation is required urgently.
- This work examined the most common support scheme mechanisms in the LCOE analysis. It was clear that the most appropriate scheme for Northern Ireland is a CfD scheme because based on the results of the SWOT analysis, the Pugh matrix analysis and the LCOE financial modelling it is more equitable for society as it spreads the investment risk between the generators and the regulator and also reduces market volatility.
- Finally, regular analyses of LCOE in conjunction with the wholesale electricity market reference price in a unit commitment model is required in order to monitor and manage any support schemes in real time to avoid over payment or underpayment of any schemes as we transition to net zero by 2050.

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Nomenclature

Abbreviations

Symbol	Description
AD	anaerobic digestion
BEIS	Department for Business, Energy and Industrial Strategy
BETTA	British Electricity Trading and Transmission Arrangements
CCGT	combined cycle gas turbine
CCS	carbon capture and storage
CCUS	carbon capture, utilisation and storage
cf.	Conferatur in latin, or see in English
CfD	contracts for difference
CHP	combined heat and power
COBA	Cost Benefit Analysis
CPM	Capacity Payment Mechanism
CRM	Capacity Remuneration Mechanism
DAM	day-ahead market
DR	Demand response
DS3	Delivering a Secure Sustainable Electricity System
ETM	electricity target model
EU	European Union
EV	electric vehicle
FFR	fast frequency response
FiP	feed-in premium
FiT	feed-in tariff
GB	Great Britain
GC	green certificate
GDP	gross domestic product
GHG	greenhouse gas
ISEM	Integrated Single Electricity Market
IRR	Internal rate of return
LCA	life cycle analysis
LCCC	Low Carbon Contracts Company
LCOE	levelised cost of energy
OCGT	open cycle gas turbine
OFGEM	Office of Gas and Electricity Markets
PESTEL	political, economic, social, technological, environmental, legal
POR	primary operating reserve
PPA	power purchase agreement
PV	photovoltaic
REGO	Renewable Energy Guarantees of Origin
ROC	Renewables Obligation Certificate
RoCoF	rate of change of frequency
ROI	Republic of Ireland
ROK	Republic of Korea
SEG	Smart Export Guarantee
SEM	Single Electricity Market
SIR	synchronous inertial response
SNSP	system non-synchronous penetration
SONI	System Operator for Northern Ireland
SWOT	strengths, weaknesses, opportunities, and threats
TRL	technology readiness level
TSO	transmission system operator
UK	United Kingdom
USA	United States of America
VAT	value-added tax
WACC	weighted average cost of capital

Units and Notation

Symbol	Description
CO_2	carbon dioxide
c-Si	crystalline silicon
$DECEX_t$	decommissioning expenditure in year t
d_r	discount rate
E_t	energy produced in year t
GW	gigawatt
Hz	Hertz
I_t	Investment inclusive of debt costs in year t
kg	kilogram
kW	kilowatt
kWh	kilowatt-hour
L	litre
m^3	cubic metres
MVArh	megavolt-ampere-reactive-hour
MW	megawatt
MWh	megawatt-hour
MWs^2h	megawatt second^2 hour
$OPEX_t$	operation and maintenance expenditure in year t
p	pence
p.u.	Per unit
T	year value
TWh	terawatt-hour
W	Watt
Wh	Watt hour
¥	Chinese yuan
€	euro
£	pound sterling

1.0 Introduction

Northern Ireland must contribute to the United Kingdom (UK) emissions reductions targets under the Climate Act 2008 [1]. There are two pieces of Climate Change legislation currently under consideration in the Northern Ireland Assembly. Northern Ireland's energy policy planning follows advice from the Committee on Climate Change in terms of feeding into the UK's 2050 net zero carbon roadmap. In addition, Northern Ireland policy considers, where relevant and appropriate to energy security, developments in the all-island Integrated Single Electricity Market (ISEM). The ISEM operates on an all-island basis (i.e., North and South) in the context of the European Union (EU) electricity target model (ETM), just like the British Electricity Trading and Tariff Arrangement (BETTA). Now although, negotiations and planning with regards to the EU ETM and the ISEM and BETTA are on-going due to the UK's exit from the EU (i.e., Brexit), it must be noted that irrespective of the actual policy contextual placement, wholesale electricity market operations in the ISEM will continue and reflect policy in Northern Ireland. This research study considers all the overarching policy that will affect the Northern Ireland power system landscape in the assessment of support scheme options to incentivise renewables and by default the transition technologies, as the power system migrates to net zero, including the latest recommendations from the Committee on Climate Change. The Committee on Climate Change recommends an overall 82% reduction in greenhouse gas (GHG) emissions and suggests an interim of 48% by 2030 in order to achieve the UK's net zero by 2050 target. Moreover, supplementary targets are suggested for carbon dioxide (CO_2) emissions by 2050, as well as a 96% reduction in all other GHG except methane. This plan is schematically shown in Figure 1 [2].

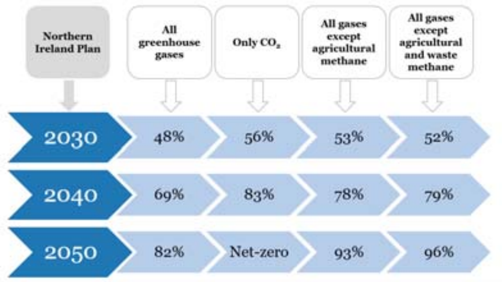

Figure 1 - Committee on Climate Change reduction recommendations

Renewable energy in Northern Ireland is mostly wind (84%), with some solar (4%) and the remainder is made up of biomass, biogas and landfill gas (12%). During the last ten years, renewable energy development in Northern Ireland has been mainly steered by two targets. The first target was to reach 40% electricity power consumption from renewable energy resources by 2020 [3]. The second target was to cover 10% of the total heat demands using renewable resources by the end of 2020. In Northern Ireland, the target of 40% renewable electricity was achieved ahead of the scheduled plan. Renewable electricity in Northern Ireland has increased remarkably from below 10% in 2010 to above 47.7% in 2020. The highest share of this value (i.e., 84%) was provided by wind alone, followed by solar photovoltaic (PV), biomass and other renewable sources [4]. Northern Ireland's generation portfolio in the High Electrification Scenario of the Northern Ireland Energy Strategy to 2050 is shown in Figure 2 [5].

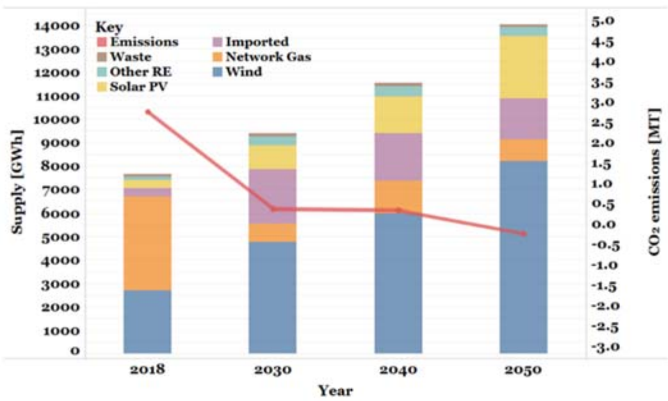

Figure 2 – Northern Ireland's high electrification generation portfolios up to 2050

Worldwide, governments provide energy-based subsidies in order to achieve specific policy goals. For example, emissions reduction targets, renewable energy penetration level objectives, energy market regulation, affordable energy for vulnerable groups in society, technology development, technology cost reduction, economic stimulus and energy system reliability and security [6]. These support subsidies or schemes are usually in the form of grants or a form of feed-in tariff (FiT), with contracts for difference (CfD) schemes being widely adopted over the past decade. Countries using FiTs traditionally set FiT rates on a sliding scale, however without market forces the rate of reduction can either be too aggressive or passive. In Northern Ireland and the Republic of Ireland (ROI), meteorological conditions and incentive schemes have resulted in the rapid development of renewable wind generation. Over a single decade, from 2010 to 2020, the all-island installed wind capacity increased from 1,782.6 MW to 5,576.1 MW, an increase of 212.8 % [7]. However, this wind generation is often curtailed to allow grid operation at a safe level of System Non-Synchronous Penetration (SNSP[1]). As a result, the system operator has been developing schemes to deliver ancillary services[2] to support this renewable generation e.g., DS3 (Delivering a Secure Sustainable Electricity System).

It is well recognised that the introduction and widespread adoption of new technology in a mature industry like power, is nearly impossible without some type of financial incentive or support scheme. It is important that decision-makers and the public understand the technology drivers, and the various support schemes so the most effective and just choices are made as the Northern Ireland economy transitions to a net zero economy by 2050. In general, the introduction and adoption of new technologies is the primary objective and the main benefit of support schemes [6]. The fiscal view is an essential part of renewable energy deployment and progression. If a technology does not have an economic advantage, it will not be able to compete with conventional and more mature generation. Competitiveness varies between different technologies and plant sizes (due to economies of scale) thus incentive structures must be designed on an individual technology basis. Robust financial modelling is a key to establishing a project's financial feasibility and economic competitiveness under different market conditions and input variables. A financial model can provide different decision-making metrics, for example, internal rate of return, return of investment, net present value and payback period. The potential revenues from a renewable energy project come from three potential sources, 1) support incentives, 2) out of market payments and 3) the sale of energy. However, another approach called the levelised cost of energy (LCOE) is often used by regulators and industry to determine the total systems cost of an energy transition.

1.1 Aim and objectives

As the main aim of this study was to assess the possible support scheme options to incentivise renewable investment in Northern Ireland for power generation an LCOE approach was used. To achieve this aim, three objectives were carried-out. Objective 1 was a Pugh and SWOT analyses of generation technologies as support scheme options are integrally linked to technology. Objective 2 was a Pugh and SWOT analyses of support schemes in Great Britain (GB), the EU and some high gross domestic product (GDP) countries to understand the advantages, and disadvantages of existing schemes, and what lessons can be learned from their implementation in other markets. Objective 3 provided data-driven policy recommendations for Northern Ireland based on the LCOE analysis, in the context of the changing power system landscape.

1.2 Report structure

This report has seven sections. Section 1 introduces. Section 2 presents a technology overview in the context of Northern Ireland. Section 3 examines each support scheme, how they operate and their application in the UK and the ROI. Section 4 captures a review of historic and current support schemes options available in GB, the EU and some high GDP countries. Section 5 provides a narrative around the changing power system landscape in relation to Northern Ireland's future generation mix and power system security with high renewable technology penetration. Section 6 contains the modelling and analyses carried out. It was informed by SWOT (i.e., strengths, weaknesses, opportunities, and threats) and Pugh analyses of the possible technologies and support schemes considering technology readiness levels (TRL), life cycle analysis (LCA), historical lessons learned and a Delphi study. A detailed LCOE model was developed to estimate the economic competitiveness of each technology in the context of the different support schemes. Section 7 presents an overall discussion, conclusion and recommendations for Northern Ireland, in regard to support scheme options to incentivise renewables investment. There are four appendices that summarise the baseline data and information used to inform the analyses.

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[1] **SNSP** is a measure of the non-synchronous generation (i.e., in simplest terms variable renewable generation) on the system at an instant in time.

[2] **Ancillary services** are support services provided to power grid operators by generators and support service providers to maintain stable power system frequency and voltage levels.

2.0 Technology Overview in the Context of Northern Ireland

In this section, each technology is briefly described, the level of penetration in Northern Ireland, GB and the ROI is summarised and where there is significant development elsewhere, this is stated. Table 10 in Appendix A provides a summary of the SWOT for each technology. Table 12 in Appendix B highlights the Pugh matrix comparison of each technology against the established criteria. The key findings of the TRL and LCA investigation, SWOT analysis and Pugh matrix analysis of each technology are discussed in Section 6.0.

2.1 Anaerobic Digestion, Biogas and Biomass

Anaerobic digestion (AD) is a chemical process where bacteria is utilised to break down organic matter such as animal manure, wastewater bio-solids and food wastes in the absence of oxygen [8]. This organic matter can also be described as feedstock. Biomass is renewable organic material that comes from plants and animals [9]. The products of AD include biogas (primarily a mixture of carbon dioxide and methane) and bio-fertiliser (digestate). A sealed, oxygen-free tank called an anaerobic digester is required to enable the AD process to occur [10]. AD plants are categorised according to the feedstocks used. These categories are 1) agricultural (AD plants that use predominantly agricultural feedstock such as manures, slurries, crops and crop residues) and 2) waste (AD plants that use predominantly municipal, commercial and industrial waste streams as feedstock). Each AD plant can be further subcategorised by the end-use of the biogas, such as plants that facilitate combined heat and power (CHP) or biomethane to the grid [11]. Appendix 3.2 of the Northern Ireland Biogas Research Action Plan 2020 highlights and discusses four drivers to introduce methane in power plants. These drivers are 1) GHG emissions reductions, 2) renewable energy targets and energy security, 3) intermittency of wind and the need for reliable base load and 4) power plant efficiency [12].

The UK Agri-Food and Biosciences Institute states that there are two main benefits of AD, positive environmental impact and direct financial returns. Regarding the first benefit, positive environmental impact, AD captures methane which is released during normal utilisation of farm slurries. Thus, providing a renewable energy source with no net increase in GHG emissions. The second benefit, direct financial returns, biogas derived from AD can be used to generate electricity and/or heat (via CHP, modified gas boilers or biomethane to the grid). Therefore, the AD operator can receive the market value for the electricity and/or heat plus increased income from green certificates awarded and sold [13]. The disadvantages of AD include that the process requires a long time for stabilisation of the microbial culture within the reactor, post-treatment of the process waste is required and constant monitoring of potential of hydrogen, temperature, feed rate, and production of inhibitors is required [14]. Furthermore, the absence of district heating infrastructure or heat supply network can reduce opportunities for CHP or heat via modified gas boilers [15].

In Northern Ireland, the majority of AD plants use agricultural feedstock and the rest utilise municipal, commercial and industrial waste (64 agricultural plants and 12 waste plants in 2021) [16]. Across the UK, there are 685 operational AD plants in 2021 (which include sludge digesters at wastewater treatment plants) [17]. In the ROI, Gas Networks Ireland has forecasted that up to 9.8 TWh per annum and 1.8 TWh per annum of renewable gas derived from AD will be delivered from the agriculture sector and waste industry by 2030, respectively [18]. The most popular type of AD plant in Northern Ireland has an estimated capacity of 500 kW, costing between £2 million and £4 million, depending on various factors such as grid connection costs, location, type of inputs to the AD and building costs [15]. However, small-scale AD is suitable for European farms, as their average size and land productivity cannot achieve the typical feedstock requirements of large-scale AD plants. Hence, small-scale anaerobic digestion is a promising renewable energy technology for Northern Ireland, especially for isolated rural farms, low population communities or stand-alone waste treatment facilities [19].

2.2 Combined Cycle Gas Turbine and Open Cycle Gas Turbine

A Combined Cycle Gas Turbine (CCGT) is a power plant that combines two fundamental thermodynamic cycles, the Brayton cycle and Rankine cycle, which are associated with gas and steam turbomachinery respectively [20]. A CCGT is a complex interconnected system that uses a heat recovery steam generator and the gas turbine's hot exhaust flow to transform feed water to gaseous form, powering the steam power plant [21]. CCGTs achieve higher thermal efficiency than their Open Cycle Gas Turbine (OCGT) counterparts (where a gas turbine is operated in isolation with no steam turbine, i.e., open cycle), as some of the waste heat is recovered [22].

In Northern Ireland, CCGTs provide the bulk of the baseload generation requirement (48.7% in 2019) [4]. The deployment of CCGTs has been responsible for a reduction in carbon intensity (CO_2/MWh) due to the higher operating efficiencies. Combined Cycle Gas Turbine technology has the following advantages, fast installation time, low emissions, flexible operation and it is a mature technology. However, for the UK to achieve the net zero emissions target by 2050, CCGT plant will need to use carbon capture and storage technology or alternative fuels such as hydrogen or biomethane. These technologies are in development, therefore, investment in new CCGT plant is not risk free.

In OCGTs, the exhaust gases that leave the turbine are released into the atmosphere, hence, operating in an open cycle (Brayton cycle only) rather than a combined cycle (Brayton and Rankine cycles). A gas turbine is a type of internal combustion engine that functions using rotary motion. Gas turbines are composed of three main components: the compressor (air is compressed up to 30 times inlet pressure), the combustor (fuel is introduced to the compressed air, commonly natural gas or distillate fuel oil) and the power turbine (mechanical work is extracted from the high temperature, high pressure gas flow via the unique aerodynamic profile of turbine blading). A gas turbine is coupled to a generator to produce electricity [23], [24].

Open Cycle Gas Turbine plants have traditionally been used for peak lopping and as replacement plant during emergency conditions. Open Cycle Gas Turbines are much less efficient than CCGTs at 35% compared to 60% [25]. The main advantages of OCGT are rapid start capability (3 minutes to synchronism), ramping[3] flexibility, fast construction time, fuel choice (liquid or gas) and portability. The disadvantages of OCGT are high operational costs, high emissions, and high maintenance costs. OCGT technology is a suitable counter-balance to variable renewables where rapid deployment, short run duration and fast ramping is often required. The existing Northern Ireland generation sites (i.e., Ballylumford, Coolkeeragh and Kilroot) are all equipped with OCGT plants which are used for peak lopping and black start operations.

2.3 Carbon Capture, Utilisation and Storage

Carbon Capture, Utilisation and Storage (CCUS) technologies involve the capture of CO_2, and there are two main types of processes. Either a device is coupled to an industrial process and removes CO_2 from the flue gasses, or direct from air capture [26]. Currently, CCUS technologies are more effective when coupled to industrial processes, due to the significantly higher percentage of CO_2 available in the flue gases being passed through the process [27]. Carbon capture can be a biological or chemical process. The biological process removes CO_2 from the atmosphere, with photosynthesis being the most significant approach. Chemical processes can include, but not exhaustively, chemical absorption, membrane capture, calcium carbonate looping or chemical looping combustion. In all of these processes CO_2 is captured by an intermediary then stripped, usually by heat or a chemical process prior to storage or transport [27].

Carbon utilisation is a temporary use of CO_2. For example, CO_2 is needed for some food or beverage production or can be pumped into greenhouses to increase crop yields. However, at the end of the process the CO_2 is generally returned to the atmosphere. Storage is a more permanent solution where CO_2 is stored in a permanent state; often this will be underground and in many cases in depleted oil reservoirs. Controversially, enhanced oil recovery is often considered a form of carbon storage. This is where CO_2 is pumped into oil reservoirs to extract more oil than otherwise would have been available for extraction [28].

The main advantage of CCUS is that it achieves emissions reductions, emissions avoidance, and/or negative emissions [29]. Another advantage is that some CCUS options can be retrofitted to existing mature technologies such as natural gas-fired power plants, whether open- or combined-cycle, or CHP plants. Moreover, CCUS helps capture CO_2 from important industrial processes where few or no other decarbonisation options exist (i.e., iron, steel, cement, chemicals or natural gas processing) [30]. There are a range of disadvantages with CCUS technology depending on the capture process. For example, low CO_2 concentration negatively affects the carbon capture efficiency in post-combustion carbon capture processes (utilised in gas-fired power plants). Furthermore, some CCUS technologies are still under development and there is inadequate large-scale operation experience [31].

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[3] **Ramping** is the ability to change the rate of power production either under instruction. Fossil fuel generators can do this to support operations under instruction and are often asked to do so by the grid operator for balancing purposes, whereas wind and solar generators do this spontaneously depending on wind speed or cloud movement. Ramping by renewables needs careful management as it can cause unexpected grid impacts.

Northern Ireland can avail of the UK's Industrial Energy Transformation Fund which was launched in 2020 to implement CCUS. This fund is designed to help businesses with high energy use [32]. According to research by Arup, this £289 million fund is for mature energy efficiency technologies and deep decarbonisation technologies, which includes industrial carbon capture [33]. Some work has been done already to assess the viability of CCUS technologies in Northern Ireland. The Bryden Centre and the Northern Ireland Department for the Economy collaborated in 2020 and published a study that looked at the commercial and public sector views on the need and practical approaches of CCUS in Northern Ireland [34].

2.4 Energy Storage

Several energy storage technologies exist, ranging from mature types like pumped hydroelectric storage to developing techniques like 'power-to-x', where excess power is used to convert electrical energy to another form, like hydrogen, methane, or heat, as well as compressed air energy storage. These MW scale schemes compete in the all-island ISEM ancillary services market in the DS3 scheme. It delivers services such as fast frequency response, voltage support, primary, secondary and tertiary operating reserve to the all-island grid. Increasing penetrations of wind and solar PV generation in the EU has resulted in grid congestion, imbalance issues also becoming a common occurrence leading to renewable curtailment [35].

Battery storage depends on the state of charge and presents a sink and a source. Battery storage can be used to store energy when the system load is low and subsequently release energy at peak times [36], [37]. Portable electronics, electric vehicles (EV) and power grids have supported the rapid development and use of rechargeable batteries such as lead acid, nickel cadmium and lithium-ion batteries. Lithium-ion batteries have gradually become the dominant choice for energy system applications with their high-power density (1,000 – 10,000 W/L), high energy density (100 – 500 Wh/L), high energy efficiency (75% to 97%), low-discharge rate and operational range [38], [39]. As lithium-ion prices fall, the deployment of batteries should develop at both distribution and transmission level. At the distribution level, the inclusion of energy storage is important to prevent excessive network build out. Northern Ireland Electricity Networks introduced a scheme called 'FLEX' for services to resolve network congestion and ultimately avoid further network build out [40], [41]. Battery storage at the distribution level is a suitable technology for the 'FLEX' scheme. Battery properties coupled with system support services mean that battery energy storage can facilitate higher shares of renewable generation. In Northern Ireland, recent storage developments use lithium-ion batteries of up to 50MW.

Compressed air energy storage systems store energy by pressurising air into specially designed containers or reservoirs when electrical grids are experiencing low demand and/or high supply. When the electricity grid is stressed (i.e., times of high demand and/or low supply), the stored air is then expanded through air driven turbines which are coupled to generators to produce electricity [39]. Large scale compressed air energy storage systems have the following typical characteristics: power densities ranging from 0.5 – 2 W/L, energy densities ranging from 1 – 6 Wh/L, power ratings ranging from 100 – 1000 MW, energy capacities up to 1000 MWh, efficiencies of 40% to 70% and facility lifetimes of 20 to 40 years [42]. The salt beds below certain parts of County Antrim would be suitable for compressed air energy storage. Feasibility studies have been carried out with a view to creating an underground cavern for the storage of compressed air generated using excess renewable electricity. At times of high demand, the air is released and then used in the combustion process of the gas turbine-based electricity generation, improving the operational efficiency of the system. The latest indications are that the company developing this project has gone into liquidation and the development has stalled [43].

Hydrogen production is feasible as an energy storage system to reduce grid curtailment and lower the total capacity requirement of wind power. Siemens Gamesa is developing an integrated wind turbine and an electrolyser which will use the excess generated electricity to produce hydrogen, by splitting water molecules into hydrogen and oxygen [44]. Siemens Gamesa is predicting that through cost reductions in turbines and in electrolyser technologies, combined with the introduction of CO_2 pricing, that hydrogen produced in this way could be competitively priced in the next five years. Another significant development with this technology deployment is an announcement by Ørsted in January 2021 to trial a 2 MW electrolysing facility powered by offshore wind energy to produce approximately 1,000kg of hydrogen per day. The National University of Ireland, Galway has indicated in a recent research report that there is a variety of potential production scenarios for hydrogen in Northern Ireland. For example, locating hydrogen production sites in areas of high wind such as the Fermanagh-Omagh or Derry-Strabane regions [45].

2.5 Geothermal

Geothermal energy refers to heat that is sourced below the surface of the earth, thus, the availability of geothermal energy depends on subterranean topology [46]. Geothermal energy is considered a reliable and abundant source of renewable electricity and heat [47]. In large-scale installations, hot water and steam-based geothermal fluid is extracted via a well drilled in the earth's crust [48]. When this geothermal fluid reaches the well-head, three thermodynamic processes occur: 1. flashing (pressure is controlled to produce superheated steam), 2. separation (water is removed from the steam to prevent damage to the steam turbine blading and improve thermal efficiency), and 3. expansion (steam is expanded through the turbine to produce mechanical work) [49]. Locating large reservoirs with high levels of geothermal energy is an important economical consideration, as energy costs per unit of geothermal energy are significantly lower for large-scale installations and these costs fall further as the thermal quality of the liquid extracted rises [50]. Moreover, some steam can be bled off larger scale power generating geothermal plants to supply industry and district heating networks or plants can be specifically designed for the sole purpose of heat provision [51]. In small-scale installations or domestic systems, geothermal energy is harnessed utilising ground-source heat pumps and shallow geothermal resources (the upper few metres of the ground below the surface) to provide space heating and cooling [52], [53]. An example of the application of a small-scale geothermal energy system in Northern Ireland is the geothermal heat pumps which adopt borehole technology at the School of Biology building at Queen's University Belfast [54].

The main advantages of geothermal energy include it is a renewable resource, a large potential resource, with a high-capacity factor, with a heat provision, and that the carbon footprint is relatively much lower when compared to utilisation of fossil fuels, however there is some pollution associated with geothermal energy [55]. The primary disadvantage of geothermal energy, as highlighted, is that it is dependent on the subterranean topology and thus location specific. Another disadvantage is that if geothermal resources are over exploited for producing electricity and heat provision, it can lead to reduced utilisation of geothermal reservoirs and resource availability, especially if the rate of geothermal fluid extraction exceeds the natural rate of replenishing this resource [56]. Moreover, the geothermal fluid contains non-condensable gases such as CO_2 and traces of other pollutants and increasing geothermal well numbers can lead to ground water quality issues [57].

In Northern Ireland, the installed capacity of power producing based geothermal energy is estimated to be negligible according to recent generation mix data [3]. However, progress is being made by the Geological Survey of Northern Ireland and Geological Survey Ireland towards identifying suitable deep geothermal energy reservoirs in Northern Ireland [58]. Further studies have identified geothermal reservoir formations in Northern Ireland, especially in Larne and Aghalee [59]. Moreover, the Palaeogene Mourne Mountains Complex in County Down exhibits a potential geothermal energy resource due to the high levels of radioactivity in its granitic rocks [60]. Additionally, geophysical surveys carried out by the Geothermal Association of Ireland identified areas in Lough Neagh and the Rathlin Basin with high potential for geothermal district heating [61].

2.6 Hydropower

Globally, hydropower is the largest source of renewable energy, with an excess of 9,000 dams and supplying approximately 70% of all renewable energy worldwide [62]. Hydropower can be split into three main categories: 1. run-of-river, 2. storage and 3. pumped storage [63]. Run-of-river hydropower plants primarily use the volumetric flow of the water rather than, secondarily, water head for power production [64]. Storage based hydropower utilises a dam and a reservoir to store vast quantities of water. When required, hydraulic turbines convert the energy of flowing water into electricity [65].

Pumped hydro is similar to storage-based hydro, however, the key difference is that pumped hydro provides peak-load electricity supply. This is firstly achieved by implementing an upper and lower reservoir with a significant elevation difference. Secondly, water is passed from the upper reservoir to the lower reservoir, through hydraulic turbines, to produce electricity during times of excessive electricity demand and/or lack of electricity supply. Finally, high-capacity pumps return the water, from the lower reservoir to the upper reservoir during times of low electricity demand and/or surplus electricity supply [66].

Pumped hydroelectric facilities have power densities ranging from 0.45 – 1.5 W/L and energy densities of 0.5 – 2 Wh/L. Moreover, power ratings and energy capacities are superior, when compared to other types of energy storage, with 100 – 5000 MW and 500 – 8000 MWh respectively. Pumped hydroelectric has energy efficiency values which range from 70 – 85%, with long lifetimes of 40 – 60 years [67].

Pumped storage projects were initially developed to provide peaking and balancing support for coal and nuclear, however, the changing energy generation landscape is shifting how pumped storage is utilised. The addition of wind and gas, replacing coal, means that many pumped storage assets in the UK are no longer operating on daily cycles, pumping at night and generating during peak daytime hours. Rather, pumped storage assets have substantially increased ramping and sometimes cycling up to 60 times a day [68].

Hydroelectric generation in Northern Ireland constitutes a small fraction of the total electricity generated from renewables, it is captured as part of 'other renewables' in the latest Northern Ireland generation mix values ('other renewables' constitutes 0.7% of the generation mix and includes hydropower and CHP) [3]. While implementation of hydropower is dependent on land topology [69], studies have concluded that the island of Ireland has more suitable locations than originally anticipated for constructing pumped hydroelectric facilities [70]. The capacity of small-scale hydro in Northern Ireland is approximately 6 MW and consists primarily of a large number of small run-of-the-river projects [4]. An investigation carried out in 2017, highlighted that the potential of low-head hydropower in Northern Ireland for producing electricity remains an unexploited resource and a potential of 12.07 MW was identified [71].

2.7 Nuclear Power

Most nuclear power stations operate on the principle of nuclear fission, however, the International Atomic Energy Agency states that a prototype fusion reactor is expected to be built by 2040, and electricity generation is anticipated after 2050 depending on funding and technical advancement [72]. Nuclear fission is a chemical reaction where an unstable nucleolus within an atom (typically Uranium U-235 for nuclear power generation) breaks up into smaller fragment nucleoli, thus, the difference in mass between the parent nucleolus and resulting fragment nucleoli results in a substantial energy release [73].

Traditional nuclear power stations are typically installed with a large capacity (around 1 GW) and have reliable capacity factors (above 90%) [74], [75]. EDF Energy's Hinkley Point C is the first new nuclear power station under construction in the UK in two decades, with a capacity of 3.2 GW and two third-generation pressurised water reactors [76]. Small modular nuclear-fission reactors are an emerging technology which have power capacities up to 300 MW. They have advantages to offer over traditional large nuclear power reactors in the fields of safety (smaller amount of fuel and their amenability to accommodate passive safety systems), construction (delays reduced), operation (flexibility in operating small units), environmental (alleviation of nuclear-waste disposal) and economics (overcome the cost overruns, location flexibility and suitable for micro-grids or small communities) [77].

The authority to build nuclear power in Northern Ireland is not a devolved matter. Any such decision would be made by Westminster and the Department for Business Energy and Industrial Strategy (BEIS). While both centrally produced nuclear power and emerging small reactors both have clear advantages, this research report has not included nuclear in further analyses in subsequent sections due to the Irish Electricity Regulation Act 1999, section 18, which stipulates that production of nuclear power is prohibited on the island of Ireland [78]. In addition, nuclear is not part of the electricity generation portfolio mix. Therefore, nuclear was not included in the analysis in this study.

2.8 Onshore and Offshore Wind Power

Wind power has rapidly scaled since the 1970s and is the largest contributor to renewable generation in the UK and the ROI [3], [79]. Onshore wind is a mature, proven technology and benefits from a short construction duration. Power production from modern horizontal axis wind turbines depends on the interaction between the wind and the rotor. Thus, mechanical work is extracted from the kinetic energy in the wind utilising optimum blade aerodynamics and control methods (blade pitch-control, rotor yaw-control and variable-speed part-load operation) [80]. The rotor is coupled to the generator, either via a speed-reducing gear box or by direct–drive configuration, to enable the production of electricity [81].

The main advantage of wind is that it is a cost-effective and sustainable source of renewable electricity. Moreover, it provides economic stimulus through jobs and industry growth [82]. There are three main disadvantages of wind power. Power generated from wind fluctuates over time due to short-term weather conditions and long-term climatical variation, thus, this intermittency challenges the power system's stability [83], [84]. There are negative environmental externalities that relate to the physical nature of turbine installations, associated power transfer equipment and the geographical positioning of such equipment [85]. Wind turbines are inherently a non-synchronous technology; hence, high penetration can decrease grid reliability as they cannot provide the rotational system inertia in the same way as conventional synchronously-connected generators [86].

The UK total onshore wind capacity is projected to grow from 2025 onwards, reaching 30 GW by the end of 2030 [87]. This is in fact more than double the current operational capacity of 13.7 GW, according to new research from RenewableUK [88]. Northern Ireland has one of the best wind resources in Europe, hence, 83.7% of renewable electricity generation was from wind (from April 2020 to March 2021) [3]. There is a total of 1280 MW installed wind turbine capacity which is connected to the grid in Northern Ireland according to SONI (System Operator for Northern Ireland), and this number is set to grow to 1400 MW by 2024 [4].

The offshore wind industry has had phenomenal growth in recent years, growing an average of almost 30% per year since 2010 [89]. In Europe, installed offshore wind capacity increased by 2,918 MW in 2020, bringing total installed capacity to 25 GW across 12 countries. Installations in 2020 consist of nine arrays containing 356 turbines. Northern Ireland does not have any offshore wind farms currently installed. However, the ROI has 25MW of installed offshore capacity in operation since 2004 in the Arklow Bank Wind Park between Dublin and Wexford [90].

The majority of offshore wind is located near significant load centres in the southeast, in the Irish Sea to service Birmingham, Liverpool and Manchester in the midlands and near load centres in Scotland nearing Edinburgh, Glasgow and Inverness in the north. The major populations centres in Northern Ireland and in the ROI are also located along the coast. When compared to traditional onshore wind turbine installations, offshore wind has the following advantages: abundant wind resource, larger power production, lower turbulence derived from land topology and resulting vertical wind shear, space for development, and less visual and audible intrusion [91]. Disadvantages of offshore wind include operation and maintenance issues (excessive wind gusts can cause wind turbine damage or reduce power production and gearbox failure can cause long downtime and incur high costs) [92], [93]. The British Isles has significant offshore wind energy resources and has the potential to meet not only electricity demand in GB and on the island of Ireland, but also has significant export potential to supply the EU. This should be looked at carefully by decision-makers in Northern Ireland, the ROI, GB, and the EU in the context of Brexit, and the EU's Projects of Common Interest (PCI) programme [94], as well as the European Green Deal [95].

2.9 Solar Photovoltaic Power

Solar energy is a proven technology that has scaled rapidly over the last forty years and is utilised widely in many activities, such as irrigation systems in the agriculture industry, and heating, cooling and lighting in the building industry, and water desalination to produce water with low concentrations of seawater [96]. The major solar technology connected to electricity grids is solar photovoltaic (PV) which converts sunlight into direct-current electricity, the other dominant technology is concentrated solar power which uses mirrors to concentrate solar rays, producing steam [97]. PV panels are constructed of cells containing thin layers of semi-conductor materials, typically silicon monocrystalline, silicon polycrystalline or a hybrid [98]. These cells are then connected together in chains to produce larger units known as modules or panels [99]. Globally, despite the COVID-19 pandemic, at least 139.4 GW of solar PV systems was installed and commissioned by the end of 2020, thus, reaching a total cumulative capacity of 760.4 GW at year end [100].

The main advantage of solar PV is that it is an abundant sustainable resource. Another advantage is that battery storage systems can be combined with both residential and commercial solar PV installations to permit storage of solar based electricity during off-peak low-demand times and subsequent discharge during peak periods [101]. Some disadvantages of solar PV include, 1. the effectiveness of solar PV relies on the weather conditions [102], 2. there are various degradation and failure mechanisms of the physical PV panels such as discoloration, delamination, corrosion of metal components and output terminals [103], 3. insufficient end-of-life management of decommissioned solar panels can lead to waste generation, and 4. dust can significantly reduce the efficiency of solar PV modules [104].

Across the UK, there is a total cumulative installed capacity of 13.54 GW of solar PV as of July 2021. On the other hand, in Northern Ireland, the total cumulative installed capacity of PV systems was 391.3 MW, with 130.7 MW of large-scale PV (greater than 25 MW) [105]. SONI expects solar PV in Northern Ireland to grow to 1,200 MW in their 'Accelerated Ambition' scenario by 2030 [106].

2.10 Tidal and Wave Energy

Tidal power uses the movement of water to rotate a mechanical turbine that, in turn, generates electricity [107]. There are several different methods of harnessing tidal energy, these include: 1. tidal streams, 2. tidal barrages and 3. tidal lagoons [108]. The first is tidal stream generation, where the movement of water between high and low tide rotates a turbine. The equipment resembles conventional wind turbines, consisting of blades, gearboxes, generators and supporting structures [109]. Tidal currents are generally slower than wind currents, however, the greater density of water compensates for this in terms of power (seawater at 1025 kg/m^3 compared to air at 1.25 kg/m^3, standard temperature and pressure) [110]. A tidal barrage consists of a structure, similar to a dam, with turbines placed at the bottom. The structure creates a barrier between the sea and the tidal basin, using tidal elevation differences to produce power [111]. A tidal lagoon is a 'U' shaped breakwater that is built out from the coast. The tidal lagoon has integrated hydro turbines, which rotate as the water rises and falls with the tide, thus, generating electricity during both the incoming and outgoing tides [112]. The main advantage of tidal energy is that it is a renewable and reliable (tides are predictable) source of electricity, with a high energy density [113]. One disadvantage of tidal energy is that it requires mitigation against the corrosive nature of seawater, i.e., exotic materials, sacrificial anodes and special coatings [114]. Furthermore, accurate ocean current analysis and bathymetry is required to assess energy resource [115].

Development of tidal energy has been undertaken in Portugal, Canada, France, the USA and the UK, moreover, these nations have even defined policies for tidal energy since the 1970's [116]. Currently, the UK has in excess of 1,000 MW leased tidal stream energy sites and 10 MW of operational tidal stream capacity, including a number of multi-turbine arrays [117]. The UK's potential tidal stream resources could supply up to 30 GW, this is about half the total potential energy from tidal resources across Europe [118]. In Northern Ireland at the moment, there are no grid connections to tidal generators, however, The Crown Estate has awarded development rights for sites off the north coast of Northern Ireland close to Torr Head and Fair Head. The coasts around the island of Ireland have reliable and consistent tidal races, the potential of which has already been unlocked through SeaGen. This was the world's first commercially viable tidal stream generator with a capacity of 1.2 MW however it was decommissioned in 2019 [119].

Wave energy converts energy in the waves into useful electrical power and the technology to achieve this is called a wave energy converter. Different concepts of wave energy converters can be categorised into 3 types. 1. Oscillating body, which converts wave motions into device oscillations to generate electricity. 2. Oscillating water column, which uses trapped air above a water column to drive turbines. These come in both fixed and floating models. 3. Overtopping, a device that applies reservoirs to generate a head flow to drive turbines [120]. At present, the TRL of wave energy is behind tidal and offshore wind, despite research and development also commencing in the 1970s. However, the UK government intends to facilitate tidal development and is strengthening its position in the net zero transition [120]. The Carbon Trust has evaluated that the UK's total wave resource is around 230 TWh/year with the majority found in deeper offshore parts. The UK and Ireland have an excellent wave resource, estimated at 35% of Europe's and 1% of the global wave resource [121].

3.0 Support Schemes Overview

In this section a range of support scheme options are introduced. Additionally, a SWOT analysis for these specific support schemes is presented in Table 11 attached in Appendix A. A Pugh matrix is provided in Table 13 attached in Appendix B to rank each support scheme against established criteria. The results of this investigation and the key findings were used to inform the modelling in Section 6.0.

A range of support scheme options (also known as national energy policies) have been employed globally to deploy a higher level of renewable energy [122]. Figure 3 highlights the various support scheme options which most countries are utilising to directly support investment in renewable energy technology. These support scheme options seek to promote renewables in different sectors including heating and cooling, transport, and electricity using regulatory supports, reducing financing cost, expenditure on research and development, reducing fossil fuels subsidies, and carbon pricing [123], [124]. Subsidies for renewable energy are generally related to project investment or actual electrical generation from power plants, these are investment-based schemes and production-based schemes respectively. The latter schemes can either target the quantity of electricity generation or set the price of power generation through quantity-based schemes and price-based schemes respectively [125].

Figure 3 - Support schemes to develop renewable energy deployment

In GB, the Office of Gas and Electricity Markets (Ofgem) operates renewable energy support schemes on behalf of the government [126]. Thus, Ofgem works with a wide variety of energy system stakeholders, such as energy companies and consumer groups, to achieve government set policy targets following the most economical and consumer-focused method. In the ISEM, the wholesale electricity market arrangement for the island of Ireland [127], support schemes are administrated by the Utility Regulator in Northern Ireland [128] and the Commission for Regulation of Utilities in ROI [129].

3.1 Capacity Payment Mechanisms, Export Guarantee and Power Purchase Agreement

A Capacity Payment Mechanism (CPM) is a source of fixed revenue for participants who offer generation capacity [130]. The participants can be generators or demand side aggregators. On the island of Ireland, the payment mechanism is known as the 'capacity remuneration mechanism'. This system uses a rolling annual auction for up to 4 years in advance. Participants submit bids specifying their capacity volume in MW and the price sought per MW [131].

In most power systems the Transmission System Operator (TSO) determines the capacity required and reviews all bids, up to and including the last bid equally, until the capacity level is reached. The price at this point is known as the 'market clearing price' and all successful participants receive this price. Bids above the market clearing price are only accepted if there is a local security of supply issue, for example a constraint, where the existing transmission grid cannot deliver sufficient power from external sources to maintain system security [132]. The type of generation/demand side units that bid into this market tends to be dispatchable equipment. Typically, capacity markets are technology neutral and although some wind generation has been successful, it tends to be dominated by large fossil fuel and carbon intensive generators. Therefore, as fossil fuel generators are retired, this must be replaced by renewables which are guaranteed to be available when required if the security of supply standards are to be maintained.

The UK government introduced a new scheme in January 2020, replacing the traditional FiT scheme (which closed in March 2019), with the Smart Export Guarantee (SEG). The SEG ensures that all medium and large energy providers (i.e., SEG Licensees) offer an export tariff to their customers who generate low-carbon electricity and export it back to the grid [133]. The SEG generators, i.e., customers with small-scale renewable generation facilities are eligible for the SEG scheme if they met the capacity requirements of up to 5MW (or up to 50kW for micro-CHP) in the following technologies: AD, hydro, micro-CHP, Solar PV, and wind [134]. In the ROI, the Commission for Regulation of Utilities issued a 2020 report on microgeneration. This report captured the sentiment of the new Irish Renewable Energy Directive, where energy customers are entitled to "receive remuneration, including, where applicable, through support schemes, for the self-generated renewable electricity that they feed into the grid, which reflects the market value of that electricity, and which may take into account its long-term value to the grid, the environment, and society" [135].

A power purchase agreement (PPA) is a bilateral agreement typically between an electricity generator and a buyer. A PPA defines the commercial terms for the sale of electricity in terms of capacity and energy. Power purchase agreements are long term and are usually key to the financing of a project. As electricity markets have evolved and renewables are replacing fossil fuel generation, PPAs are transitioning to operate more like a CfD.

3.2 Contract for Differences

The focus of renewable incentives across many jurisdictions has moved towards CfD schemes. An overview of the payments in a typical two-way CfD is shown in Figure 3. This is representative of the system used in the UK where money will pass either from the regulator to the generator when wholesale prices are below the strike price or from the generator to the regulator when the wholesale price of electricity is above the strike price [136]. Under this process, capacity auctions are held at regular intervals; in the auction an overall capacity will be determined, and this is usually broken down into smaller allocations per technology with the idea that more mature technologies will not stifle the development of newer potentially initially costlier technologies. The UK currently has 15 GW of renewable energy funded via CfD [137], this has been allocated across different funding rounds with the most recent (as of 2021) being allocation round 4. The first funding round, allocation round 1, ran from October 2014 and closed for applications in March 2015 [136].

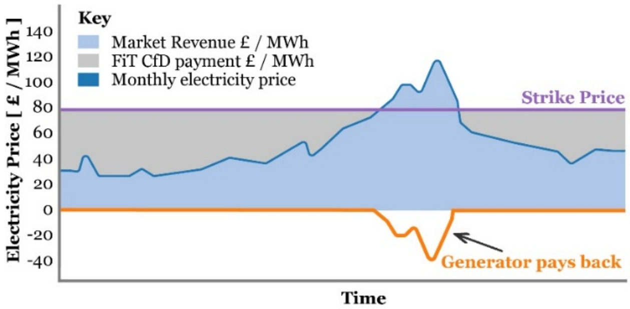


Figure 3 - Graph of a typical two Way CfD mechanism (adapted from [138])

The objective of CfD is to determine the value of the incentive paid to the generator through a competitive bidding process [139]. Germany, and other EU states use a one way CfD mechanism, in this system payment can only pass from the regulator to the generator when wholesale prices are below the strike price, there is no payment from the generator to the regulator when the wholesale price is higher than the strike price. This has led to auctions where developers have won contracts to install offshore wind arrays with bids of € 0.00 MWh. In this case the developer is assuming that the wholesale price will be higher than the unit cost of generation for that development [139], [140]. Other EU countries using CfD have some fundamental differences in their implementation, for example in the Netherlands and Denmark, developers bid on already feasible specific identified sites, thereby not having to incur initial development and feasibility costs [139]. Strike prices in the Netherlands, Denmark and Germany are also not indexed to inflation, whereas in the UK they are. Other differences include the term for the subsidies, as an example, Denmark limits subsidies to 50,000 full load hours, as opposed to other countries who set a term limit in years from installation [139], [141].

Advocates of CfD schemes note the dramatic reductions in the cost per unit of energy shown in many of these schemes. For example, there have been recent significant reductions in cost per MWh for offshore wind in the UK (reducing from over £100 MWh in the initial rounds of capacity auctions to around £40 MWh in the latest rounds) [137]. This has, in some cases, led to claims that the CfD scheme structure increases risk taking and under costing in order to win bids, conversely cost reductions seen could be attributed to normal reductions, seen as a technology becomes more mature [142]. Transparency of the

CfD process and the publication of latest costs means that this can all be tracked. The Low Carbon Contracts Company and the Electricity Settlements Company (two private limited companies wholly owned by BEIS) have online dashboards which summarise CfD scheme data and metrics, such as operational costs (historical, actual and forecast) and information regarding CfD allocation rounds [143]. Larger scale project financing works effectively with CfD schemes. However, the complexity of the scheme means that smaller domestic initiatives are better supported through grants and single payments.

In the GB scheme a generator cannot participate in both CfD and in the CM (capacity market). In essence this means that participants who wish to operate in a CfD scheme do not qualify for the Capacity Remuneration Mechanism (CRM) due to their generation type not being dispatchable. It is important however to draw the distinction between capacity and energy payments. Capacity payments are primarily paid out to ensure generation is available when required and are used by equipment owners to cover the fixed costs of running plant. Owners of peak lopping equipment, which only run for a few hundred hours per year, rely on the capacity market to operate profitably. Energy payments on the other hand, fluctuate depending on supply and demand and for non-dispatchable renewable generators, a guaranteed revenue, a CfD scheme is more suitable.

3.3 Feed-in Tariffs and Feed-in Premiums

Feed-in tariffs have been used extensively to provide financial support for renewable energy integration across the globe. Legislation and administration of these schemes vary depending on the region, technology type, scale and rates paid [144]. However, the principle of FiT remains the same i.e., it is a fee paid per unit of energy produced, to the generator by energy regulators to allow renewable energy sources to be economically competitive with fossil fuels [6]. This fee is allocated by metering and is represented as currency per unit of energy, for example p/MWh. In the UK, the FiT was introduced in 2010 and Ofgem was tasked to administer this scheme on behalf of the Department for Business, Energy and Industrial Strategy, to ensure compliance from electricity suppliers and reports to the Secretary of State [126]. Rates paid in the majority of these schemes are allocated on a sliding scale, meaning that as time passes and technologies mature and improve, the amount to be paid gets reduced. For example, FiTs for wind arrays between 1.5 and 5 MW capacity were specified as 97 p/kWh in 2016 dropping to a value of 49 p/kWh in the most recent allocation [145]. A feed-in premium (FiP) is a variation of the FiT and it is a price-based policy instrument whereby eligible renewable energy generators are paid a payment in addition to the wholesale price (i.e., a premium) [146], [147]. Feed-in premium arrangements can either be fixed (i.e., independent of market prices) or sliding (i.e., depending on the evolution of market prices) [148].

3.4 Green Certificates and Renewables Obligation Certificates

The European Environment Agency defines a Green Certificate (GC) as “an official record proving that a specified amount of green electricity has been generated” [149]. Thus, GCs serve as a mechanism to capture the environmental-based financial value of renewable energy production. Moreover, GCs can be exchanged separately from the energy produced. In the UK, there are two types of renewable GC, 1. Renewable Energy Guarantees of Origin (REGO), and 2. Renewables Obligation Certificates (ROC) [150]. The REGO scheme provides transparency to consumers about the proportion of electricity that suppliers source from renewable generation [126]. The Office of Gas and Electricity Markets issues one REGO certificate per MWh of eligible renewable output to generators of renewable electricity. The purpose of the certificate is to prove to the final customer that a given share of energy was produced from renewable sources. As such, the primary use of REGOs in Northern Ireland and GB is for Fuel Mix Disclosure. The Fuel Mix Disclosure requires licensed electricity suppliers to disclose to their customers the mix of fuels (i.e., coal, gas, nuclear, renewable, and other) used for generation [126]. Due to EU exit arrangements, the UK government put measures in place to ensure REGOs are issued, and that Guarantees of Origin from EU member states are accepted from January 2021 [126]. However, trading impacts may occur, as the European Commission has stated that from January 2021 onwards, REGOs from the UK will no longer be recognised by member states [151]. According to Ofgem, ROCs are issued to accredited generators for the renewable electricity they generate [126]. Hence, operators of accredited generation facilities can sell their ROCs independently of their electricity. However, there is a requirement for such operators to demonstrate compliance to their Renewable Obligation, which is calculated as a percentage of their total supply and this percentage is to be derived from a renewable source [152].

3.5 Investment Bonds, Loans, Grants and Tax Incentives

Investment bonds are a method of providing funding for renewable energy investment projects, bonds enable the investment cost to be shared between current and future generations [153]. The idea of using investment bonds to fund support scheme options (such as FiTs) takes advantage of the concept that renewable energy generation costs will decrease into the future and will become less expensive than fossil fuel generation [154]. Bonds are long-term debt securities where by the contractual (renewable energy investor) promises to pay an agreed principal amount by a specified maturity date, with interest [155]. According to the Loan Market Association, a loan for renewable energy investment or a 'green' loan is "any type of loan instrument made available exclusively to finance or re-finance, in whole or in part, new and/or existing eligible green projects" [156]. A non-exhaustive list of renewable technology loans in the UK is highlighted in Table 1.

Table 1 - Renewable technology loans in the UK

Loan	Description	Technology	Ref.
Home Energy Scotland loan	Up to £17,500 interest-free for installing domestic renewables for consumers living in Scotland	Domestic renewables	[14]
Salix finance	A not-for-profit company funded by the Department for Business Energy and Industrial Strategy, providing finance for revolving funds or interest free loans to accelerate investment in energy efficiency technologies across the UK public sector	Small scale projects such as solar PV	[157]
Urban Community Energy Fund	£10milliom fund to kick-start renewable energy generation projects in urban communities across England. Community groups will be able to access grants and loans to support renewable energy developments	Wind, solar, anaerobic digestion, CHP and hydro	[158]
Rural Community Energy Fund	£15million is aimed at helping rural communities in England access funding to carry out feasibility studies for renewable energy projects, fund pre-planning studies and preparation of planning applications	Wind, solar, anaerobic digestion, CHP and hydro	[159]
Green Investment Bank	The Green Investment Bank is a government financed £3.8billion commercial bank, supporting 5 key environmental sectors, with a mission to accelerate investment in the UK's transition to a green economy	Large scale renewables	[160]

In the UK and ROI, grants to cover the capital costs of renewable electricity generating infrastructure are limited. On a domestic level grants exist mainly for renewable heating technology such as heat pumps or solar thermal. On a commercial level, grants do exist for renewable projects however they are targeted at planning stage tasks such as feasibility studies. A non-exhaustive list of renewable technology grants in the UK is highlighted in Table 2.

Table 2 - Renewable technology grants in the UK

Grant	Description	Technology	Ref.
Community and Renewable Energy Scheme enablement grant	Funding of up to £25,000 for non-capital aspects of a renewable energy project such as feasibility studies in Scotland	Feasibility/ consultation costs	[161]
Sustainable Energy Authority of Ireland solar PV	New solar panel grants of up to €3000, for installing solar PV systems on houses built before 2011 in the ROI	Domestic solar PV	[162]
Low Carbon Buildings Grant	A historical scheme in the UK which grant aided certain renewable electricity generating technologies to householders. This scheme closed in 2010	Domestic solar PV, Small scale hydro, wind	[163]

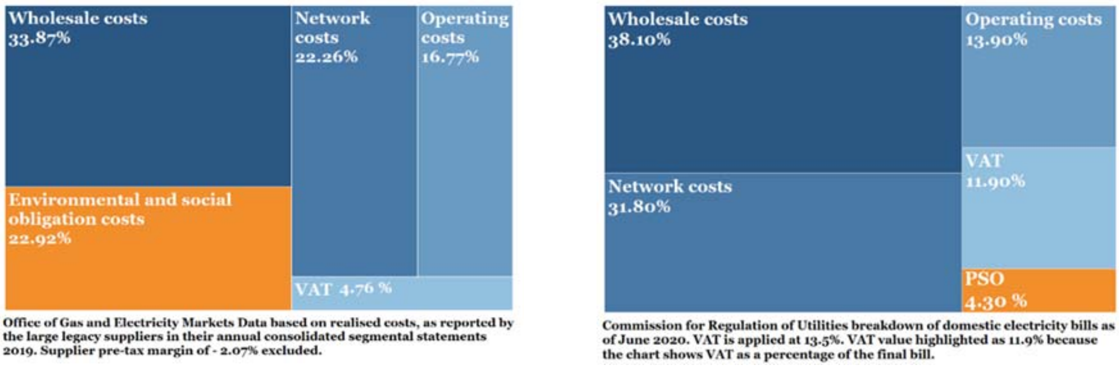
Tax incentives are a method of reducing taxes for renewable energy investors or energy consumers in exchange for specific actions or investments in designated technologies [164]. The 'Climate Change Levy' is an environmental tax that encourages business in the UK to operate in a more environmentally friendly way [165]. Exemptions to this tax were available on the purchase of electricity which came from renewable energy sources. However, the exemption for this was scrapped in 2015 because it was seeing taxpayer money benefiting electricity generation abroad. This has not only removed the incentive for sourcing renewable electricity but has damaged investor confidence. Today, specific 'green' tax credit mechanisms are very limited in the UK however businesses can make use of the Annual Investment Allowance for certain renewable investments. This scheme allows a business to deduct the full value of an item from the profits before tax. This is a general scheme that covers a range of items falling under the category 'plant and machinery.' The maximum expenditure which can be offset was £1 million in 2020.

In addition to this, the UK government has implemented a 'super' deduction for expenditure on plant and machinery purchased between 1st April 2021 and the end of March 2023 [166]. Companies can claim 130% capital allowance on qualifying investments, and this includes a range of renewable energy technology such as solar panels and wind turbines. A similar scheme does not exist in the ROI therefore a specific tax relief system is in place for renewable energy projects. A corporate investment in renewables is allowed up to 50% tax relief per project (with an upper limit cap of £7.5 million). In the UK, value-added tax (VAT) on solar panels is charged at a reduced 5% rate. This is only applicable when the supplier also installs them.

3.6 Public Contribution to Support Schemes

The public (i.e., domestic, commercial and industrial electricity consumers) help finance government operated support schemes which are used to incentivise renewable energy investment. This is achieved through allocation of a proportion of the electricity bill to fund this investment. In the UK, this proportion of an electricity bill is called the 'environmental and social obligation costs' and was estimated to be 22.92% of an annual domestic electricity bill as shown in Figure 4(a). Essentially, larger energy suppliers are required to help pay for government energy policies. These costs cover schemes to support energy efficiency improvements in homes and businesses, help vulnerable people and encourage the take-up of renewable technology (i.e., support schemes) [126]. Similarly, in the ROI, a 'Public Service Obligation' is mandated by the Irish Government and is charged to all Irish electricity customers to support the sustainable generation of electricity. The Public Service Obligation Levy rate, as of 1st October, is 77.80 euro per annum inclusive of VAT. Figure 4(b) highlights for a domestic electricity bill (as of June 2020), the proportion which goes towards Public Service Obligation is 4.3% [167].

Public contribution toward support scheme options to support renewable investment is important for funding the future generation mix. Furthermore, some of the money raised via consumer bills is directly transferred into domestic and commercial energy-saving improvements (for example, solar panels, heat pumps, insulation, and double glazing) such as the UK's 'Green Deal' loan and ROI's 'Support Scheme for Renewable Heat' [168], [169].



(a) (b)

Figure 4 - Breakdown of electricity bills in (a) the UK [170], (b) ROI [171]

4.0 Review of Global Support Schemes

4.1 Support Schemes in Great Britain, Northern Ireland, Ireland and the European Union

The Climate Change Act 2008 is the legislation driving the UK target for net zero CO_2 emissions by 2050, with a 51% reduction by 2025 and a 57% reduction by 2030, based on 1990 levels [1], [172]. In recent years, coal plants have been replaced with efficient gas-based technology (CCGTs) and renewables (mainly onshore and offshore wind). The biggest issue for GB is curtailment due to reduced inertia[4] caused by the level of wind generation. Curtailment issues can be resolved by reducing the inertial floor requirement and by the installation of renewable energy generators with the ability to participate in the balancing market [173]. A FiT for export to the grid ended in 2019 and has been replaced with a SEG which pays small low carbon generators for exported energy [174].

A scheme called 'Dynamic Containment' was recently launched by National Grid where technology like battery storage responds to correct frequency deviations [175]. Roof-top solar PV is popular in British residential areas and in 2019 there was 13.1 GW of solar PV with small scale systems making up 56% of this total, with the remaining 44% from large industrial scale systems [176]. Grid scale battery energy storage installations in GB compete in the ancillary services market however, growth of embedded storage at a domestic level is slow mainly due to the initial costs and insufficient revenues. There was a plan to rollout smart metering for both gas and electricity with 2020 set as the target date for completion [177] but due to technical issues, this target was missed and has been reset to 2024. The UK Climate Change Committee has recommended that from 2025 all new homes be fitted with low carbon heating [178].

The Northern Ireland Protocol was negotiated between the UK and the EU as part of the exit agreement for the UK to leave the EU membership. This Protocol covers four broad areas, ensuring unfettered access for businesses to the UK market, no tariffs on internal UK trade, supporting trade from GB to Northern Ireland and other arrangements to support the delivery of the Protocol in Northern Ireland. The SEM[5] is covered as part of the other arrangements section and sets out clearly that the Protocol provides the basis for the continued operation of the ISEM and trade of wholesale electricity across the island of Ireland. This position is being supported by technical discussion to avoid any disruption to this system and market [179].

A CfD scheme to support renewable generation is currently in operation in GB. Regarding a similar scheme for Northern Ireland, there are two options: 1. a UK wide scheme where Northern Irish projects compete along with GB projects in CfD auctions and 2. a separate Northern Ireland specific scheme where only projects from Northern Ireland can participate. In the UK wide scheme costs will be socialised and will be added to Northern Ireland consumers bills with no guarantee of successful Northern Ireland schemes and consequently no impact on Northern Ireland renewable targets. In a specific Northern Ireland based scheme costs will be socialised only among Northern Ireland consumers. As the markets for GB and Northern Ireland are separate and given that the second north-south interconnector will further integrate the systems in Northern Ireland and ROI, a specific Northern Ireland scheme may be the optimum fit. The design of a Northern Ireland specific CfD scheme would require analysis to include the impact on wholesale prices of the second north south interconnector and, the overall island renewable strategy.

Following the UK withdrawal from the EU in 2020, a new relationship began which includes the Northern Ireland Protocol [180]. The aims of the Protocol are to 1) avoid a hard border between Northern Ireland and ROI, 2) ensure the integrity of the EU's single market for goods, and 3) facilitate unfettered access for Northern Ireland goods to GB. In essence, this means that Northern Ireland remains in the single market. According to the SEM Committee, the Protocol has explicitly provided a legal basis for the ISEM to continue to operate on the island of Ireland [181], including electricity trading across the Moyle interconnector between Northern Ireland and GB, and the East West (EWIC) interconnection between ROI and GB. However, this trade may be less efficient due to the unavailability of platforms that previously existed when the UK was a full member of the EU. In response the SEM Committee has put in place measures between GB and the ISEM to address these losses. Owners of both renewable and conventional fossil fuel equipment may suffer short term difficulties with the supply of

[4] **Inertia** in a power system is the energy stored in large rotating generators and some industrial motors. It is vital for grid stability during an unplanned outage event as it supports stability and security.
[5] The **Single Electricity Market (SEM) committee** oversees the wholesale electricity market. It came into effect in 2007 as the SEM, and it was replaced with the Integrated Single Electricity Market (ISEM) in 2018.

parts, consumables, and services previously procured from GB however it would be expected that these issues would be resolved in time. On a wider scale, the impact of the UK exiting the EU (i.e., Brexit) on the energy sector is summarised in Table 3 with reference to Northern Ireland issues [182].

Table 3 - Northern Ireland Protocol issues

Issue	Comment
How does Brexit affect the Integrated Single Electricity Market operated in Northern Ireland and ROI?	The Northern Ireland Protocol provides for continued operation of the SEM regarding generation, transmission and distribution of electricity including cross border exchanges
How does Brexit affect the Moyle, East-West Interconnector and Northern Ireland/ROI interconnectors?	The UK-EU Trade and Cooperation Agreement applies to Moyle and East-West interconnectors, but not to the internal Northern Ireland/ROI connections
How does Brexit affect renewable and low carbon policies?	UK is released from the EU targets however the Trade and Cooperation Agreement TCA states that integration of renewable electricity is very strongly supported
Environmental standards for fossil fuel plants.	The EU Industrial Emissions Directive (2010) has been implemented into UK law therefore the impact on coal plants and older gas plants will continue as before with many expected to close by 2024
How will Brexit affect the supply of EU gas?	12% of UK gas is from EU sources. Any interruption in this can be made up from liquefied natural gas imports where available capacity exists although this could affect price
How will Brexit affect the cost of gas?	If export tariffs were imposed on EU gas or other countries flowing gas to the UK, then price could be impacted
How will Brexit effect renewable and low carbon support schemes?	State aid measures may be necessary to enable support scheme implementation in Northern Ireland. “State aid is any advantage granted by public authorities through state resources on a selective basis to any organisations that could potentially distort competition and trade in the EU” [183]

A range of support schemes adopted in the EU are summarised in Table 4. Tendering or administrative procedures may be deployed in order to set the level of support for each support scheme. The FiT is an incentive plan that provides users with a range of payments for electric power generated from renewable sources that are fed into the network. Furthermore, in the case of GCs, quota obligation can also be used. According to the Council of European Energy Regulators 2021, there has been a significant increase in the FiP schemes implementation. It is also to be noted that there are a number of countries that deploy more than one support scheme. The combination of FiT and FiP schemes is more often used.

The number of Council of European Energy Regulators member countries that deploy FiP has increased from six in 2015 to 17 member countries in 2020. Investment grants are still used in a very limited way and are only implemented in six countries. As shown from Table 4, Spain is the only country that completely relies on investment grants with specific particularities. It is worth noting that Table 4 shows support schemes for only 12 countries among all the European countries. Similarly, GC schemes are still less common among all countries and the UK is phasing out its GC scheme in the future.

Comparing these countries in terms of support, it can be seen that PV, onshore wind, bioenergy, and hydropower are among the most widely supported technologies. Nevertheless, offshore wind power is only supported by countries with a coastline as well as those who have already developed relevant regulatory frameworks. The duration of the support schemes is also varying significantly from one country to another. As demonstrated in Table 4, the Netherlands deploys the shortest duration of support schemes, starting at eight years. While Spain and Italy have a support duration of up to 30 years. It is to be noted that these support schemes are continuously modified in order to achieve renewable energy deployment in a cost-effective way.

Among the EU countries, renewable support schemes in Germany accounted for €22 billion, Italy for about €11 billion, Spain and the UK accounted for €5 billion each. Total subsidies were marginally higher in 2016 and reached €66 billion in 2017. Germany has a high percentage of renewable generation at 33% [184]. Strategically situated in central Europe, Germany is an exporter of electricity via grid connections with neighbouring countries. The ‘Energiewende’ is the legislation for GHG reduction and renewable energy targets. It was introduced in 2010 and is a plan working towards 2025 to transform the power system to mainly renewables. Nuclear generation is being replaced by a combination of efficient fossil-fuel plant and renewable generation [185]. The emissions policy is a 55% reduction on 1990 levels by 2030 and a reduction of 80 to 95% on 1990 levels by 2050 [186].

Table 4 - EU policies to facilitate the development of renewable power generation [187]

Country	Type of support	Procedure finding the level of support or the quota	Solar (PV)	Onshore wind	Offshore wind	Bioenergy	Hydropower	Support duration (years)
Austria	FiT	Administrative	Yes	Yes	N/A	Yes	Yes	13 to 15
	Investment grant	Administrative	Yes	N/A	N/A	N/A	Yes	
Denmark	FiP	Tendering	Yes	Yes	Yes	N/A	N/A	N/A
	FiT	Administrative	N/A	N/A	N/A	N/A	Yes	
	FiP	Administrative	N/A	N/A	N/A	Yes	N/A	
France	FiT	Tendering	Yes	N/A	N/A	N/A	N/A	
	FiP	Tendering	Yes	Yes	Yes	Yes	Yes	
	FiT	Administrative	Yes	N/A	N/A	Yes	Yes	10 to 20
	FiP	Administrative	N/A	Yes	N/A	Yes	Yes	
Germany	FiP	Tendering	Yes	Yes	Yes	Yes	N/A	20
	FiT	Administrative	Yes	Yes	N/A	Yes	Yes	
	FiP	Administrative	Yes	Yes	N/A	Yes	Yes	
Greece	FiT	Tendering	Yes	Yes	N/A	N/A	N/A	20 to 25
	FiP	Tendering	Yes	Yes	N/A	N/A	N/A	
	FiT	Administrative	Yes	Yes	N/A	Yes	Yes	
Italy	FiP	Tendering	Yes	Yes	Yes	Yes	Yes	15 to 30
	FiT	Administrative	Yes	Yes	Yes	Yes	Yes	
Netherlands	FiP	Tendering	Yes	Yes	Yes	Yes	Yes	8 to 15
Portugal	FiT	Administrative	Yes	Yes	Yes	Yes	Yes	12 to 15
ROI	GC	Administrative	N/A	Yes	Yes	Yes	Yes	15
Spain	Investment grant	Tendering	Yes	Yes	N/A	Yes	Yes	20 to 30
Sweden	GC	Administrative	Yes	Yes	Yes	Yes	Yes	15
	Investment grant	Administrative	Yes	N/A	N/A	N/A	N/A	
UK	FiT	Administrative	Yes	Yes	N/A	Yes	Yes	12 to 25
	FiP (contracts for difference)	Tendering	Yes	Yes	Yes	Yes	Yes	
	GC	Administrative	Yes	Yes	Yes	Yes	Yes	

The climatic conditions in Germany suit solar PV and on a sunny day can contribute up to 50% of consumption [188]. In 2019, 8.2% of electricity generated was from solar PV [188]. With the high-level of renewables, Germany is also a leader in energy storage and in particular battery energy storage. The German electricity market encourages a combination of solar and storage and has a consistent annual growth in terms of storage. The home storage systems are mainly deployed for PV self-use and reduction of electricity costs, whilst the larger systems compete in the ancillary services market. The German government has plans to decarbonise the heating sector by using heat pumps [189]. In the transport sector, the policy is to prioritise rail transport, increase taxation on air travel and private vehicle use plus support and education [190]. In 2016 legislation was passed for the roll-out of smart metering. The scheme commenced in 2017 and is planned to be completed by 2032 [191].

4.2 Support Schemes in some high GDP countries by Region

Table 5 summarises electricity policies and support schemes in some high GDP countries [192].

Table 5 – Energy policies and support schemes in some high GDP countries

Country	Population (million) [193]	Economy type [194]	Renewable generation % [184]	Energy policies/Support schemes	Comments
Australia	25	High	15.7	Domestic customers with PV and battery storage engage with FiTs, self-supply and are competing in the ancillary services market [195]	Domestic rooftop solar PV coupled to small battery energy storage is the best opportunity to take advantage of the climatic conditions
Brazil	209	Upper mid	79.1	New tariff schemes introduced in recent years by the government primarily aimed at retail customers [196]	Electrification of all sectors will create problems at distribution level therefore energy storage development required
China	1,392	Upper mid	25.4	Rollout of smart metering which the government intends to use in conjunction with a smart grid [197]	Strong state influence will be of benefit if policies regarding the transition to renewable energy can be successfully implemented
India	1,353	Lower mid	17.2	High level of the population has no access to electricity therefore electrification is the main priority with plans for a smart metering rollout	Embedded generation in the form of PV coupled with battery energy storage is a potential solution for rural electrification with microgrids as an option [198]
Russia Federation	144	Upper mid	17.2	Reform of the electricity sector began in 2001 to increase the efficiency of generation and encourage private investment to drive development [199]	Plans to meet Paris Agreement targets by reduction in emissions related to oil production but long-term goals set [200]
South Africa	58	Upper mid	5.5	The electricity supply industry remains a vertically integrated monopoly but there are proposals for restructuring and reform [201]	Well suited for solar (both PV and thermal) however cannot compete with the coal fired power stations using the abundant indigenous reserves
Republic of Korea	52	High	4.0	Government plans to introduce a smart grid and metering system [202]	Major manufacturer of energy storage equipment with two companies in the top ten global list of lithium-ion batteries
USA	329	High	17.2	Liberalised retail and wholesale market with opportunity for customers to source electricity from renewable suppliers [203]	In 2000-2001 the state of California electricity shortage and multiple blackouts caused by wholesale market manipulation which caused an increase in wholesale prices [204]

4.2.1 Australia, China, India and Republic of Korea

Australia plans to meet an emissions reduction of 26-28% on 2005 levels by a combination of hydro, solar, and wind [205]. There are plans to expand the 'Snowy Mountain' hydro scheme, but this is expected to be met with opposition [206]. Although large-scale hydro development is potentially a solution to meet emission reductions, these schemes are often faced with difficulties such as planning delays, environmental issues, land redeployment and extremely high capital costs. Australia has the highest percentage of rooftop solar PV in the world [207]. This has resulted in battery storage development and thermal storage where the solar energy is concentrated using materials like molten salts and used to generate electricity [208]. In 2018 the findings of a Climate Council of Australia report [209] noted that energy storage was developing mainly due to falling storage costs particularly in households coupled with embedded solar PV.

The Australian Energy Regulator has a smart meter installation program for all new developments [195]. Gas fired heating is used where required, with full conversion to decarbonised gas planned by

2050 [210]. In the transportation sector, there are incentives to purchase EVs including interest free loans with a plan to have EV penetration at 30% of the fleet by 2040 and a network of fast charging stations [211]. The transition from 84% fossil fuel electricity generation to renewable will be a massive political challenge, particularly as Australia is a net exporter of coal. Climatic conditions favour domestic rooftop solar PV coupled to small battery energy storage as the best opportunity to decarbonise the electricity sector.

China, as the most populous country in the world, is a global driver of renewable power generation development, with a total installed capacity of more than 894 GW at the end of 2020 [212]. This accounts for 29% of the total renewable installed capacity of the world, leading in hydropower, wind, and solar PV [213]. Since 2006, the National Energy Administration of China has adopted a FiT policy to accelerate the development of offshore and onshore wind, solar PV, solar thermal, and biomass. The FiT scheme is classified into four types based on the availability of natural resources and the potential of renewable energy in each region in China, as shown in Table 6. As illustrated, type 1 has the lowest cost and the greatest potential. Due to the high potential of renewable power availability in this region, type 1 receives lower tariff rates than other regions. Furthermore, the FiP schemes are only available for distributed solar PV (residential rooftop as well as small-scale commercial and industrial units).

China with nearly 70% of electricity generation from coal accounts for 28% of global CO_2. The energy policy captures a 60–65% reduction of carbon intensity per unit of gross domestic product with CO_2 emissions peaking in 2030 [214]. There are plans to reduce carbon intensity by driving policy to increase the use of renewables and nuclear [215]. Coal is the main source of heating and any switch to gas would mean a high dependence on imports [216]. The transportation sector contributes 9% of CO_2 emissions but due to rapid economic development and country size there are no apparent plans to decarbonise [217]. The Chinese government is encouraging the growth of renewables but with nearly 70% of electricity generation by fossil fuels, this represents a huge task.

The Chinese government has recognised the need for energy storage [218]. China is a major manufacturer of lithium-ion battery cells which are widely used for battery energy storage however, embedded energy storage development is still in the very early stages. There is a rollout of smart metering in China with government plans to develop a smart grid [197]. This is led by the distribution companies, and in 2018 China was the global leader for smart meter installations although this must be put in perspective considering the size of their system [219]. The challenge for China, in its transition to a low carbon economy, will be moving from predominately coal fired generation to renewables.

Table 6 - Chinese policies to develop renewable power generation

Type of support	Renewable technology	Rate [¥]			
		Type 1	Type 2	Type 3	Type 4
FiT	Offshore wind (intertidal)	N/A	N/A	N/A	0.47
	Offshore wind (coastal)	N/A	N/A	N/A	0.75
	Onshore wind	0.29	0.34	0.38	0.47
	Solar PV (utility scale)	0.4	0.45	0.55	N/A
	Solar PV (poverty alleviation purpose)	0.65	0.75	0.85	N/A
	Solar thermal	1.15			
	Biomass	0.75			
FiP	Solar PV (distributed, industrial)	0.1			
	Solar PV (distributed, residential)	0.18			

India is the second most populous country in the world and has a rising electricity demand. Additionally, it has the highest number of people (1.1 billion) globally who have no access to electricity. Power generation in India is heavily reliant on fossil fuel, currently at 80%, but it has 17% from renewables (i.e., 9% hydro, 3% wind, 2% solar PV and 3% biomass). The Indian government plan to achieve a 33-35% reduction of the ‘emissions intensity’ compared to 2005 levels. Thus, there are arrangements for 40% of electricity to be renewable or nuclear [220]. Coal is still used widely in the heating sector with electrification and biomass seen as potential solutions [221]. In the transportation sector, the electrification of railways and vehicles will be key to decarbonization [222].

Embedded generation in the form of solar PV for rural areas coupled to a mini-grid is an option being considered [198]. This will require storage of between 70-200 GW by 2022 [223]. This energy storage will be required either on a large scale at the transmission level or at the distributed level. Due to the size of the population and the economy, India like China will become a major player in the storage market. There are plans for smart metering rollout and in a country with electrification of rural areas still in development phase, this presents an opportunity. The main challenge for India, like China will be the transition from fossil-fuelled generation to a low carbon scenario.

In the Republic of Korea (ROK), generation is based on 69% imported fossil fuel, 26% nuclear and 4% renewables. Government policy is for an increase in the share of renewable energy generation to 20% by 2030, coupled with plans to reduce the number of coal plants [224]. The coal plants will most likely be replaced with higher efficiency gas plants (CCGTs), but to reach the goal of 20% renewables the government has announced the installation of PV (37 GW) and onshore and offshore wind (3 GW and 13 GW respectively) [225]. Due to electrical isolation, as renewables grow, system inertia will reduce, and frequency response will no longer be available from large fossil fuelled generators. The paper in [226] looks at the benefits that pumped hydro would bring, concluding that 880 MW of newly installed pumped hydro would reduce the cost of electricity and provide system services to balance renewable energy. In Seoul, there is a government scheme to assist low-income families to become involved in the installation of small solar PV units (260 W) on residential verandas [227]. Although recipients were initially satisfied with the technology, this changed when envisaged savings and capacity did not materialise with some residents expecting electricity bills of zero. This is an example of a scheme which was not thoroughly enough explained in the implementation phase.

The plans to develop renewables in the form of solar and wind will need firmed by storage in the form of batteries or pumped hydro. The most likely firming technology will be battery storage as new hydro installations are often faced with environmental restrictions. The ROK government plans to introduce a smart grid infrastructure and associated smart metering technology [202]. ROK emissions from heat, cooling and cooking make up 23% of total CO_2 emissions (double the G20 average), with plans to reduce this by increased efficiencies, reduced demand, and electrification [228]. Additionally, the ROK is aiming to become a leader in development of H_2 as an alternative energy source in conjunction with Hyundai Motor Group [229].

4.2.2 Brazil and the United States of America

Brazil has used its unique topology to become a global leader in installed renewables (mainly hydro-electric power) which annually contributes over 60% of the generated electrical energy. The hydro plants are used to balance solar (0.1%) and wind (7%), but gas (11%) remains as baseload and for providing the inertia and frequency response services. The emissions policy in Brazil is for a 37% reduction on 2005 levels by 2025, and a 43% reduction on 2005 levels by 2030 [230]. In recent years there has been a reduction in annual rainfall, and this coupled with rising demand has resulted in the hydro schemes becoming less effective as an energy storage resource. Rooftop solar PV is the best opportunity for an embedded generation with 7 GW planned by 2024 [231]. Domestic storage has been growing especially in the northeast of the country where the sunny climate suits solar PV and also to take advantage of peak and off-peak tariff schemes [232]. Additionally, there is a time-of-use tariff for consumers with a monthly consumption above 250 kWh and this coupled with domestic solar PV may drive demand for smart metering devices [196].

Brazil has a well-established ethanol fuel industry using sugar cane as feedstock which is used to produce both heat and power. In the transportation sector, biofuel is favoured over EV due to the huge investment required for EV infrastructure [233]. The decreasing effectiveness of hydro, rising demand and the growth in wind and solar will present a technical challenge considering that hydro is mainly grid scale with solar PV at the distribution level. As in any system electrification of heating, cooling and transport will exacerbate issues at the distribution level due to the increased load.

The USA withdrew from the Paris Agreement in 2019, with the reason given as the agreement being bad for the economy and putting the USA at an economic disadvantage. However, the country re-joined in 2021 following a change in government leadership. The government's long-term plan is for emissions to be 76% below 1990 levels [234]. The USA is a large producer of oil and gas with fossil fuels providing 64% of electricity, nuclear at 19% and hydro at 8% and renewables at 9% [184]. In the state of California, domestically installed solar PV has led to a high number of domestic storage installations. This high level of solar PV has caused network issues where system demand spikes in the evening resulted in the dispatch of fossil fuel machines operating sub-optimally. This exposed the need for energy storage. In the USA, building related emissions are the highest per capita in the G20. Only a few states have policies to decarbonise heat e.g., in California, from 2020 all new homes are to be fitted with PV and be of high efficiency design [235].

In the transportation sector there are no targets to phase out fossil fuel cars, however, there are tax credits for EVs with some states imposing higher registration costs [235]. In 2017 nearly half of USA electricity customers have smart meters installed [236]. There is separate legislation for each state which accounts for the differing penetration levels. The USA, with its system size and relatively high level of wind penetration (6% in 2017), is a growth area for both renewables and energy storage. Total installed wind capacity, predominantly onshore, in the US exceeded 117 GW at the end of 2020, while solar PV surpassed 75 GW. The USA is adopting production tax credit per kWh of renewable energy power generation. The production tax credit provides 2.5 cents/kWh for electric power generated from wind, closed-loop biomass, and geothermal resources. Moreover, a cooperative tax credit of 1.3 cents/kWh is applied on electricity produced from open-loop biomass, landfill gas, hydropower, and marine larger than 150 kW [237]. It is essential to note that the production tax credit rate on wind power is phased down by 40%, while it expires for all renewable generations commencing construction following December 2021.

In the USA, wind projects can receive tax credit depending on the following reasons: 1. the year that the project starts. 2. the year in which 5% of the total capital cost for the project has been spent and the construction has started [238]. The 5% down approach is known as safe harbouring. Safe harbouring allows wind project developers to receive the production tax credit at a given year's level, they must finalise construction no more than four years after construction commences. In the USA, federal corporate income taxes can offer 30% of the cost of a solar PV plant through investment tax credit [239]. The investment tax credit can be claimed for solar PV technology and other power plants that are in service during the tax year. The percentage of investment tax credit eligibility is designed as shown in Figure 5.

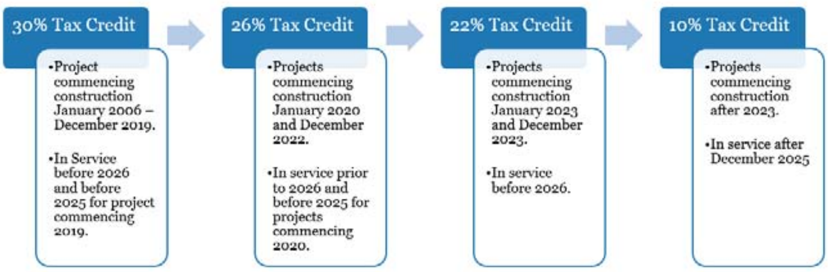


Figure 5 - USA tax credit applied to installation renewable power generation

4.2.3 Russian Federation

The Russian Federation has the fourth largest power system in the world with gas and coal accounting for 63% of generation with the remainder made up of hydro (17%), nuclear (19%) and oil (1%). The Russian Federation plans to meet its commitments to the Paris Agreement by lowering emissions related to oil production with no long-term goals set [200]. There is a slow development of renewables even though the LCOE, considering the Russian climatic and economic conditions, show that wind and solar are comparable with conventional generation with wind being the second least expensive after gas [240].

There is a widely held perception that renewable energy is too expensive, even though Russia was a pioneer in this area with small scale wind turbines in the 1930s and the first use of solar in the Sputnik space program of the 1950s. There is little evidence of either embedded energy storage or smart metering, however, there is widespread use of district heating schemes mainly using fossil fuels. The district heating infrastructure presents an opportunity for electrification using renewable energy. There is no evidence of plans to decarbonise transport. Russia as a major exporter of oil and gas, thus, is somewhat conflicted in the growth of renewables. Therefore, for Russia, growth in the embedded energy storage and generation area may be slow.

4.2.4 South Africa

South Africa is almost wholly dependent on indigenous coal for electrical generation. Generation by renewables for 2017 was comparatively low with 1% solar PV and 2% wind. The Integrated Resource Plan 2019 proposes to reduce the use of coal and increase renewables and gas [241]. As a developing country consistent supply of electricity is an issue and there are still many residences still to be electrified. The major barrier to the development of renewables is identified as cost and risk [242]. The government has introduced a feed in tariff called 'REFIT' [243]. The state-run electricity supplier 'ESKOM' and partly state-run fuel provider 'SASOL' exercise huge power and naturally want to protect their respective fossil fuel businesses.

South Africa is well suited climatically for solar (both PV and thermal), however, these technologies cannot compete with the coal fired power stations which utilise the abundant indigenous reserves. Solar PV is a potential solution for remote areas; thus, storage will also be required. The mismatch between capacity and demand results in enforced blackouts, and this has led to wealthy consumers installing home battery systems. Substandard power quality at the distribution level has prompted a study into using smart metering to monitor parameters [244]. In the transportation sector, car ownership per capita is low therefore, public transport development and non-motorised infrastructure are seen as the best opportunity to decarbonise this sector [245]. The challenges for South Africa in transitioning to a low carbon economy are a) the high reliance on indigenous coal and b) reaching a state where the system capacity can meet demand. However, climatically the country is well suited to solar and concentrated solar power at the grid level.

5.0 Changing Power System Landscape

The section briefly discusses the changing power system landscape due to ambitious GHG emissions level reductions and renewable energy targets in response to climate change. It also discusses Northern Ireland's future generation portfolio mix in light of these challenges, highlighting SONI's targets and power system security issues which may arise due to the changing power system landscape and increased levels of non-synchronous[6] generation.

Globally vertically integrated centralised power systems are transitioning towards a decentralised energy system with infrastructure for heating, cooling, storage and electricity production. A decentralised energy system will have micro-renewables, battery energy storage, district thermal networks, and more community or consumer involvement [246]. The electrification of transport and more active consumer involvement (i.e., prosumers) will challenge the current power system status quo [247]. Furthermore, increased penetrations of non-synchronous generation means that grid frequency and voltage support is becoming more critical [248], [249]. It is possible to manage increasing levels of variable renewable generation using demand response (DR[7]) from batteries, electrolysers, CHP, EVs, data centres, and smart loads in the home (e.g., storage heaters, electric heat pumps, fridge freezers etc.). Innovation in DR will be critical to asset and grid operations and management as renewable generation continues to increase [192], [250], [251], [252], [253], [254]. Gas and power system interconnection for balancing will also play a significant role during the net zero transition [255], [256], [257]. The challenge is getting DR onto the power system.

The British Isles has significant onshore and offshore wind energy resources and has the potential to meet not only electricity demand in GB and on the island of Ireland, but also the EU [258], [255]. This should be looked at by decision-makers in Northern Ireland, ROI, GB and the EU in the context of Brexit, and the EU's Projects of Common Interest (PCI) programme [94], as well as the European Green Deal [95]. This could positively benefit the economies of Northern Ireland, the ROI, GB and the EU, in terms of better energy security and achieving net zero by 2050 emissions reduction targets. So careful consideration in any Brexit negotiations should be given to the concept of wind from the British Isles in a European Supergrid [259], with an EU wholesale electricity market support scheme.

During the net zero by 2050 transition, grid operators, and the regulators on the island of Ireland will need to make tough social and economic decisions. Therefore, many actions are needed to overcome the socio-economic, regulatory and technological barriers to widespread deployment of renewables and DR infrastructure. These include 1) research and development of new and existing technology, 2) energy network advancement, 3) community involvement in policy making, 4) consumer lifestyle changes, 5) improved energy system education, 6) reform of energy institutions and energy subsidies, 7) rural electrification, 8) new incentives and tax relief mechanisms, 9) co-operative agreements, and 10) the introduction of multi-lateral projects [260]. Caution when divesting from natural gas generation during the net zero by 2050 transition is also needed, because divestment from gas generation without the necessary generation and infrastructure in place to ensure system security will not be prudent economically, and in terms energy and emissions [257].

5.1 Northern Ireland's Future Power Mix in the Context of the ISEM

All coal, peat and oil consumption is to be decommissioned in the ISEM by the end of 2030. Currently generation adequacy[8] is made up of coal, gas, pumped hydro, biomass, some battery energy storage, high-voltage direct-current interconnectors, with some demand side units [261], [106]. On the island of Ireland, new clean dispatchable resources are required to ensure that the generation portfolio meets adequacy standards, ensuring that electricity demand is met when renewable energy sources are unavailable or when other generating plants or interconnections are forced to shut down due to unforeseen events. Gas-fired generation is likely to play a key role, replacing older conventional plants and providing the multi-day capacity needed to assure supply security during extended periods of low wind. In the future when energy is increasingly supplied by renewables, the market design must attract

[6] There are two types of generation, **synchronous and non-synchronous**. Synchronous produces constant controllable electricity at all times. Therefore, it is fully dispatchable, making it reliable and predictable for grid operations. Examples include nuclear, coal, oil and gas generation. Non-synchronous is variable electricity generation. It is therefore not fully dispatchable since the electricity fluctuates with time constantly. This is because the generation is from a variable renewable resource, such as wind and solar. It is not predictably, and it does not produce constant electricity all the time, which means it is less reliable, and requires better grid integration oversight and management.

[7] **Demand response** is the modification of a customer's electricity consumption by a grid operator during power system imbalances (i.e., when supply will not meet demand) to maintain power system supply, frequency and voltage.

[8] **Generation adequacy** is the ability of the generation in the power system to match the load on the power system at all times.

the levels of capacity required to operate a safe and secure system. Figure 6 shows the breakdown of installed capacity of all power generation by fuel type for GB, Northern Ireland and the ROI as of 2020.

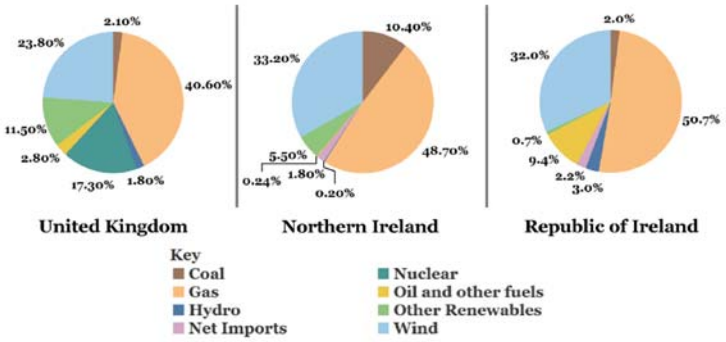


Figure 6 – Fuel mix in the UK, Northern Ireland and the Republic of Ireland [4], [262]

Grid-scale renewable energy, notably new offshore wind, onshore wind, and solar technologies are likely to grow significantly. This significant increase in renewable power will be accompanied by the phase-out of baseload coal and peat plants and the deployment of innovative technologies like battery energy storage. Onshore wind is the most common renewable generation method in Northern Ireland, and it consists of a mix of large-scale wind farms connected to transmission and distribution grids, as well as around 200 MW of small-scale and micro-turbines connected to the low voltage grid. Onshore wind energy is currently cost competitive with conventional power plants, and this is anticipated to continue in the future. Over the last decade more than 800 MW of onshore wind generation has been integrated into the network [106]. Since 2018, there has been no large-scale wind generating installation in Northern Ireland. The connection of new renewable generation in Northern Ireland has slowed dramatically over the previous two years, owing to a lack of policy beyond 2020, the termination of financial incentives in 2017, and a need for extra network capacity. In 2014, previous proposals for an offshore wind farm near County Down were cancelled.

There is approximately 1.5 GW and 4.4 GW installed renewable generation capacity in Northern Ireland and ROI respectively [261], [106]. Renewable energy resources are currently providing 40% of the annual electricity needs. In January 2021 SONI operated the grid with up to 70% variable renewable generation [263]. The portfolio under the 'Accelerated Ambition' scenarios in Northern Ireland and the 'Co-ordinated Action' scenarios in ROI aim to increase the installed renewable capacity to about 4.2 GW and 12 GW by the end of 2030, respectively. This means that 70% of the annual electricity demand will be met by renewable power plants. Reaching this target also means that the grid will require to handle 95% instantaneous SNSP. Figure 7 shows the major milestones required to tackle the challenges of managing the electricity system safely while attaining the 2030 renewable electricity targets [106]. Thus, significant changes in the way system operators manage the grid will be required to deal with unique challenges that will not be faced in large, interconnected power systems for the next few years. The main challenge is a lowered inertia floor down from the current security constraint of 23 GW with a significantly lower minimum number of large synchronous units required (currently, 8 large conventional synchronous units must be synchronised across the island of Ireland).

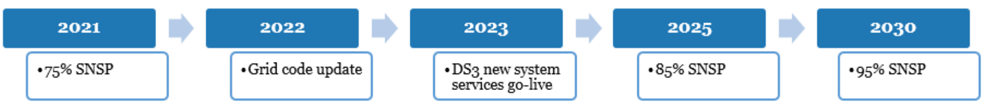


Figure 7 - Challenges to be addressed in order to securely approach the target of 2030

Minimising the total number of synchronous generators in the electricity grid means that provision of system inertia is reduced. Moreover, insufficient reserve capability means frequency varies more often, thus making it harder to maintain frequency regulation during system disturbances. Lower levels of system inertia result in more severe and regular frequency oscillations, which can destabilise the system. Furthermore, fewer online synchronous generators require the grid to have enhanced reactive power support. This is due to the effects of voltage deviations on the distribution system from renewable generation. The dynamic impact of this will be reduced fault current injection during transient short circuit events[9] [264]. Figure 8 shows the impact of operating the power system with high intermittent renewable power generation [265].

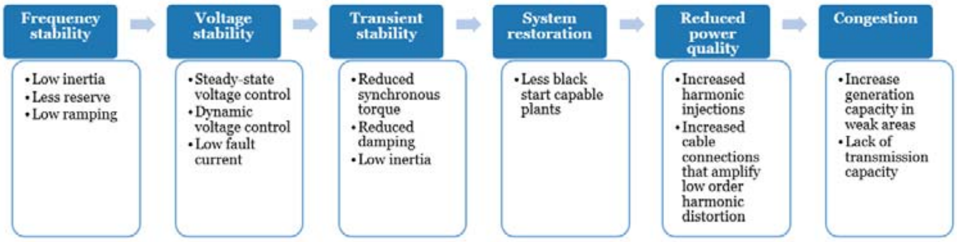


Figure 8 - System stability issues with high intermittent renewable power generation

5.2 Power System Security with High Renewables Penetration

Ancillary services are electricity products for energy balancing, frequency regulation, voltage support, constraint management and reserves. These are essential services needed by the system operator to maintain the secure operation of a power system. Conventional synchronous power plants traditionally provided these services at fixed prices. As synchronous generators are displaced by non-synchronous generation (i.e., wind and solar), the inherent characteristics of the unit's supplying energy to the network will change. This is because intermittent or variable renewable technologies introduce greater fluctuations in the system frequency, and thus create high voltage export constrained areas, higher reserve requirements, and more local network congestion. This gives rise to technical challenges that require new forms of ancillary services provision.

Both TSO's, SONI, and EirGrid have introduced a new range of ancillary services under the DS3 program [266]. The objective is to complement the displacement of conventional generation and facilitate higher levels of renewables by increasing the SNSP level. In total fourteen system services have been developed in conjunction with the regulatory authorities, five of which have been procured to date. The newly introduced services have modified the definitions of the system services traditionally used. The supply of these new ancillary services is now opened to all technologies at the transmission and distribution level that meet the DS3 requirements rather than just being procured from conventional synchronous generators. These services are, generally, categorised into frequency and voltage control services, as demonstrated in Figure 9. These control services maintain transmission frequency within a standard range of 49.8 and 50.2 Hz during steady-state conditions [267]. This process requires service participants to regulate their active power support continuously. Similarly, the network voltage must not exceed 1 p.u. ± 0.1 during operational switching and ordinary contingencies. This procedure requires service providers to regulate their reactive power[10] injections to attain reliable voltage across the network.

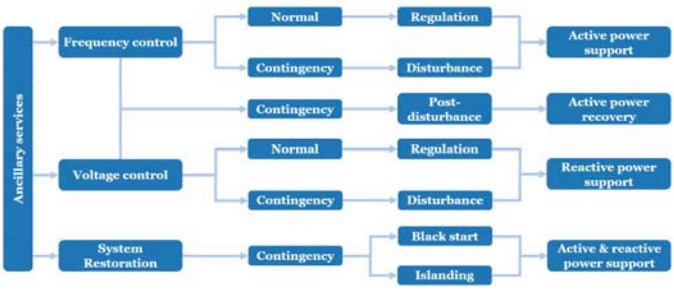


Figure 9 - Essential ancillary services to maintain power system stability

On the island of Ireland, a range of system services are available to restore the state of the power system when a disturbance occurs, as illustrated in Table 7.

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[9] Under fault conditions, synchronous machines connected to the transmission system can supply very high levels of fault current which is an important characteristic for power system security. This '**fault current injection**' characteristic is critical to maintaining the power system voltage profile during transient short circuit events (i.e., a trip or an unplanned outage). Non-synchronous generation (i.e., renewables) do not offer this characteristic, plus the levels of generation connected to the distribution system is not large enough to offer this either. Hence increased power system stability issues.

[10] **Reactive power** services ensure voltage levels on the system remain within a given range, above or below nominal voltage levels. System operators instruct generators or other asset owners to either absorb or generate reactive power to maintain voltage within this required range.

Table 7 - New and existing system service products in all-island power system [268]

Service name	Units of payment	Product description	New/ Existing	Activation	Payment rate (€)
Synchronous Inertial Response	MWs^2h	Kinetic energy stored x (SIR factor -15)	New	Automated	0.005
Fast Frequency Response	MWh	MW provided within 2 s to 10 s	New	Automated	2.16
Primary Operating Reserve	MWh	MW provided within 5 s to 15 s	Existing	Automated	3.24
Secondary Operating Reserve	MWh	MW provided within 15 s to 90 s	Existing	Manual	1.96
Tertiary Operating Reserve 1	MWh	MW provided within 90 s to 5 min	Existing	Manual	1.55
Tertiary Operating Reserve 2	MWh	MW provided within 5 min to 20 min	Existing	Manual	1.25
Replacement Reserve (Synchronised	MWh	MW provided within 20 min to 1 h	Existing	Manual	0.25
Replacement Reserve (De-Synchronised)	MWh	MW provided within 20 min to 1 h	Existing	Manual	0.56
Ramping Margin 1	MWh	The increased active power output that can be provided with a good degree of certainty for the given timeframe	New	Manual	0.12
Ramping Margin 3					0.18
Ramping Margin 8					0.16
Fast Post-Fault Active Power Recover	MWh	Active power > 90% within 250 ms of voltage > 90%	New	Automated	0.15
Steady-state Reactive Power	MVArh	Reactive power capability x (% of capacity that capability is achievable)	Existing	Automated	0.23
Dynamic Reactive Response	MVArh	Reactive power capability during large voltage dip >30%	New	Automated	0.04

In the ROI, there are a number of services that inject/provide active power support to ensure secure recovery of the system frequency following a disturbance. These services comprise reserves across varying time windows, as shown in Figure 10. The graph also demonstrates the activation order timeline of each product during disturbances. It can be seen that the new products complement the existing services in order to maintain reliable system frequency over the complete timeframe of the disturbance.

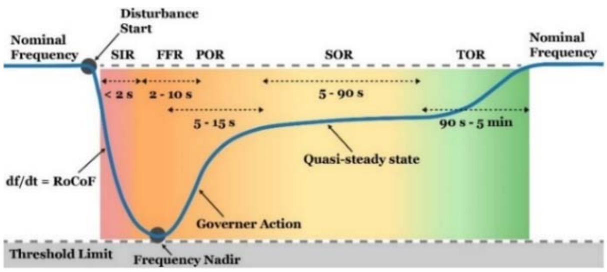


Figure 10 - Typical frequency response characteristics in the island of Ireland

There is an overlap between the old and new products which allows greater operational control over the system stability and facilitates a higher level of intermittent renewable generation. As an example, synchronous inertial response (SIR), fast frequency response (FFR) and primary operating reserve (POR) interface within the first 15 s from the start of the event. The SIR is specially designed to mitigate the high rate of change of frequency (RoCoF) while the FFR is developed to address sudden power imbalance by increasing the time required for frequency to reach the nadir as well as to mitigate initial RoCoF. It is worth noting that 53% of the FFR service volumes are now being contracted from new technologies such as demand-side units and wind farms [265]. It is also essential to note from Table 7, that the FFR service is the second most expensive service in the Irish power system following POR which will present a significant portion of the whole system cost [269].

When the system is operated beyond 70% of instantaneous renewable generation, a dynamic reactive response is another essential service to maintain stable voltage across the network. During large voltage dips, the dynamic reactive response quickly injects reactive current prior to the activation of the existing steady-state reactive power product. Both active and reactive power response services interact with each other in a new service referred to as fast power-fault active power recovery. This service becomes an important segment when the voltage dip introduces an active power dip at the terminal of the converter-based renewable technologies [270]. The phenomenon consequently results in a deeper frequency nadir that is much greater than originally initiated through the event. Thus, the fast power-fault active power recovery unit providers will be rewarded based on how quickly their active power is recovered following voltage disturbance to mitigate the impact of such disturbances on the system frequency. To date, all the services, except (dynamic reactive response and fast power-fault active power recovery) have been procured from a number of new technologies such as batteries, demand-side units, wind farms, and interconnectors. System restoration services are rarely activated during a complete grid blackout following cascading system failures.

Only a minority of generators in the island of Ireland grid have the capability to restart without the need for an external power supply [271]. Thus, the TSO has contracts in place with a variety of black start service providers (i.e., pumped storage, hydropower, gas turbines and interconnectors) to start up without an external power supply). There are three common ways to procure ancillary services in the market. First, a mandatory response is a prerequisite condition of being connected to the network [272]. This could be reimbursed at a predetermined price or at the expense of opportunity. Second, through a long-term bilateral contract for a specific service at a certain location (between the TSO and the distribution system operator as well as the service provider). Third, on the basis of invited bids, through a market-based procurement system. Regular auctions are usually taken at one or six months in advance, or this can also be done in real-time to co-optimised dispatch. The all-island wholesale Single Electricity Market (SEM) committee authorised a €235 million annual expenditure cap for DS3 system services, for 2020, in its SEM-17-80 decision paper [273]. The SEM committee also restated its position on system services agreements, highlighting that they should be consistent with energy trading arrangements. Total DS3 system services spending is expected to exceed €300 million in 2022, based on the expansion of units providing fast responding services, as indicated in Figure 11. It is also clear that the growth of units delivering fast-acting treatments is the primary cause of the increase in services. This is anticipated to increase for SONI and EirGrid's 'high-wind scenario', to above €380 million in 2022 [266].

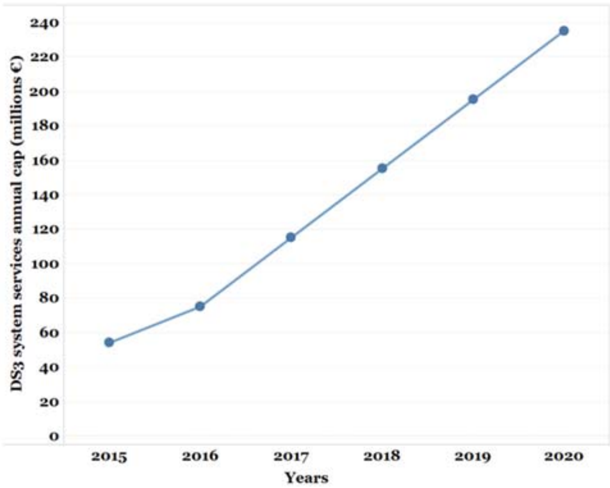


Figure 11 - DS3 system services annual cap as per SEM committee recommendation

Some technologies have a higher potential for raising system services costs [269]. The impact is large if technologies provide high-value, fast frequency services with high availability. These properties are common among battery energy storage systems and demand-side units. The net cost of system services is lower than expected where a new conventional plant is included. This is due to the fact that the conventional plant will most likely displace another conventional plant in the energy market, as well as the reserves of that unit. The incremental costs to the system may appear due to the increased ramping capabilities which have lower associated tariffs than fast frequency response.

Finally, wind farms are increasingly being hired to provide high-value reserve services, but they can only do so if they are operated below maximum power point tracking[11]. As a result, wind does not yet add a major cost to system services. The analysis conducted by SONI and EirGrid suggested an increase in the whole system services from €8 million per quarter to more than €40 million per quarter, by the end of 2022 as a result of fast responding technology. Because of the impact of the temporal scarcity scalars that incentivises the provision of system services at times of need, the difference between a regular or typical wind year and a high wind year is significant. When SNSP levels are between 60% and 70%, payments are multiplied by 4.7, and when SNSP levels surpass 70%, payments are increased by 6.3.

[11] **Maximum power point tracking** (MPPT) of a wind turbine or solar PV panel is when the maximum power is extracted from the technology using a control algorithm that tracks the I-V (i.e., current voltage) curve.

6.0 Modelling and Analysis

In this study, a number of different approaches were adopted to contextualise the future power system in Northern Ireland. TRL and LCA approaches were used to assess the available technologies, followed by a Delphi study to capture critical views of energy experts. The SWOT and Pugh analyses focused on the suitability of technology and support schemes for Northern Ireland. These approaches were then used to inform the LCOE analysis.

6.1 Technology Readiness Levels

TRL was developed by the National Aeronautics and Space Administration in the 1970's to estimate technology maturity. The TRL scale is used by the EU to secure Europe's global competitiveness, regarding the eligibility assessment of projects [274]. It permits engineers to have a consistent reference datum to benchmark technology, regardless of technical background [275]. The TRL scale is a widely used approach to determine the development or maturity of readiness for the market uptake and potential investments [276]. It is shown in Figure 12.

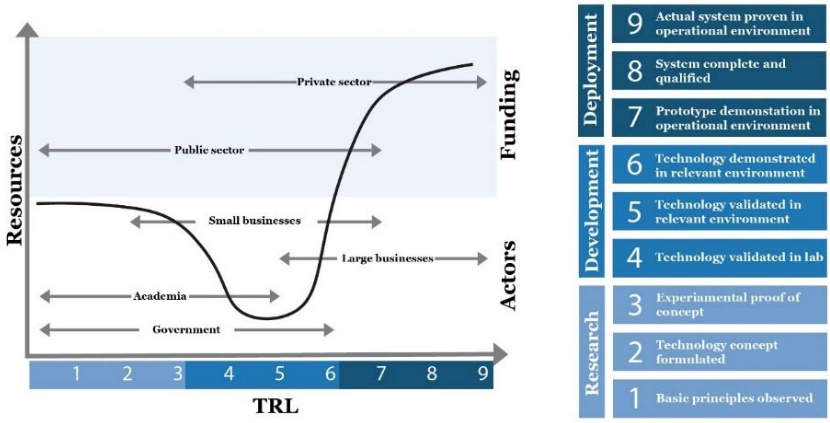


Figure 12 - Technology readiness levels (TRL), adapted from [277]

6.2 Life Cycle Analysis

Life cycle analysis (LCA) takes a whole life approach to understanding the costs and impact of a project. Figure 13 illustrates the LCA process. The underpinning concept of LCA is that every facet of a project consumes resources and creates waste and that every component has to be accounted for and costed in the analysis of the project, from conception to the grave [278]. This complexity means LCA needs to be simplified and this often leads to comparisons that are not necessarily like-for-like.

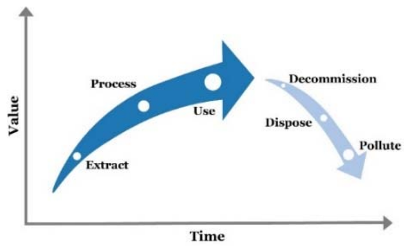


Figure 13 - Typical linear LCA

Finance and debt costs make up a significant element of LCA, this is particularly true for renewable energy technologies where the proportion of upfront costs are significantly higher than fossil fuel plants. The cost over the life cycle does start to balance with fossil fuel plants having much higher operational costs, primarily from fuel costs. Operational costs for renewable energy technology, while significantly lower than fossil fuel plants, are still substantial and are responsible for approximately 25% of the overall costs for offshore wind energy [279]. Life cycle costs in energy production are normally presented as a ratio between the total costs and the amount of energy produced. This is the LCOE and is presented as a currency per unit of energy for example, £/MWh. Table 8 indicates the TRL and LCA for each technology.

Table 8 - TRL and LCA for technologies

Technology	TRL	LCA	Ref.
Anaerobic Digestion, Biomass & Biogas	AD is already widely used in waste water treatment plant for treating plant for sewage sludge & for processing agricultural biomass (TRL =9) AD could be more developed for lignocellulosic biomass with high total solid content (TRL = 7)	For agricultural AD Install cost Small scale = £750,000 – £1m. Large scale plant: ~£15m+ Capacity Factor = 86.3%, LCOE = £19/MWh to £43/MWh Lifespan= 20 years	[280], [281], [282], [283]
CCGT & OCGT	**CCGT:** Mature technology with high fuel to electricity conversion efficiency (60%), TRL = 9 CCGT combined with Carbon Capture and Storage (CCS) technology in development (lower efficiency and higher installation costs), TRL = 4-6 **OCGT:** Mature technology. Low fuel to electricity conversion efficiency (30-35%), but flexible operation and quick start facility suits a system with high renewables	**CCGT:** Installed cost £1400/kW (with CCS), £600/kW (without CCS) LCOE £20-30/MWh (with CCS) £10/MWH (without CCS and excluding CO_2 costs) Lifespan 25 years **OCGT:** Installed cost £500/kW LCOE £130/MWh Lifespan 25 years	[284]
CCUS	**CCGT with CCS:** Deployment still at first of a kind, but as development is beginning on a commercial scale, TRL=9 **Direct from air CCS:** lower TRL, prototypes exist but commercial and technical feasibility for large scale deployment still to be determined TRL = 7	**For CCGT + CCS** Install cost = £1600/kW Capacity factor = 87% Project lifespan = 25 years LCOE = £87 MWh	[27], [284], [285]
Energy Storage	Ranges from mature hydro storage, TRL =9 to flywheel development, TRL = 1-3 Storage using Lithium-ion cells is most mature of the battery technologies and with falling costs is becoming widespread, TRL=8-9	Battery storage Install cost = £300-£1000/kW Lifespan = 10-20 years	[192]
Geothermal	Flash point, binary and small scale domestic systems are well established and have extensive use across multiple regions, TRL=9	Install cost = £7,340/kW Capacity factor = 90% Project lifespan = 25 years LCOE = £133 MWh	[284]
Hydropower	Technology well established with multiple large-scale projects across the world. Various installation configurations, from river dams building reservoirs to pumped hydro using two reservoirs at different levels Pumped hydro storage, TRL = 9 Profitable low head hydro power, TRL= 6 Efficient passage of fish, TRL =4	Install cost = £3,620 /kW Capacity factor = 45% Project lifespan = 40+ years LCOE = £88 MWh CAPEX = £3,460/kW O & M = £36.50/kW/year Insurance = £1,000/MW/year Connection charges = £8,100/MW/year	[284]
Onshore & Offshore Wind	**Onshore wind:** Horizontal axis wind turbines are well established, TRL=9 Trend is towards larger turbines increasing capacity factor and output 10MW+ turbines soon to be deployed **Offshore wind:** Majority of early offshore HAWT are geared but recent trend towards direct drive permanent magnet turbines, many deployed, TRL = 9 Monopile foundations & other fixed bottom foundations TRL=9, Floating foundations, TRL=7	**Onshore wind:** Install cost = £1,120 /kW Capacity factor = 34% Project lifespan = 25+ years LCOE = £46 MWh **Offshore wind:** Install cost = £1,630/kW Capacity factor = 51% Project lifespan = 25+ years LCOE = £57 MWh	[279], [284]
Solar PV power	**Solar cells and modules:** Crystalline silicon (c-Si), TRL = 7-9 Stacked cells on c-Si, TRL = 4 Copper-Indium-Gallium-Selenide, TRL = 7-9 **System technology:** PV inverter technology, TRL = 7-9 Grid connection and management, TRL = 7-9 Manufacturing and plant engineering, TRL = 7-9	Micro-scale (0-4kW) install cost = £1628/kW Small-scale install cost = £1,685/kW (4-10kW range) & £1,088/kW (10 -50 kW range) Capacity factor = 10% Lifespan = 25 – 50 years	[286], [287], [288], [289]
Tidal & Wave Energy	**Wave:** Oscillating water column, TRL = Point absorber, TRL = 8 Over topping device, TRL= 5 Rotating mass, TRL= 7 & Attenuator, TRL = 7 Oscillating wave surge convertor, TRL = 6 **Tidal:** Tidal Kite, TRL = 5 Oscillating hydrofoil, TRL = 5 Vertical axis turbine, TRL = 4 Horizontal axis turbine, TRL = 8 Enclosed tips, TRL =7	**Wave:** CAPEX = £4,940/kW O&M = £43.30 / kW/year Insurance = £12,700/MW/year Connection charges = £34,500/MW/year **Tidal:** CAPEX = £4,144/kW O&M = £150/kw/year Insurance = £12,700/MW/year Connection charges = £34,500/MW/year	[121], [110]

6.3 Delphi Study

Since the Delphi technique has proven to be a reliable approach in setting the direction of future-orientated research in previous studies [290], this approach has been employed to study the opinions of energy experts on the technologies and potential support mechanisms to achieve Northern Ireland's 2030 and 2050 net zero targets. A Delphi study seeks the opinion of a panel of experts to evaluate the extent of agreement and resolve disagreement on an issue through a series of structured questionnaires (commonly referred to as rounds) [291], [292]. The sampling strategy was purposive to ensure that participants met the inclusion criteria and designed to include experts from four different types of sectors, namely: government, academic institutions, private sector firms, and civil society and independent research institutes as Figure 14 illustrates.

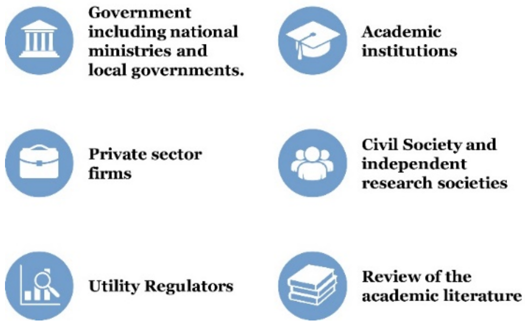


Figure 14 - Sectors and methods for our Delphi study

The expert selection aimed to recruit a heterogeneous group that must actively be researching themes related to renewable and sustainable power generation and transition towards a net zero carbon future. Given the Northern Ireland focus, all the invited experts must have had either experience working in Northern Ireland and/or knowledge about current and existing energy policies taking place there. Moreover, all participants were required to be fluent English speakers and 18 years or above. In total, 150 experts were approached, from these 27 experts participated. The Delphi questionnaire was open from 23rd August to the 3rd September 2021. The majority of participants were unknown to the authors and were selected based on their expertise rather than through another methodology (i.e., snowballing). Figure 17 displays our approach to the Delphi process.

Figure 15 - Approach to Delphi Process

An extensive and comprehensive review of existing literature addressing support mechanisms and schemes to incentivise renewables investment at a global scale was conducted to formulate the questions for our Delphi survey. The survey consisted of questionnaires through which experts evaluated and commented on policy alternatives to achieve Northern Ireland 2030 and 2050 net zero carbon targets. It is worth noting that our questionnaire, although it was technology-oriented, also attempted to address economic, environmental, political and social dimensions. The questionnaire consisted of 21 statements altogether. Moreover, we allowed panellists to suggest factors that were not included in the question. The results of the Delphi study can be observed in Appendix D.

Since this study was conducted by the Northern Ireland Department for the Economy, they were in charge of ethics approval from their own institution. However, both Queen's University Belfast and Northern Ireland Department for the Economy ensure that all information collected during the study was kept securely in a password-protected computer and handled following the General Data Protection Regulations and Queen's University Belfast guidelines on processing personal data.

6.4 Strengths, Weaknesses, Opportunities, and Threats Analyses

A SWOT analysis is a strategic framework used for assessing the internal capabilities and external situations of business propositions, research ideas, technology and concepts [293]. However, there are some shortcomings despite its popularity in planning. These include subjectivity in defining SWOT factors, and their qualitative nature, and thus, require supplementation with additional quantitative analyses (Pugh matrices for example) and SWOT analysis takes a snapshot view in a single instance in time [294]. Tables 10 and 11 in Appendix A capture the SWOT analyses completed for the technologies specified and the support scheme options available. A consideration of the applicability for implementation in Northern Ireland is applied when completing the SWOT. The information compiled in the SWOT tables was then used for the subsequent Pugh matrices.

6.5 Pugh Matrices

Pugh matrices are criteria-based decision matrices which use criteria scoring to select potential solutions [295]. The technologies and support scheme options were assessed against established criteria informed by the SWOT analysis. The completed tables can be observed in Appendix B, Tables 12 and 13. Again similar to the SWOT analyses, a consideration of the applicability for implementation in Northern Ireland is applied when completing the Pugh matrices. If the concept in relation to the criteria is better than the baseline, it is given a '+1', if it is the same as the baseline it is given a '0' and if it is worse than the baseline it is given a '−1' [192]. The results of the Pugh matrix-based analyses are attached in Appendix B in Technology Assessment in Table 12.

Onshore wind had the highest score, with a total of '1' above baseline. CCGT, energy storage, Hydro and OCGT came in joint second, matching the baseline. Tidal energy had the lowest score with '-6' below baseline, with Wave energy having the second lowest score ('-5' below baseline). The results of the Support Scheme Option Assessment are attached in Appendix C in Table 13. The Contract for Difference scheme (Northern Ireland Pot), CfD (Separate Northern Ireland based scheme), FiP, FiT, GCs and investment loans and grants all had the joint highest score of '6' above baseline. The CfD (GB scheme) and export guarantees came in joint second, with a score of '5' above baseline. CPM had the lowest score, of '-1' below baseline, with tax incentives having the second lowest score ('4' above baseline).

6.6 Financial Analysis

The detailed LCOE model is provided to indicate the economic competitiveness of each technology and assist with energy system stakeholder decision making associated with support schemes. Appendices A to D contain further information which supports the LCOE analysis. Levelised cost of energy is used widely to compare the economic competitiveness of energy portfolios [142]. The baseline LCOE was calculated using cost and cash flow sheets from the National Renewable Energy Laboratory [296]. Individual LCOE's were created for the generation of electricity from AD, CCGTs, hydro, geothermal, onshore and offshore wind, solar PV, tidal, and wave. Typical renewable energy installation life cycles have the majority of the costs up front [279], this is in contrast to thermal generation where the majority of cost consists of fuel which is spread across the project life cycle. This means that costing renewable energy using a marginal cost, as per thermal generation, does not work and the fuel costs are virtually zero. A function to estimate LCOE is shown in Equation 1.

$$LCOE = \frac{\sum_{t=1}^{n} \frac{I_t + OPEX_t + DECEX_t}{(1+d_r)^t}}{\sum_{t=1}^{n} \frac{E_t}{(1+d_r)^t}} \qquad \textbf{Equation 1}$$

where I_t is investment inclusive of debt costs (£ or €) in year t, $OPEX_t$ is the operation and maintenance expenditure in year t, $DECEX_t$ is the decommissioning expenditure in year t, E_t is the amount of energy produced in year t (MWh) and d_r is the discount rate applied. Figure 16 illustrates the steps in the financial analysis used to determine the LCOE.

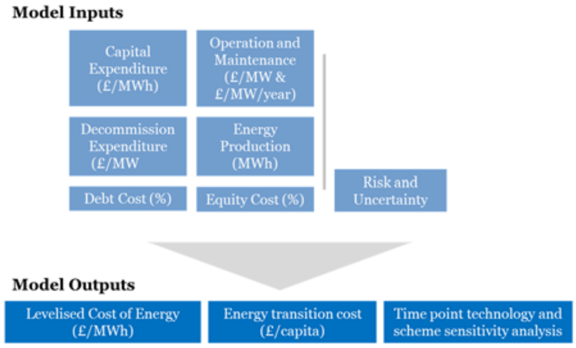


Figure 16 - Development of a financial model for an energy project

Model inputs and assumptions were taken from BEIS's report on electricity generation costs in the UK in 2016, 2020 and from 'assumptions for generation technologies' spreadsheet [284], [285], [297]. Mid-range projections were used where appropriate for the capital and operational costs. The funding source of each project was taken to be split 50:50 between debt and equity. The interest rate on debt and target equity internal rate of return (IRR[12]) was deemed to be equal and adjusted to meet the specified weighted average cost of capital (WACC[13]). The decommissioning costs at the end of the project lifetime were deemed to equate to the salvage value for each technology (therefore net cost is zero) apart from offshore wind which had an additional cost of £500,000. Project costs were deemed to be depreciated by 100% in the first year in accordance with the UK's business investment allowance.

The scenarios created are hypothetical potential future generation portfolios, in which Northern Ireland implements each particular incentive, and were compared to the 'do-nothing' baseline scenario. Data from BEIS) was used for the baseline because data is not readily available for Northern Ireland because there are limited or no installations (with onshore wind and limited large scale solar PV being the exception). For consistency it made sense to use the BEIS data for all technologies, otherwise additional 'noise' would have been added to the analysis. A full list of Inputs and Assumptions for the analysis are listed in Table 14 attached in Appendix C. The baseline LCOE estimates do not include subsidies and are taxed at 19% as per the corporation tax rate in the UK and will apply to Northern Ireland. Entities based in ROI would be liable for a 12.5% corporate tax rate. Where possible, carbon costs have been removed from fossil fuel generation so that only the cost of generation is compared. There are scenarios where CCS has been added to account for future carbon capture at the generator and the cost of this technology is included. Wholesale pricing data was taken from the SEM, BETTA, and an EU Day-Ahead Market (DAM) average, and was plotted to show trends over the past 3 years. For the purpose of this comparison, the BETTA data was converted to euro using August 2021 rates and is shown in Figure 17.

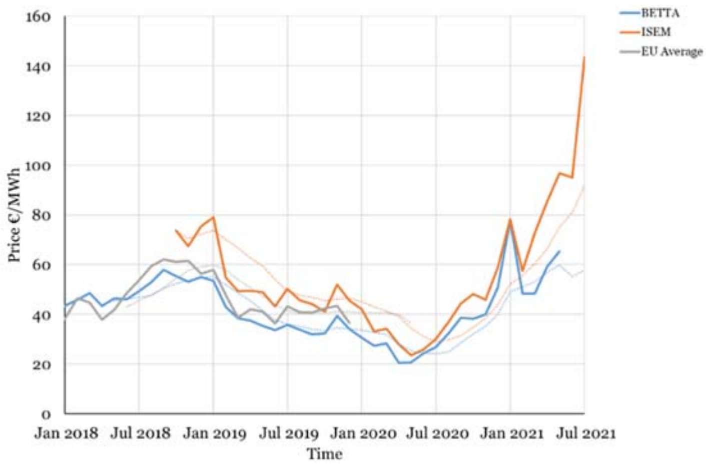


Figure 17 - Daily average price (based on DAM) for ISEM, EU average and BETTA

[12] **Internal rate of return** (IRR) is used in financial analysis to estimate the profitability of potential investments. It is a discount rate that makes the net present value (NPV) of all cash flows equal to zero in a discounted cash flow analysis.
[13] **Weighted average cost of capital** (WACC) is used in financial analysis by investors to assess the returns on an investment. In essence it is a measure of the cost to borrow when making a capital investment.

The LCOE for each technology is plotted against the average daily wholesale price of electricity in the SEM, with the wholesale electricity pricing taken from 'SEMOPX' [298] and the wholesale data is smoothed using a 10-point moving average, shown in Figure 18.

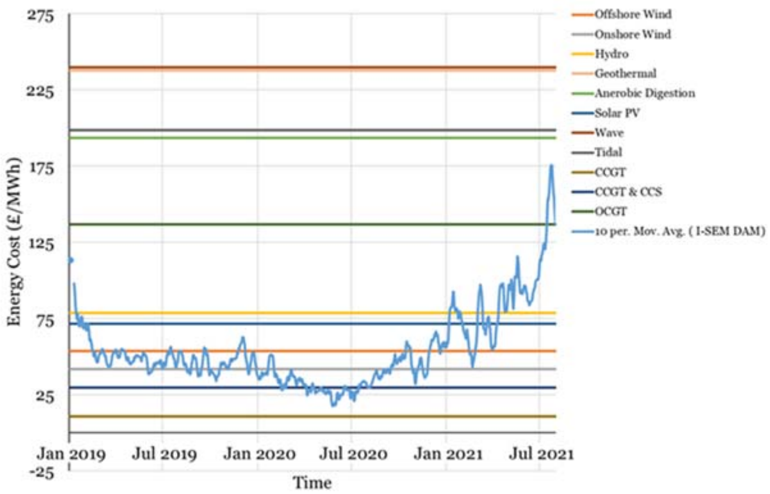


Figure 18 - Daily average price (based on ISEM DAM) and LCOE

This data was used to create a projection whereby the wholesale prices from SEM, BETTA and EU average were increased in line with a target 2% inflation rate to 2040, this was plotted against the projected LCOE from differing technologies to 2040, as shown in Figure 19.

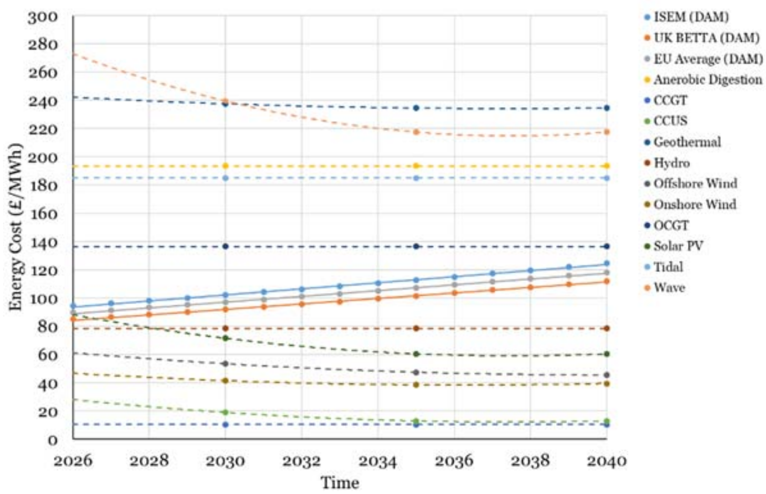


Figure 19 - Projected daily average price (based on DAM) for ISEM, BETTA, EU and LCOE

The LCOE for eleven different technologies were compared, and for each technology four different scenarios were created. These where then estimated over three time points, 2030, 2035 and 2040. The technologies and the model assumptions are shown in Table 14, Appendix C.

6.7 Fixed Rate One Way Payment Schemes

In this section a do nothing, tax/investment bond, FiT/FiP and GCs/ROCs scenario were modelled in 2030, 2035 and 2040 using BEIS data to examine the impact of fixed rate one way payment schemes on the cost of energy [284], [285], [297]. The results of this analysis are plotted in Figures 20, 21 and 22. The FiT rates and ROC banding levels were taken from Ofgem's most recent publications [145], [299], and for the tax/investment bond scenario the tax rates were dropped to 0% and the interest rates were lowered in the LCOE to reflect lower cost capital from investment bonds for the investment bond scenario.

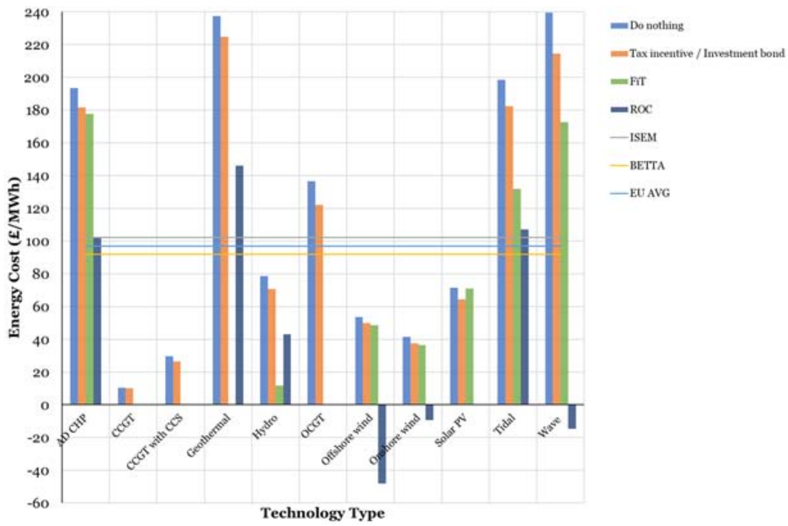


Figure 20 - Impact of incentive schemes on cost of energy for 2030

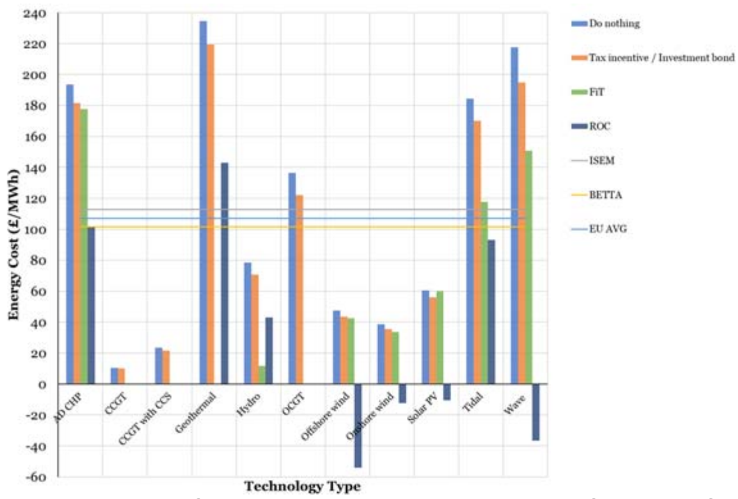


Figure 21 - Impact of incentive schemes on cost of energy for 2035

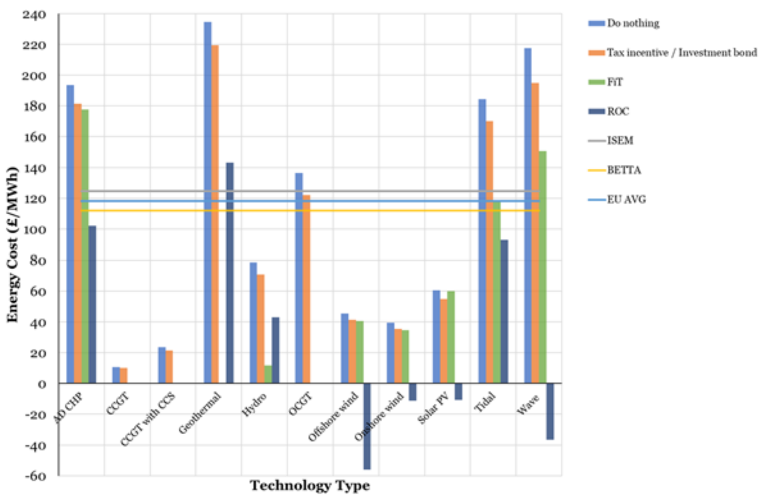


Figure 22 - Impact of incentive schemes on cost of energy for 2040

The analysis shows that the viability of each technology examined is almost wholly dependent on the support available and the time point examined. This is the limitation of this study. These figures from the analysis of fixed rate one way payment schemes also illustrate that 1) the do nothing scenario is the most costly because all of your costs are passed directly to the wholesale market, 2) the tax incentive and the investment bond schemes gave almost the same outcomes, 3) the FiT scheme reduced the cost of energy and 4) the importance of matching the ROC rate to the technology, and that where the ROC banding is set too high the cost of energy production can actually be negative. Note that these figures illustrate how in the time slices analysed, a negative energy cost can result with a ROC because the future value of the ROC is greater than the cost of generation. Overall, the fixed rate one way payment schemes analysis highlight that investment risk is not shared evenly between the regulator and the generators and cost the regulator more over time.

6.7 Two-way Variable CfD Payment Scheme

As CfD schemes track the wholesale market reference price over time, a different analysis approach was used because it is not possible to accurately predict the wholesale market reference price into the future. This is another limitation of this study. Instead, a hypothetical payment profile for offshore and onshore wind, and solar PV under the current GB two-way CfD scheme, based on actual ISEM DAM wholesale pricing from Jan 2019 to August 2021 was established (cf. Figure 23). These technologies were selected based on the SWOT and the Pugh analyses as the most suitable for Northern Ireland. This data was plotted as a 5-point moving average to smooth the data sets and assist identification of trends. The values here represent what the payment per MWh would be under a two-way CfD, for each technology at each time period, with positive values representing a payment from the regulator to a generator and negative values showing payments from a generator to the regulator. This figure clearly shows that as the wholesale price increases the cost to the regulator decreases.

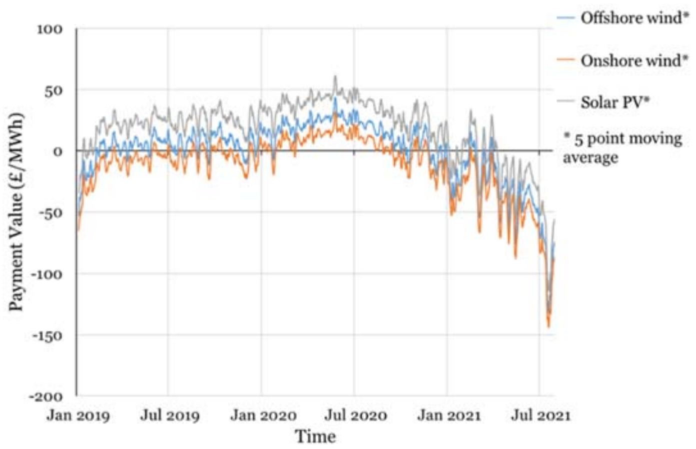


Figure 23 - Hypothetical payment profile for offshore & onshore wind, and solar PV under a two-way CfD mechanism

This figure highlights that a CfD mechanism provides protection from market volatility. It in essence provides stability for investors and generators as they have a guaranteed price for energy produced over the contract lifespan. Likewise, regulators know what the cost of energy is going to be for the contract lifespan and there is no opportunity to get into a negative cost of production. So, the risk is shared more evenly between the regulator and the generators, indicating that this is more equitable for society.

6.8 High Electrification Scenario, LCOE and a Cost per Capita

In this section the high electrification scenario, from the Department for the Economy 'Energy Transition Model' (ETM) for the Northern Ireland Energy Strategy was used to estimate a total cost of energy in terms of 1) per MWh, 2) per capita and 3) per number of electrical connections for 2018, 2030, 2040 and 2050. This was done by first calculating the cost of generation per MWh for each of the technologies. Then taking the cost of energy and the projected energy mix, a weighted average cost of energy in £/MWh was estimated as shown in Figure 24. The capita figures were taken from population data projections from the Northern Ireland Statistics and Research Agency [300] and the connections were taken from data provided from the Utility Regulator [301]. The cost of generation is shown by the changing value of the weighted average LCOE over time in Figure 24.

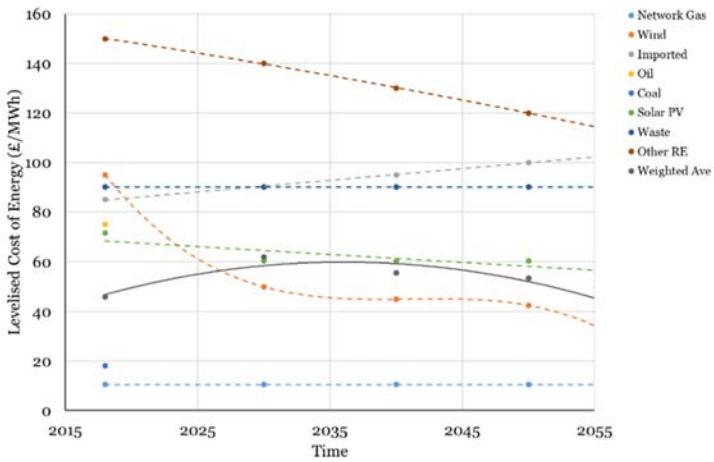


Figure 24 - Cost of energy per MWh for energy mix scenarios 2018 to 2050

The outputs from this analysis are shown in Table 9. The caveat here is that the impact of market support schemes are the 'unknown unknowns' in this consumer cost estimation, as the focus is the generation mix portfolio transition. But it should be remembered that the total generation mix cost per MW decreases over the same period, as the cashflow changes in the electricity market. Other costs such as distribution/transmission costs, unknown fuel costs and increases in the cost of equipment/salaries are not included in this estimate. These calculations also do not include subsidies so we can reflect the absolute cost. What this analysis determines is the direct costs arising from the introduction of new technologies to change the generation mix in today's money projected into the future in 2030, 2040 and 2050.

Table 9 - Total Generation costs and costs per capita in 2018, 2030, 2040, and 2050

	2018 Gen Cost (£)	2030 Gen Cost (£)	2040 Gen Cost (£)	2050 Gen Cost (£)
TOTAL (millions)	409.4	583.06	641.07	750.83
TOTAL per MWh	45.88	62.01	55.58	53.43
TOTAL per capita	217.19	299	325.42	377.3
Northern Ireland Population [315]	1,885,000	1,950,000	1,970,000	1,990,000
No. of consumers	897,241	897,241	897,241	897,241
Cost per consumer	456.29	649.83	714.49	836.82
Retail Cost per consumer	593.18	844.79	928.84	1087.87

7.0 Discussion and Conclusions

This research report reviewed and assessed possible support scheme options to incentivise renewable investment in Northern Ireland for power generation. It was prepared in tandem with other work being undertaken by the Department for the Economy's to inform Northern Ireland's new Energy Strategy, and as such, contributes to the evidence base for Northern Ireland's new Energy Strategy. The overarching policy used to direct this study was the UK's Climate Act 2008 and the Climate Change legislation currently under consideration in the Assembly. The study focused on power generation specifically, other energy sources, vectors and sectors such as hydrogen, ammonia, biogas for transport and heating were not included.

The research involved three main elements, 1) a review of the suitability of renewable power generation technologies for Northern Ireland as support schemes options are integrally linked to technology readiness levels and maturity, 2) an appraisal of historical and existing support scheme options in GB, the EU, and some high gross domestic product countries, and 3) a Delphi study to capture the expert views and opinions from different organisations in industry, government and non-government organisations. Next, three analytical approaches were used to inform the study's keyfindings and recommendations. These were a SWOT analysis, a Pugh matrix analysis and LCOE analysis to assess the feasibility of implementing the power generating technologies and support scheme options in Northern Ireland. The LCOE financial model compared the economic competitiveness of the different power generating technologies and associated support scheme options.

The technologies examined to enable Northern Ireland's net zero transition by 2050 were agreed with the Renewable Electricity Branch at the Department for the Economy. They included AD, CCGT, OGCT, CCUS, energy storage (i.e., batteries, and compressed air energy storage), geothermal, hydropower, nuclear power, solar PV, onshore and offshore wind, as well as tidal and wave energy. Four groups of incentives schemes were examined in the analyses. These schemes were identified based on the best available published information as part of the state-of-the-art desktop study. These were 1) CPM, CfD, and Export Guarantee, 2) FiT and FiP, 3) GC and ROC and 4) investment bonds, loans, grants, and tax incentives. Gas was included in the analyses in light of recent grid security concerns in power systems with high renewable penetrations.

The generation portfolio mix LCOE calculations, based on the analyses using the high electrification scenario from Northern Ireland Department for the Economy data, shows that between 2030 and 2040 the average LCOE for the generation mix rises but then falls from 2040 to 2050. However, due to the expected increase in electricity consumption between 2040 and 2050, driven by increasing electrification and by the introduction of infrastructure like data centres, the cost per capita actually increases. While costs generally are trending downwards, there are significant differences in the LCOE from varying renewable energy sources. Additionally, integration costs can differ due to the changing levels of ancillary services to maintain grid stability. These differences are primarily driven by upfront capital expenditures, but the utilisation and availability of a particular technology is a strong determinate for LCOE. For example, the typical offshore wind capacity factor is in the range of 40-50 % with up to 63% claimed by General Electric for the new Halide-X 12 MW turbine [302]. An increase of capacity factor from 50 to 63% would decrease LCOE by approximately 20%. Advancements like this in already established technologies can lead to market dominance by single technologies if short term cost effectiveness is the only criteria whereby a technology is developed. New technologies which may have the potential to be cost effective in the longer term will need additional support to get established.

Capacity payments are a way to keep dispatchable energy available to improve energy security where grid penetration of variable renewable energy sources is high. In real terms these payments act like a CfD for fossil fuels where during periods of low demand and low prices generators are going to get paid for being available, then during periods of high demand and high costs they will be creating revenue from the sale of energy. Capacity payments are a potential revenue source for infrastructure with large uninterruptible power supplies installed whereby during times where grid frequency or demand becomes an issue these supplies could be used to feed energy back onto the grid. Uninterruptible power supplies are common in datacentres, hospitals and many other large buildings [303].

Based on the results of the SWOT analysis, the Pugh matrix analysis and the LCOE financial modelling of the fixed rate one way payment schemes (i.e, tax/investment bond, FiT/FiP scheme and GCs/ROCs) and the two-way variable CfD scheme showed that the CfD scheme is the most equitable for society because it shares the investment risk more evenly between the regulator and the generator. The CfD mechanism provides protection from market volatility. It in essence provides stability for investors and generators as they have a guaranteed price for energy produced over the contract lifespan. Likewise, regulators know what the cost of energy is going to be for the contract lifespan and there is no opportunity to get into a negative cost of production. The analysis also highlighted that the do nothing scenario is the most costly. In addition, in a do nothing scenario there is no guarantee that the market will follow the least emissions pathway without clear direction meaning carbon cost and net zero by 2050 targets uncertainty risks in the market. This uncertainty may also stall investment in the market. Initially this transition will add costs to the 'system' which will ultimately be borne by the consumer. However, the cost is not as dramatic in wholesale market terms as it first appears, if one considers that retail electricity market prices in Northern Ireland are approximately a third of the total retail costs. Whether any support schemes are paid through levies added to bills, increases in wholesale prices or in the form of direct government support in for example tax incentives, there will be an increase to energy bills. Energy prices have always seen an upward trend over the long term, in line with the cost of living typically, however, there have been occasions where dips, drops and spikes have occurred due to sudden economic shocks (e.g., Wall Street Crash, Covid19 etc.). The current reliance on fossil fuel generation and the projected increase in both population [300] and the energy usage per capita means that the carbon intensity of Northern Ireland electricity generation mix must reduce to meet the national net zero targets. To facilitate this transition, grid penetration of existing renewable energy resources will need to continue to increase, and new technologies will need to be introduced, but in the context of a strong pragmatic regulatory framework.

Wholesale prices in the ISEM, BETTA, and across the EU have shown significant volatility in the past 3 years with the SEM dropping to €23/MWh in May 2020, climbing to €143/MWh in July 2021, and more recently in September 2021 €402.41 during a period of low wind which coincided with a number of gas plants being offline [298]. Any significant development in energy generation will need shielding from this volatility, and out of market payments and divesting from gas too soon are not a solution [260]. The likely trend for the wholesale market price over the medium to longer term is to increase at least in line with inflation and volatility is still likely. Contract for Difference mechanisms can provide protection from market volatility. Costs reductions in more mature technologies are likely to slow due to diminishing returns and the LCOE will stabilise, with cost of energy reductions for more mature technologies likely to come in the form of capacity factor increases. Lower TRL technologies such as wave and tidal are likely to see significant cost of installation reductions in the future combined with increases in capacity factors. These technologies could attract different types of investors, with investors seeking lower risk and willing to take lower returns tending towards more mature technologies like wind and solar while tidal and wind could potentially be options for investors seeking higher risk and returns.

The ISEM is specifically referred to in the Northern Ireland Protocol [179] which states that it will be protected and not directly affected by Britain leaving the EU. However indirectly, with Northern Ireland outside the BETTA and part of the EU single market and regulations, developers working in GB maybe reluctant to take on projects based in Northern Ireland that will feed the SEM and not the BETTA. This could lead to scenarios where Northern Ireland projects fail to get developed if Northern Ireland were to join the GB CfD scheme. A consultation of CfD performance and future direction in GB has recently been concluded, with the process identifying some opportunities for improvement. This consultation concludes that without support mechanisms many renewable energy projects would not be viable and that CfD schemes specifically have enabled faster roll out while delivering lower costs for consumers [304].

The Low Carbon Contracts Company (LCCC) has projected customer levy charges, will rise from £6.20/MWh in 2022 rising to a mean of £10.86/MWh by April 2022 [305]. It must also be noted that in the longer term as technologies mature and costs reduce this impact is likely to reduce and this is shown in our projections. There is no such thing as free energy, and careful management of the net zero transition message to the consumer, the media and the decision makers is critical. In essence everybody in society must play their part in the net zero transition. Ultimately a PESTEL analysis (i.e., political, economic, social, technological, environmental, legal) with a cost benefit analysis (COBA) of the whole energy system across sectors is required to compares savings and efficiencies across the three pillars or three 'E's' of sustainability. This should support and inform better decision making when pitting economics, energy security, the net zero transition and the public good against each other in order to achieve the so-called just transition. Public views on support scheme mechanisms are affected by public debate and discourse in the media and on social media, but often there is a lack of understandings. So, as aptly pointed out in the DELPHI survey of experts, "*society would need to understand the costs, risks, benefits, fairness and control or any energy support schemes and or subsidies given*." Therefore, a 3E-COBA with a PESTEL is very important to put the context, challenges and tough decisions in context for all.

An added uncertainty and often underestimated complex dimension by those at the coal face of the power system is that the traditional paradigm of centralised 'electricity' generation is currently transitioning towards a future where a decentralised 'energy' infrastructure is prevalent across the transmission and distribution system. New investors from the ICT sector, not normally associated with power generation are offering technologies at different levels in the grid (e.g., smart meters, electric storage heaters, electric hot water tanks, electric heat pumps, smart appliances etc.). Some of these may have deep pockets and may force unforeseen changes due to unregulated customer aspects in the retail electricity market. This is a weak point in the regulatory management of the power system. These influences are to an extent regulated in the wholesale electricity market through for example the DS3 services. However, caution and foresight are needed when considering the interaction of the wholesale and retail markets. Currently, this is overlooked by wholesale markets although the research suggests that governments and industry organisations recognise the need to plan for different market configurations.

The electrification of transportation, especially in the private passenger car sector will challenge the stability of the distribution grid. Grid upgrades at the distribution level lack a business proposition currently for smart technology deployment, resulting in uncertainty for the consumer. At the moment this is not an issue because the automotive sector is struggling due to the Covid19 pandemic to produce units. There is also reluctance by the consumer to transition to EVs until they see better infrastructure, a second-hand market to trade into and an understanding of the actual charging payment processes. On a positive note, any delays to EV technology deployment in Northern Ireland may not be as harshly felt as in ROI because car sales in Northern Ireland are more dependent on the second-hand GB market so this natural lag will soften the effects of slow EV uptake and the need for charging points on the grid. However, this may affect emissions reductions targets in transport. Again, this highlights the sectoral interactions of the whole energy system.

Power system security with high penetration of renewables is a concern, and grid inertia is key. The inherent variable nature of some renewable technologies (i.e., wind turbines and solar PV) and their non-synchronous characteristics have negative dynamic effects on the grid. This is currently managed through DS3 and out of market payments, a trend that is repeated across GB and Europe [260]. Heavy dependency on ancillary services for energy balancing, frequency regulation, voltage support, constraint management, and reserves is a risky grid and market operations strategy. It needs very careful oversight and management as it adds administrative burden, could be potentially viewed as lacking transparency and cannibalises transactions through regular market clearing (i.e., SEM). It is therefore clear that any support scheme options must consider Northern Ireland's future generation portfolio mix, the level of administration and oversight required and also the 'unknown' influences when selecting the appropriate support scheme options to incentivise renewable power generation investment in Northern Ireland.

Real time management and administration of any support scheme is critical. These schemes are typically overseen and monitored over the short-, medium, and long-term because wholesale electricity prices have historically fluctuated depending on generation technology supply prices, weather events, fossil fuel prices, currency fluctuations and other electricity security issues related to operations and levels of renewable generation and certain fossil plants being offline for maintenance. The CfD scheme in GB is monitored and reviewed regularly in an attempt to avoid unexpected spikes and imbalance in the risk sharing, two examples from this process were the non-delivery disincentive [306] and the 'Contracts for Difference for Low Carbon Electricity Generation Government response to consultation on changes to Supply Chain Plans and the CfD contract' [307].

Of course, there are a number of limitations and caveats to this study. These include the snapshot aspect of the analyses, BREXIT considerations, the SEM development into the future, unknown market conditions, such as the price of gas, the state of the economy, the price of sterling, inflation, even weather conditions into the future, energy demand, the effect of TRL on the cost of technology, new market entrants, the real cost of grid upgrades and new infrastructure costs. There are also deployment challenges related to booking and shipping of vessels in the case of offshore renewables, factories, and even gas, plus also the human resources such as engineers, scientists, and technicians. It should also be noted that energy modelling is not infallible when there are so many unknowns, however, energy modelling provides useful directions, guidance, and what ifs. Irrespective a clear support scheme strategy is needed during the net zero transition, but within that, the analyses to underpin the support scheme strategy need regular benchmarking against the changing modelling conditions and constraints. To conclude, in the absence of a clear market framework historically, the result is 1) least cost technologies tend to be the winner, 2) companies sweat assets, and avoid investment when there is uncertainty, and 3) emergency generation is typically made-up by contract gas peaking plant. Therefore, following careful examination of all the various support schemes, it is recommended that a CfD (Northern Ireland Pot) scheme is implemented because it is more equitable for society as it spreads the investment risk between the generators and the regulator and also reduces market volatility.

7.1 Key Findings and Recommendations

The five key findings of the research study are summarised as follows:

- Technologies were quantitatively assessed utilising a Pugh matrix analysis, which was informed by the qualitative SWOT analysis based on technology readiness level (TRL) and lifecycle analysis (LCA). The technologies ranked onshore wind with the highest score, and CCGT, energy storage, hydro, and OCGT in joint second. Tidal energy had the lowest score, and wave energy had the second lowest score.
- Similar to the technology assessment, support scheme options were quantitatively assessed using a Pugh matrix, which was informed by the qualitative SWOT analysis. The results of the Pugh matrix analysis rated the schemes as follows; CfD scheme (Northern Ireland Pot), CfD (Separate Northern Ireland based scheme), FiP, FiT, GC and investment loans and grants all had the joint highest score. Whereas CfD (GB scheme) and export guarantees came in joint second. Overall CPM had the lowest score, and tax incentives had the second lowest score.
- It is important to consider the power system landscape when selecting the optimum support scheme to incentivise and support renewable power generation investment in Northern Ireland. The power system landscape is being challenged by many 'known knowns' and 'unknown knowns' such as a) fossil fuel divestment resulting in capacity shortfalls, b) network congestion, constraints, and operational requirements, c) regulatory and market uncertainty, d) global fossil fuel and technology price fluctuations, e) the pace of technology developments, f) decentralised 'energy' infrastructure impacting the interaction of the wholesale and the retail electricity markets, g) electrification of transportation as industry and policy makers strive to reduce emissions.
- A Delphi study was completed as part of this research report. A total of 27 energy system experts responded and provided their opinions and insights towards support scheme options and technologies which support a net zero carbon future. The questionnaire comprised of 21 multiple-choice, rating scales and open-ended questions. The results show that solar, onshore and offshore wind, energy storage, and biogas are seen as the most viable technologies to reach 2050 net zero targets. The experts identified a) green hydrogen with OCGT and CCGT, b) demand side management, c) geothermal for heat, d) smart metering and appliances, e) other sector efficiencies (e.g., building, transport, manufacturing and agriculture), f) an all-island approach, g) community, industry and local authority participation, h) increased research and development, i) PPA, and j) stronger interconnector as having a role to play too. They also identified a) energy poverty, b) nimbyism, c) lack of media, public and political understanding, d) financial risk, e) grid, planning consent, environmental and regulatory bottlenecks, f) supply chain issues, g) regulatory oversight, and h) price cannibalisation by some technologies as the challenges they face. Overall, they recognised that there is no silver bullet solution to reach net zero targets by 2050.
- An LCOE financial model was built to assess the feasibility of implementing the power generating technologies and support scheme options in Northern Ireland. This analysis was informed by a significant desktop study of technology maturity, development and suitability for Northern Ireland and support scheme mechanisms. The analysis is based on a high electrification scenario for Northern Ireland supplied by the Department for the Economy. The results show that between 2030 and 2040 the average LCOE for the generation portfolio rises but then falls from 2040 to 2050. This is due to initial high costs followed by cost reductions in technology primarily linked to TRL. In addition, the budgetary make-up of the overall market costs change. Although the cost per capita increases this is due to expected increases in electricity consumption between 2040 and 2050, driven by increasing demand from data centres, and electric vehicles, and not the change in the generation portfolio. The caveat in the analysis is the impact of market supports schemes on each other are the 'unknown unknowns' in this consumer cost estimation, as the focus is the generation mix portfolio transition. A 'do-nothing' is the lowest cost scenario, but it will lead to

increased market volatility, and huge uncertainty in achieving net zero targets and a knock-impact across other sectors in terms of carbon costs.

The five key recommendations are summarised as follows;

- Energy system security is driven by the generation portfolio and reserve generation, and this impacts market dynamics. It not only affects wholesale market prices per MW, but retail market price per kW. Overreliance on out of market payments and ad hoc generation acquired to plug generation shortfalls needs to be addressed as market stability is founded on strong industry participation, and customer engagement. But this only happens when the regulatory, operational and network conditions are robust and well understood. Currently grid capacity is assessed annually on a rolling 9-year window. This is insufficient as targets for net zero are driven by 2050 targets. In essence energy security is pitched against total electricity system costs, but these are not included in the annual grid capacity analysis as the focus is demand. The way to address this cost and security challenge is to undertake an in-depth analysis in the form of a 3E-COBA at least every five years to track progress to 2050.
- A PESTEL analysis in tandem with the 3E-COBA of the whole energy system across the different energy sectors is required to compare savings and efficiencies across the three pillars of sustainability (i.e., social equity, environment and economics). This should take into account the social, legal and political context and facilitate an equitable just transition to net zero by 2050.
- The generation portfolio mix has been in essence decided, namely wind, and solar with storage, but gas needs to play a significant role during the transition period. This is not fully recognised in the regulatory framework. It is not secure or sustainable to have electricity shortfalls bridged every five or six years by emergency gas generation as it increases market volatility. Scrapping and mothballing[14] plans leads to further uncertainty and are only short-term solutions. The only way to address this is by being pragmatic during the transition period and agreeing that new gas generation is required urgently.
- This work examined the most common support scheme mechanisms in the LCOE analysis. It was clear that the most appropriate scheme for Northern Ireland is a CfD scheme because based on the results of the SWOT analysis, the Pugh matrix analysis and the LCOE financial modelling it is more equitable for society as it spreads the investment risk between the generators and the regulator and also reduces market volatility. Establishing a Northern Ireland CfD scheme could use expertise and experience that already exists in the BETTA to set up, operate and administer. It could be set-up as a Northern Ireland 'pot' in the UK rounds.
- Finally, regular analysis of LCOE in conjunction with the wholesale electricity market reference price in a unit commitment model is required in order to monitor and manage any support schemes in real time to avoid over payment or underpayment of any schemes as we transition to net zero by 2050. This will permit continual updating and monitoring of emissions, costs, technology impact and grid security to prioritise targeted resources and minimise societal impacts, and disruptions.

[14] In power systems plant are either **scrapped or mothballed**. If scrapped they are in essence demolished and any equipped recycled or landfilled, whereas in mothballing a plant is laid-up to prevent corrosive damage and ensure the preservation of various assets.

Appendix A - Strengths, Weaknesses, Opportunities, and Threats Analysis

Table 10 - Technology SWOT analysis (Specific for Northern Ireland)

Options	Strengths	Weaknesses	Opportunities	Threats
AD & Biogas	- Heat and electricity can be generated onsite for the agricultural sector - Circular economy, recycles farm and water waste by-products	- High-level of investment required for installation and operation - Micro-organism cultures require operational attention	- Smaller-scale AD in development, increasing opportunity for wide-spread deployment	-Some environmental concerns regarding odour if ran inefficiently. - High land use required
Biomass	-Multi-use, used for heat, AD or can be converted for use in transportation. - Can be grown in a relatively short time	-Burning biomass creates air pollution. - Can lead to deforestation. -High land use required	-Widely available. -Additional revenue for agricultural industry	-Bio-fuels derived from biomass are typically not as efficient as fossil fuels. -Can compete with food supply.
CCUS	-Can be retrofitted to existing electricity generation plants	-Emerging technology, thus incurs high cost for implementation and further research and development	-Reduce CO_2 emissions from industry processes with no other decarbonisation options	-Extra equipment, energy input and infrastructure required
CCGT	-Mature technology, rapid installation time and low-cost electricity	-Carbon emissions unless fitted with CCS technology	-Development of CCS a potential solution to emissions.	-Development of CCS does not keep pace with decarbonisation targets
Energy Storage	-Counter- balance for systems with a high share of renewables. Flexible and scalable and can provide ancillary services	-Relatively expensive although installation costs falling. Hydro systems only suitable for certain geographic topologies	-Compact battery systems can be installed right down to individual residences	-Lithium supply, degradation, and subsequent re-use of exhausted battery packs
Geothermal	- Reduces financial risk as ensures a return in investment over a fixed number of years -Can work as a heat source on a small scale for domestic properties	-Geographical stability in Northern Ireland means installation will need to be the more costly binary system for large scale projects	-Potential source of stable non-variable energy	-Can be costly over time, especially if adjusted for inflation
Hydro	-Low operational cost hydro stations need little maintenance, so they're cheaper to manage than other types of power station -Pumped hydro offers a flexible and reliable source of energy.	-Geographical limitations: hydro stations can only be built where the flow of water is sufficient to run the turbine -Can cause damage to eco system such as fish population. -In most cases there is a requirement for a licence to use the water which can hinder development. -In the case where a dam needs to be constructed, capital costs are high and this can cause further damage to the surrounding eco system	-Hydropower plants can generate power to the grid immediately, therefore they provide essential backup power during major electricity outages or disruptions -Providing flood control	-Global warming could lead to a reduction in the volume of water flowing down rivers and streams
Offshore Wind	-Wind is a source of clean and sustainable energy. -Wind power cost reduction via technology, supply chain and finance. -Synergies with other industry sectors (e.g., manufacturing, transportation and professional services) -Large economic benefits: creating jobs	-Geographical Limitation: due to the availability of wind -Intermittency High Initial Investment and costs. -High energy cost. -Risk associated with TRL maturity (for floating)	-Low CO_2 for energy production -NI has large engineering fabrication capability -Technology Advancement: As a result of technological advancement and economies of scale, the cost of renewable energy technologies has decreased from time to time	-Material price inflation, especially in the cost of steel & rare earth minerals -Nimbyism by certain members of the public for selfish reasons

	-Large installed capacity and requires -Less Space compared to other renewable sources (e.g., Solar PV) -Northern Ireland is relatively small land mass with significant coastline and multiple ports			
Onshore Wind	-Wind is a source of clean and sustainable energy. -Wind power cost reduction via technology, supply chain and finance. -Synergies with other industry sectors (e.g., manufacturing, transportation and professional services) -Large economic benefits: creating jobs -Large installed capacity and requires -Less Space compared to other renewable sources (e.g., Solar PV)	-Geographical Limitation: due to the availability of wind -Intermittency -High Initial Investment and costs -High energy cost -High market concentration and lack of varied competition in the supply chain	-Environmental degradation and fossil fuel depletion have prompted governmental and non-governmental organisations to focus on renewable energy sources such as wind, solar, biomass, and other renewable energy sources. As a result, the government's and non-governmental organisations' push to replace fossil fuels with renewable energy sources -Technology Advancement: As a result of technological advancement and economies of scale, the cost of renewable energy technologies has decreased from time to time	-Cognisance of fossil fuel technologies that have been main source of power generation over the last few centuries. These well-established existing technologies create barriers switch from conventional to wind power as a source of energy. -Endanger the wildlife -Nimbyism by certain members of the public for selfish reasons
OCGT	-Mature technology, rapid start, and flexible operation plus portability	-High LCOE due to low running hours and high installation costs	-If running hours can be kept low coupled with a carbon offset scheme, then the flexible opportunity supports renewable generation	-High LCOE reduces competitiveness and makes investment less attractive
Solar PV	-Limitless: Solar energy comes from the sun and is one of the most abundant sources of free energy on the planet -Environmental Friendly: The energy from the sun is collected and stored to generate electricity -Ease of usage/harvest: Solar energy is typically gathered by solar panels, which use photovoltaic technology to generate electricity -Less overall cost: Once solar system is installed the running cost is very low	-Available only during day time. -Efficiency is low -Large space is required -High initial cost	-Create New Business Opportunities -Increase Concerns in Using Fossil Fuels and Nuclear Energy -Availability of Subsidy and Support. -Cost Reduction	-Health risks -High carbon footprint: A carbon footprint is defined as the entire amount of GHG produced during the production of a product, either directly or indirectly -Acquaintance with Fossil Fuels: Because most electric power producing plants are intended to use fossil fuels as a source of fuel, switching to solar energy will come at a great cost to businesses and governments
Tidal & Wave	-Limits coastal erosion. -Because water is so dense, tidal power plants can generate a lot of energy even at low speeds -Abundant and widely available resource	-High capital costs -Maintenance can be difficult on an existing system -Limited data of project lifespan -Geographical limitations	-As the technology matures the costs will decrease -Could aid grid stability as ocean energy is much more reliable than wind and solar -Create new business opportunities	-Environmental concerns over the effect on sea life -Underwater noise pollution -Support and funding for research in order to develop new technology

Table 11 - Support Scheme SWOT analysis (Specific for Northern Ireland)

Options	Strengths	Weaknesses	Opportunities	Threats
Business as usual	-Little impact on electricity prices. Perception by customer base that environmental targets are being met	-No potential mechanisms will exist to effect change and current renewable generation levels will remain static	-Organic growth of renewable generation using existing schemes may occur with minimum disruption	-Fossil fuelled generation will continue to dominate the market and opportunity for change will be lost
CPM	-Removes generator exposure to wholesale prices but does not guarantee income for power sales	-May unfairly supports certain mature fossil fuel technologies.	-Provides a guaranteed revenue for dispatchable renewable generation	-Provides a "lifeline" for fossil fuel generation and potentially blocking developing renewable technologies
CfD GB scheme	-Provides a guaranteed revenue for diverse renewable generation over a large market	-The cost of the scheme is passed on to customers causing an increase in electricity prices	-Auction scheme is designed to assist developing technologies become established	-Scheme need careful management and administration to prevent single technology dominance
CfD (Northern Ireland pot)	-Enables Northern Ireland to expand renewable generation to directly affect Northern Ireland environmental targets	-Reduced customer base therefore less opportunity to widely socialise costs resulting in higher electricity prices -The 'pot' structure bands technologies together unfairly giving them market advantage	-Amalgamation of scheme with ROI widens the cost recovery base with SEM the common denominator	-Political friction between Northern Ireland Assembly and UK central government over funding of scheme
CfD (separate Northern Ireland scheme)	-Reduced financial risk as it ensures a guaranteed return on investment over a set period of time	-Results in cumbersome public service charges which are passed on to the consumers	-Allows Northern Ireland to tailor the scheme to suit their own energy requirements	-UK developers may not want to bid into SEM auctions meaning less development in large scale renewables in Northern Ireland
Export Guarantees	-Offers a route to market which supports small scale low-carbon generation of electricity Lowers costs for consumers	-Export tariff is provided by the energy supplier, but no minimum price exists and no long term certainty beyond 12 months	-Supports local and national job creation if implemented correctly. Incentivises consumer behaviour that enables the efficient management of the grid	-Export data relies on the use of smart meters which have potential issues
FiP	-Developers rewarded well during market increases. Suits dispatchable generation such as biomass and geothermal	-Developers run the risk of poor returns when the market collapses. Less suitable for small scale generators due to risk of poor return.	-With FIP there is an incentive to produce when the demand is high thus encouraging integration of renewables	-Greater investment risk. Not particularly suitable for variable generation like wind and solar.
FiT	-Encourages business model innovation and diversification of energy supply Decreases grid demand -Benefits different socioeconomic groups due to small, micro and macro payments	-Does not provide any incentive for renewable energy operators to respond to price signals of the electricity market	-Encourages more community level sustainable energy projects	-Mixed effects on technological progression -Installed capacity of wind for example has increased compared to hydro which has decreased as a result of digression
Green Certificates, ROC	-Flexible and tradable -Enable more profit and less risk for some technologies -Enable a faster GHG emissions reduction pathway -Enables society to transition to a net zero economy faster and at a larger scale -Supports local and national job creation if implemented correctly -Banding to support less developed technologies	-Results in cumbersome public service charges passed to consumers -The value fluctuates with the market -The value fluctuates with time -Create more unnecessary out of market payments with an associated administrative and regulatory burden -Technical and legal issues must be monitored robustly and revised effectively to	-Could build on and improve existing schemes	-If rates are not set correctly, then it can cause a negative cost of energy -Owners receive payments for each kWh of energy produced whether they use it or not -Place an inequitable financial burden on society if used inappropriately by industry -Enables society to transition to a net zero economy, but is more fragmented

	-Enables community type sustainable energy projects -Enables a more dynamic energy market with more participants at different levels	ensure equity for all parties -Enables society to transition to a net zero economy, but is more fragmented		-Fragments the market and creates additional administrative burden for grid operators and regulators -Fragments the market and creates additional administrative burden for grid operators and regulators -Open to manipulation due to institutional lack of transparency
Investment Bonds, Loans & Grants	-Provides low interest liquidity and potential revenue stream for regulator/government -Enable a faster GHG emissions reduction pathway -Enables society to transition to a net zero economy faster and at a larger scale -Supports local and national job creation if implemented correctly -Banding to support less developed technologies	-Does not impact whole sale fluctuations -Technical and legal issues must be monitored robustly and revised effectively to ensure equity for all parties	-Potential income stream for government -Stimulate the economy and create jobs -Society invests in their future and the net zero transition via pension funds etc. -Enables society to transition to a net zero economy, but it is less transparent and open to green washing	-Defaults on repayments -No guarantee that manufacturing jobs will be created locally and or nationally
Tax Incentives	-Decreases LCOE -Enable a faster GHG emissions reduction pathway -Enables society to transition to a net zero economy faster and at a larger scale -Supports local and national job creation if implemented correctly -Banding to support less developed technologies	-Tax incentives need careful regulatory control and monitoring -Technical and legal issues must be monitored robustly and revised effectively to ensure equity for all parties	-Stimulate the economy and create jobs	-Tax deficit must be 'made-up' by tax hikes from other parts of the economy -Tax differentials introduce economic bubbles and distortions -Skew the wholesale electricity markets resulting in retail price volatility -Can produce abusive tax avoidance -Open to manipulation due to institutional lack of transparency

Appendix B - Pugh Matrix Technological Comparison

Table 12 - Technology Pugh Matrix (Specific for Northern Ireland)

		Baseline	AD & Biogas	Biomass	CCUS	CCGT	Energy Storage	Geothermal	Hydro	Offshore Wind	Onshore Wind	OCGT	Solar PV	Tidal	Wave
Criteria	Carbon reduction	0	0	1	1	-1	1	1	1	1	1	-1	1	1	1
	Impact on consumer bills	0	-1	-1	-1	0	-1	-1	-1	-1	-1	0	-1	-1	-1
	LCOE	0	-1	-1	-1	1	-1	-1	1	0	1	1	-1	-1	-1
	Net present value or return on investment	0	-1	-1	-1	1	-1	-1	1	-1	1	1	-1	-1	-1
	Public acceptance	0	1	1	1	-1	1	1	-1	1	0	-1	1	0	1
	Risk to generator	0	0	-1	0	-1	1	0	-1	1	1	-1	1	-1	-1
	Risk to government	0	0	0	-1	0	0	-1	0	-1	0	0	0	-1	-1
	SNSP	0	-1	-1	-1	-1	1	-1	-1	1	1	-1	1	1	1
	Supply risk to supplier/consumer	0	1	1	1	1	1	1	1	-1	-1	1	-1	-1	-1
	Whole System Energy cost	0	-1	-1	-1	0	-1	-1	-1	-1	-1	0	-1	-1	-1
	Total	0	-2	-2	-2	0	0	-2	0	-2	1	0	-2	-6	-5

Table 13 - Support scheme Pugh Matrix (Specific for Northern Ireland)

		Baseline	CPM	CfD (GB Scheme)	CfD (Northern Ireland Pot)	CfD (separate Northern Ireland scheme)	Export Guarantees	FiP	FiT	Green Certificates, ROCs	Investment Bonds, Loans & Grants	Tax Incentives
Criteria	Carbon reduction	0	-1	1	1	1	1	1	1	1	1	1
	Contract length	0	-1	1	1	1	-1	0	0	1	0	0
	Cost to government	0	1	1	1	1	1	1	1	1	-1	-1
	Impact on consumer bills	0	-1	-1	-1	-1	0	-1	-1	-1	1	1
	LCOE	0	-1	1	1	1	1	1	1	1	1	1
	Net present value or return on investment	0	1	1	1	1	1	1	1	1	1	1
	Public acceptance	0	-1	-1	-1	-1	0	0	0	-1	1	-1
	Risk to consumer	0	1	-1	-1	-1	-1	-1	-1	-1	0	0
	Risk to generator	0	1	1	1	1	1	1	1	1	1	1
	Risk to government	0	0	0	1	1	0	1	1	1	-1	-1
	Risk to supplier	0	0	0	0	0	0	0	0	0	0	0
	SNSP	0	-1	1	1	1	1	1	1	1	1	1
	Wholesale energy cost	0	1	1	1	1	1	1	1	1	1	1
	Total	0	-1	5	6	6	5	6	6	6	6	4

Appendix C - Levelised Cost of Energy Model

Table 14 - Inputs and assumptions for each technology model

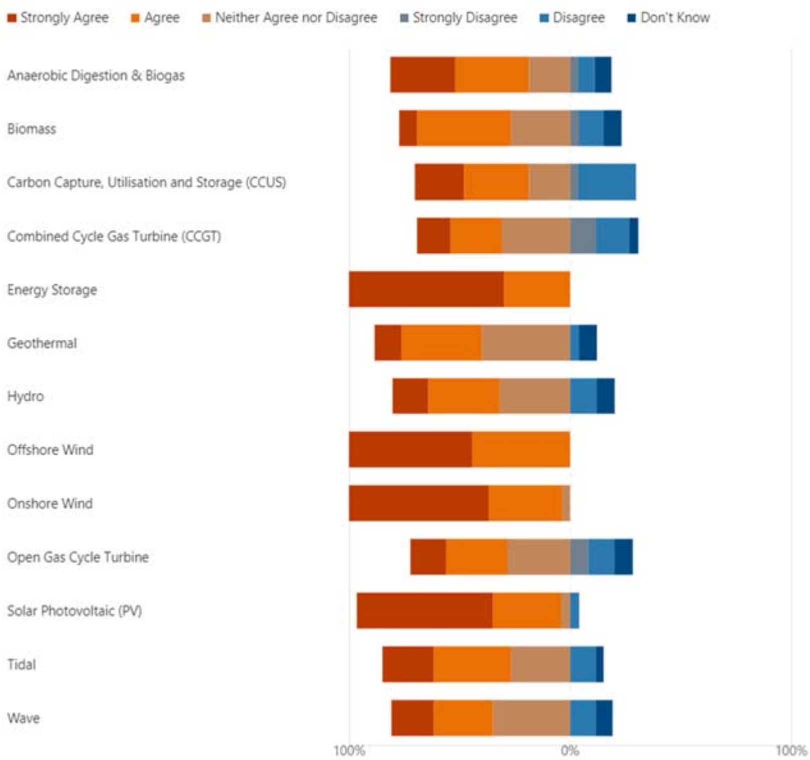
Assumptions	Renewable Technology										
	AD w/ CHP	CCGT	CCGT (with CCS)	Geothermal	Hydro	OCGT	Offshore wind	Onshore wind	Solar PV	Tidal	Wave
Reference plant size (MW)	2	500	500	15	10	300	10	10	16	10	9
Capacity factor (%)	79	93	87	90	45	6	51	34	11	37	30
Total installed cost (£/kW)	4960	623	1425	7133	3460	477	1775	1009	900	4144	4,940
O & M costs (fixed) (£/kW/year)	141	13.1	25.8	86.5	36.50	6.8	92.5	29.2	6.70	150	43.30
O & M costs (variable) (£/MWh/year)	58	4	5	13	9	4	3	6	-	-	26
Insurance (£/MW/year)	57,900	2200	16100	1700	1000	1700	2800	1600	1,900	12700	12,700
Grid connection (£/MW/year)	13,800	3500	3500	13800	8100	2500	56,800	4100	1,600	34500	34,500
Interest rate (%)	11	10.2	10.2	20	5.4	11	7	5.8	6.25	9.5	9.5
Weighted average cost of capital (%)	9.9	9.13	9.13	18.1	4.89	9.96	6.3	5.25	5.6	8.6	8.6
Target Internal Rate of Return	11	10	10	20	5.4	11	7	5.8	6.25	9.5	9.5
Revenue from Digestate (AD only) (£)	25000	-	-	-	-	-	-	-	-	-	-
Revenue from gate fee (AD only) (£)	6000	-	-	-	-	-	-	-	-	-	-
Project lifespan	20	25	25	25	30	25	25	25	30	20	20

Appendix D - Delphi Study

Q1 relates to participation in the DELPHI survey and GDPR.

Q2 is the section where the respondents provide details of the expertise, and organisation.

Q3 Power generating technologies identified as potentially important for Northern Ireland to achieve its 2030 and 2050 net zero carbon targets are listed below. Evaluate each statement.

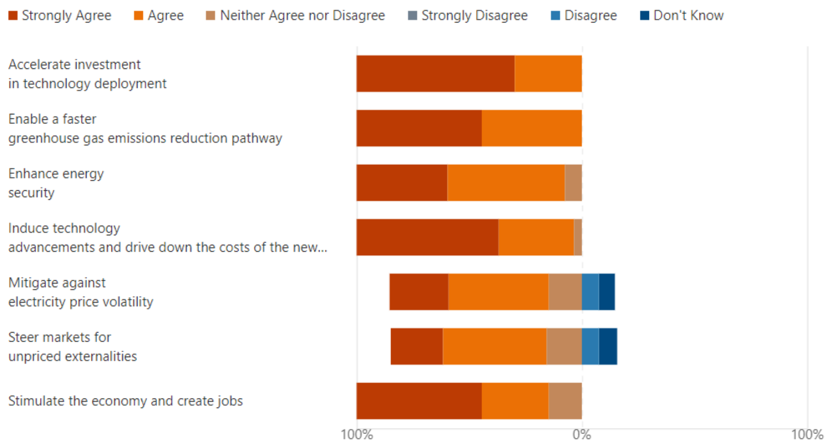


Q4 List and discuss any power generating technologies not provided in Question 3 that are important for the net zero transition.

"Whilst unabated CCGT and OCGT technologies with natural gas as a feedstock might not be required, both technologies fitted with CCUS might be part of the Net Zero solution as well as the potential for low carbon hydrogen as an alternative to natural gas as a feedstock."
"Hydrogen; Compressed-air energy storage (CAES), nuclear"
"Hydrogen fuelled gas turbines, BECCS (Bioenergy with carbon capture and storage), cross border (Republic of Ireland & GB)"
"Hydrogen, while possibly covered under 'storage' will play a significant role. It will be needed to replace CCGT which may play an important role in 2030 but should play no role in 2050."
"Floating offshore wind, Hydrogen, Nuclear"
"Energy reduction, conservation and efficiency need to be much more prominent in this space"
"Hydrogen firing of dispatchable thermal power generation likely to be essential to maintain security of electricity supply through the energy transition. Firing of gas turbines on hydrogen needs to be trialled and developed."
"Green Hydrogen"
"Hydrogen powered gas generation if not covered under the OCGT/CCGT category."
"Artificial photosynthesis, as an emerging technology offers energy production along with carbon capture"
"Hydrogen will play a critical role in achieving a net zero carbon power system. It will very likely replace fossil gas as the primary fuel source for thermal generation on the island of Ireland in the 2030s. There is likely to be a requirement for ~6GW of hydrogen power plants on the island by 2050 according to UCC MaREI's report 'Zero by 50'."
"There is potential to generate electricity from green hydrogen from fuel cell technology or in gas turbines."
"Green Hydrogen to Power and the production of Green Hydrogen should be a strong focus as the technologies involved will enable the removal and replacement of diesel generation and other carbon based energy sources. Also HVDC interconnection between Northern Ireland and Scotland and/or Europe should be considered in detail as this provides a mechanism to balance the power flows on the island and supports security of supply while greatly increasing the ability to export renewable power - hence increasing integration of intermittent renewable energy sources."
"Geothermal (but for heat generation, not power generation). Energy Storage is not a power generating technology, and there are many forms, each of which would merit a different response."
"Hydrogen peaking generation would help significantly in reaching net zero while also providing a use case for H2"

"Interconnection. Synthetic inertia, Interconnection, Fusion (assuming recent technological advances continue at current rates of development). Demand side response. Energy efficiency in domestic heating. Active consumers (marginal effect) Aggregation. Interconnection. Smart device technology in homes and businesses to manage demand. Reactive power supply through smart inverters in onshore wind and solar PV, Interconnection."
"Fuel cells driven by hydrogen is the most efficient way to produce back up power. These units can be distributed on the network and if located in consumers' homes the waste heat can be used to heat the home as well. Biogas may be better directed to heat for industry rather than power gen as the gas network will likely have to go biogas or hydrogen but not a mix in the long term For Energy storage batteries are important for system stability but not suitable at all for longer term powergen, there may be an opportunity for pumped storage or flow battery or compressed air storage in Northern Ireland but I expect for the level needed to replace fossil fuel we would need to store renewable electricity as Hydrogen chemical energy Interconnection technology is not mentioned but will be critical in securing supplies at medium level demand/ medium wind output"
"AD biomethane utilising agriculture feedstock, animal slurries to sustainably produce biomethane and use bio refinery processes to extract and commercialise by products such as bio stimulants and bio actives."
"Potential for CCGT or OCGT utilising hydrogen."
"Hydrogen fuel for OCGT and/or CCGT"
"Floating offshore wind is necessary to meet ambitious offshore wind targets as the resource potential at greater water depths and distances from shore is significantly more than for fixed offshore wind sites. Hydrogen has significant potential as an alternative fuel-of-last-resort, for difficult to abate technologies, and storage device for system flexibility in high renewables energy mix."
"Whilst unabated CCGT and OCGT technologies with natural gas as a feedstock might not be required, both technologies fitted with CCUS might be part of the Net Zero solution as well as the potential for low carbon hydrogen as an alternative to natural gas as a feedstock."

Q5) Energy support schemes and or subsidies can be pursued to achieve specific positive societal policy goals. Evaluate each statement.



Q6) List and describe any positive societal policy goals not stated in Question 5 above.

"Society would need to understand the costs, risks, benefits, fairness and control or any Energy support schemes and or subsidies given the output of the RHI"
"Stimulating the economy and jobs is the consequence of well-designed policy interventions but should probably not be the explicit objective of these."
"Some of these are dependent on other factors e.g. subsidies for fossil do not enable faster GHG emission reductions, in fact will have the opposite effect. Also, CfDs mitigate against price volatility but the NIRO doesn't."
"Unionised and well paid jobs as per International Labor Organization proposals for a just energy transition; improvements in air quality and public health benefits, reducing the burden on the NHS; help provide the policy security for private sector climate/decarbonisation finance and investment; help ensure social support for a just transition by ensuring the poorest do not disproportionately suffer or pay for the energy transition"
"Support schemes normally mitigate risk for investors in required technologies that otherwise may not be viable. Subsidies normally try to steer behaviours that while required wouldn't otherwise be achieved by the market."
"Energy justice and decentralisation of resources. Ownership of energy closer to point of production"
"All subsidies for fossil fuel generation should be removed, and instead repurposed to progress the deployment of renewable electricity generation and hydrogen electrolysers."
"A well designed support scheme can support community development either through specific community pots in schemes or through community benefit funds."
"Supports greater electrification of industry and transport using renewable energy sources. Supports growth of advanced knowledge base of technology solutions in Northern Ireland. Cleaner environment and high level of societal wellbeing when decarbonising energy use."
"Facilitation of community energy activity"
"Decarbonisation of power sector, cleaner air. Community funds for groups near assets"
"Energy support schemes for retrofitting residences are a tool that can help address energy poverty"

"Steering the market for unpriced externalities is better achieved via levies and taxes rather than subsidies; in fact, this type of approach is also best for driving an essential societal policy goal and that is to change customer behaviour both in terms of prioritising their spend and acting efficiently"

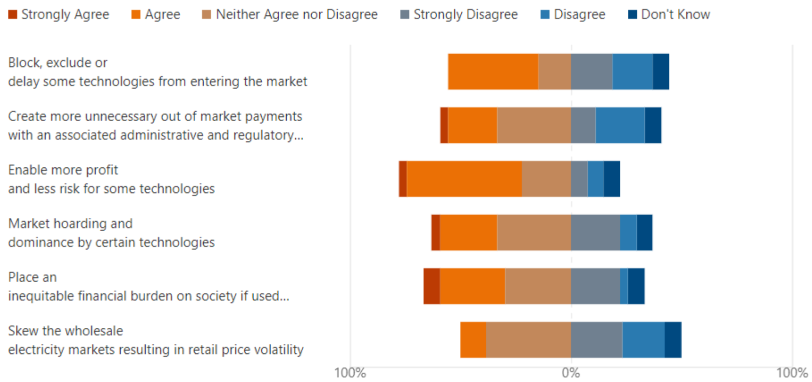
"They can make cheaper, cleaner technologies available to more people who are in fuel poverty and cannot access the capital typically required to avail of green technologies."

"RGFI (Renewable Gas Forum Ireland) in collaboration with key stakeholders in the agri-food and beverages industries have developed a fully integrated business case for AD biomethane & bio refinery. This approach can deliver significant reductions in the hard to decarbonise sectors of heat/thermal demand, agriculture and transport, creating sustainable jobs, rural circular bio economy, for industry delivering key requirements to comply with new regulations, Paris Agreement and sustainable finance, securing future investments, commercial sustainability, and decarbonising Scope 1,2 and 3 emissions. the socio economic benefits are significant with sustainable rural jobs, future proofing the agri-food sector, significantly reducing emissions, improving air and water quality, enhancing soil health with soil carbon sequestration, improving and supporting biodiversity, while displacing and reducing reliance on artificial fertilisers."

"Wider societal and economic benefits associated with creation of a decarbonised economy"

"Focus on the achievement of net zero and decarbonisation of the economy. Introduce an Northern Ireland-specific CfD for emerging offshore technologies."

Q7 Energy support schemes and or subsidies may also result in difficult to manage negative impacts on energy markets that trickle down into society and other parts of the economy. Evaluate each statement.



Q8 List and describe any negative impacts not stated in Question 7 above.

"If the form of price subsidies and protections mean that generation technologies do not face the normal price signals from wholesale energy markets then incentives for individual generators to help meet supply and demand are significantly diluted meaning that inflexible generators may cause flexibility demands and costs on the wider system."

"Bad press eg RHI, mixed messages from MLA's and Gov Departments, length of time to change legislation"

"Can introduce policy/political risk for investors along the whole supply chain if the government is too involved in picking winners (& therefore losers). In GB CfD Scheme this risk is very high and undermines investment in the project pipeline and supply chain."

"A well designed scheme should provide enough support to ensure a technology if commercially viable but not lead to excessive profits at public expense. Also, a support scheme such as CfD provides price stability, certainty for investors and low costs for consumers therefore demonstrates that it isn't a binary choice between generator benefits and consumer benefit."

"Greening of business as usual energy ownership and control, missing out on opportunities to have a more diversified energy system including community and employee owned energy enterprises"

"I think above only really applies to poorly designed or targeted support schemes or subsidies. The point of support schemes and subsidies is to develop or incentivise an outcome that market forces alone cannot. The targeted outcome may be suboptimal though or the scheme badly designed or implemented."

"lead to negative public perception on renewables"

"Focus on maximising financial return from incentives rather than potential for carbon reduction"

"It isn't possible to consider negative impacts in absence of specific examples and knowing the subsidy design. Smart subsidy design can eliminate all of the negative impacts outlined above. Renewable subsidy schemes have progressively become better designed to integrate with existing electricity market structures."

"If the selected support scheme targets specific high positive impact technologies such as offshore wind (fixed and floating); Transmission / Distribution level battery energy storage systems (BESS); Hydrogen solutions; network optimisation solutions; interconnection, then those negative impacts described above will have lower probability of occurring. The design solution is key."

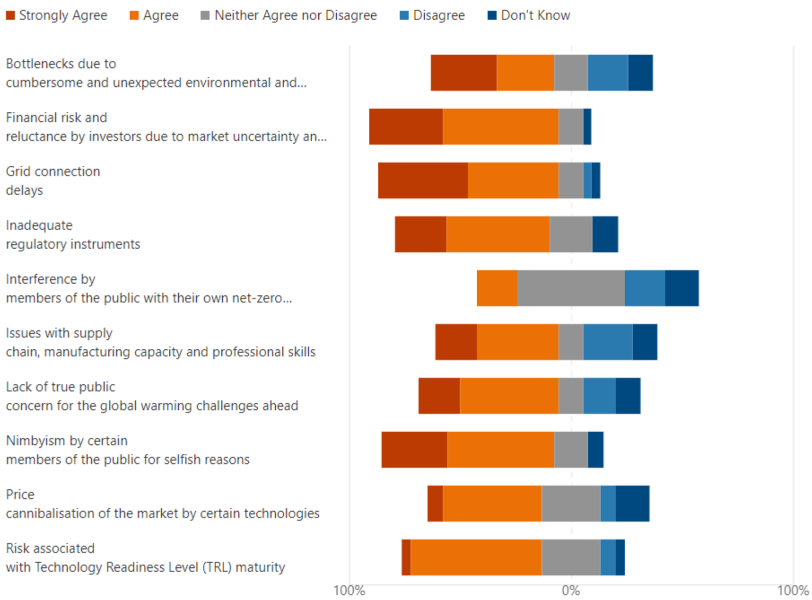
"The negative impacts are not necessarily due to the nature of the scheme itself, but rather how it is administered."

"Having renewables that are subsidised doesn't have to distort the energy markets if both the subsidy and market are designed accordingly. What has happened is that renewables have to be paid on an energy basis while thermal units have to be paid on a fixed €/MW basis. Both technologies are needed, but they should be in different markets. Current market designs are not fit for purpose as it presupposes that because technologies create energy they should be in the same market."

"I think these issues are risks that any scheme can be designed to mitigate. There needs to be protection built into schemes. One of the biggest negative risks is that the cost of energy arises does not all fall at the door of the user of energy e.g. it may appear as a tax cost, this is a negative outcome because it does not drive customers to use energy wisely (e.g. look at

water and sewerage in Northern Ireland; look at litter (the litterer pays nothing personally for the clean-up or environmental damage so there is no incentive to change behaviour); look at the proliferation of rural housing (the householder does not pay any additional costs for the extra roads; water; power infrastructure to connect and supply them)"
"Northern Ireland companies bringing technologies and business models to market will be disadvantaged because other regions/countries have more favourable inducements for adoption in the market. This inhibits the ability of Northern Ireland companies in early stage growth and capital raising."
"socio economic impacts not listed, no benefits to rural economy, impact and abilities to deliver at scale to decarbonise the economy in a balanced and equitable manner"

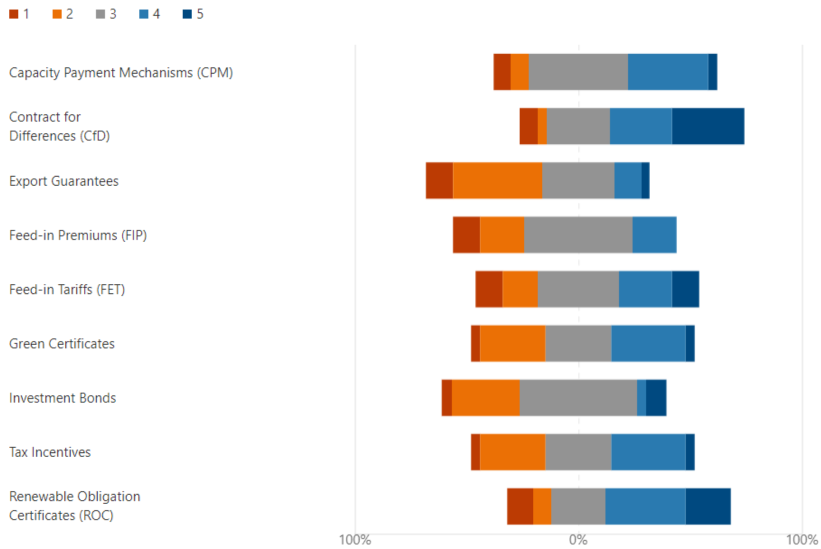
Q9 Barriers to incentivising power generating technology investment in Northern Ireland are identified. Evaluate each statement.



Q10 List and describe any barriers not stated in Question 9 above.

"lack of change in legislation means that regulatory requirements do not keep up."
"Poorly resourced systems e.g. Regulator and Planning System, in particular statutory consultees, which can result in considerable delays."
"NI market too small, need all island frame"
"Ongoing uncertainty in energy policy direction Difficulty of delivering long-term, capital intensive, strategic energy investments under market mechanisms Planning process"
"Lack of cohesive joint up strategy using appropriate technologies and solutions to address energy requirements as ONE joined up plan"
"Public perception of value derived from previous incentives"
"There needs to be more resources put in place across the System Operators, Regulators and Government departments. Resources and the right skillsets is a huge challenge for delivering net zero ambitions."
"Relative consistency in policy and support systems between Northern Ireland and neighbours (Ireland and Scotland) would be beneficial."
"Lack of trusted information for all parties."
"The Corporate PPA market is something that should also be encouraged. A barrier to this success is provision of credit support (from the buyer or seller). If the Government could be the credit provider of last resort it would help projects get finance. Tax incentives for corporates to contract with renewables would also help unlock the market"
"Credibility can be an issue and unintended consequences. For long term one off energy storage projects the support needs to be long term (could be 50 years) traditional investor return horizon will not wait that long - in this case need a different delivery mechanism - state companies/ mutuals. Also cannot have post build competition for one off schemes; it needs to be pre build but the project is defined - fear of making a mistake / getting it wrong is likely to be a barrier to progress For subsidies for home improvements major barrier is customer willingness for the disruption, need to be realistic about take up Fear of leading the way (and so locking in higher prices than if we waited) could prevent investment Serious barrier is not being able to generate when wind is blowing - i,e not enough demand/ no storage for the power"
"External and internal investors' appetite for doing business in Northern Ireland in green given previous government and regulatory volte face on support schemes. Public sector procurement conscious bias towards lowest cost at point of procurement rather than whole life savings, quality and development of indigenous companies."
"put the energy consumer first, present integrated energy system and solutions that energy consumers can select from to address their needs, residential, commercial and industrial. electrification will not solve all energy demands and needs. solutions need to be competitive and economical for consumers. Technology driven policies will not deliver the emissions reductions and targets by 2030 or 2050. consumer has to be put first to get buy in."

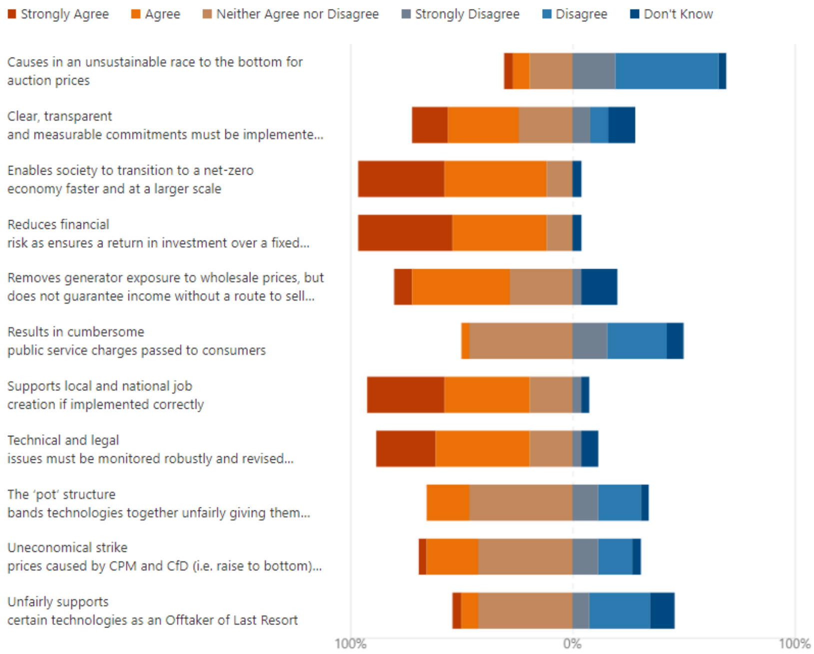
Q11 Various support schemes could be used to enable Northern Ireland's 2030 and 2050 emission targets. Rank each scheme.



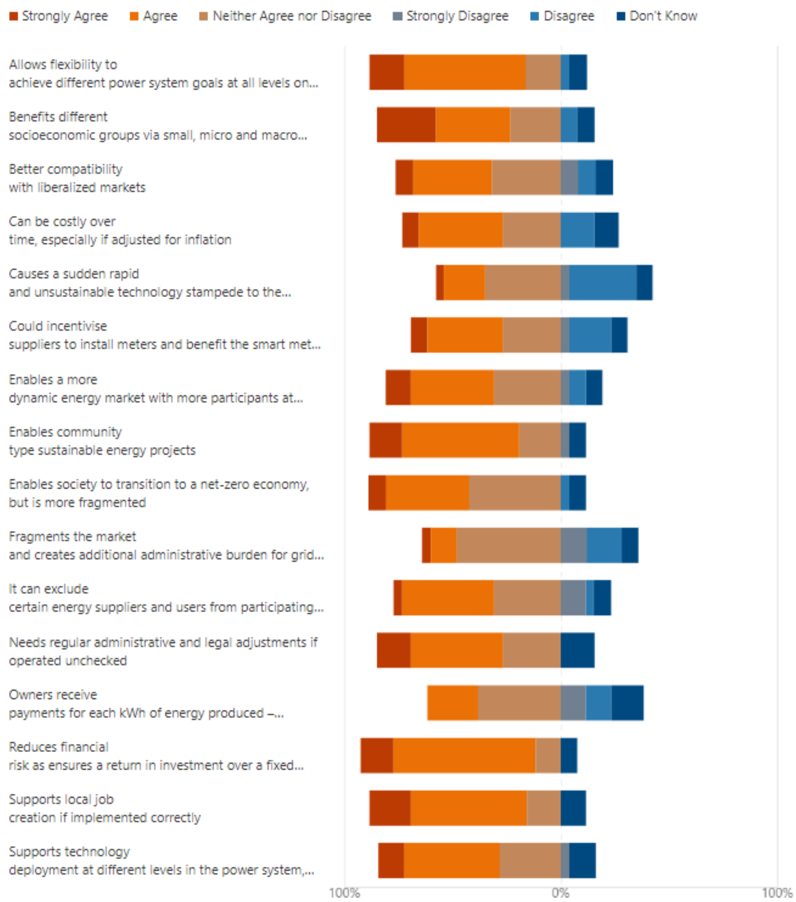
Q12 Identify, discuss and rank any support scheme not listed above in Question 11.

"You need to be more distinctive in what you mean by some of these terminologies and the various components. The CfD framework can be separated into 4 broad components: 1. The Revenue support mechanism - i.e. FiT with CfD) 2. The vehicle - in the case of CfDs it's a private law instrument 3. The payment mechanisms - i.e. settlement and levies system 4. The allocation process - specifically CfD framework can facilitate bilateral allocation, FCFS and competitive) Another important factor is compatibility of the instrument with other policies, for instance carbon pricing."
"RESS as per Republic – 4"
"Zero interest loans as available in UK."
"Support schemes which can be managed via an auction process similar to the RESS process in Ireland would facilitate faster engagement and deployment - as most active participants would be familiar with it. Some consideration of a scheme which is targeted at the small to medium sized enterprise and even home owner level would be beneficial."
"The schemes themselves may be good in principle, but the application of and implementation of same may not be."
"CPM is to encourage fixed cost units such as thermal. If these are part of the net zero roadmap I would score them on a higher basis."
"Finance guarantees, Govt. funded regulatory and financial process facilitators to assist new entrants through the process, Connection charge support. UR allowing network operators funding to build out grid reinforcements"
"The devil is in the detail on any of these schemes - eg a CPM could be great or useless depending on its design - we have a great one for existing generators in Northern Ireland currently but one that is no good for keeping the lights on - see Eirgrid asking ESB to go get some emergency generation. De risking projects via regulated returns/ risk transfer to consumers; Cap and collar schemes and competed pre-build returns - these schemes have not been mentioned these have been used for interconnector build in GB; off shore grid provision and building the gas to the west pipeline here."
"Socialisation using a renewable obligation scheme provide more certainty for the market, an obligation for renewable electricity and renewable heat, in my opinion would need to be separate. with regards to the AD biomethane fully integrated business case (RGFI/KPMG), an obligation scheme (article 23 of REDII) on the shipper/suppliers in conjunction with capital funding, commercial funding is the approach in ROI to support the biomethane industry. by mid-2030 our ambition is that AD biomethane will be self-sufficient by pursuing all opportunities and potential to commercialise and monetise by products, such as protein extraction, bio stimulants and bio actives, and carbon credits from soil carbon sequestration, voluntary scheme to trade carbon credits."

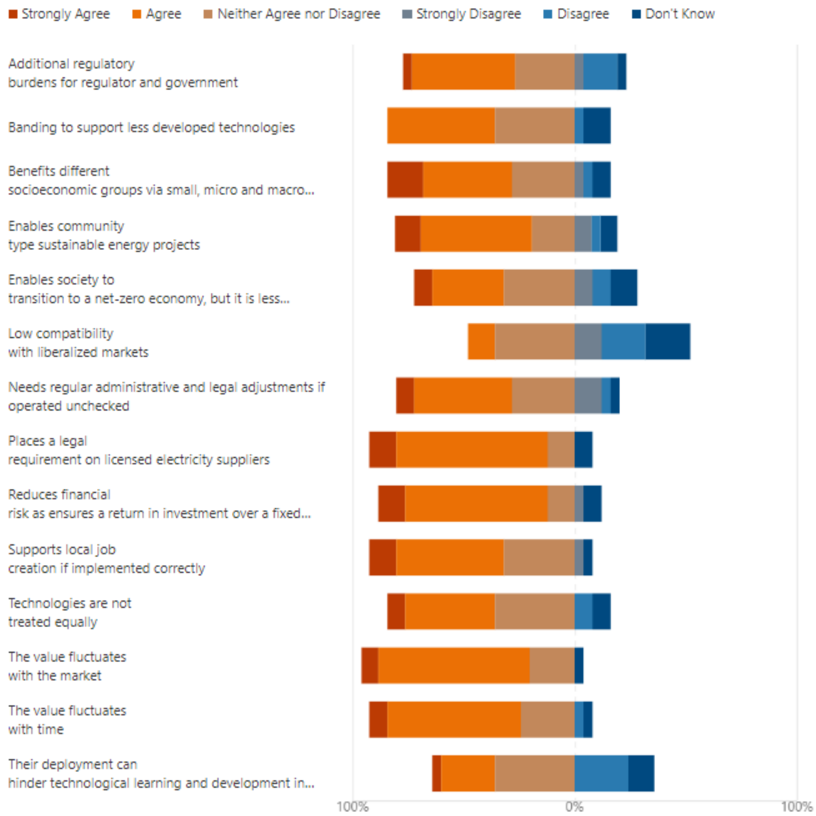
Q13 Strengths, opportunities, weaknesses and threats exist for Capacity Payment Mechanisms, Contract for Differences, and Export Guarantees. Evaluate each statement.



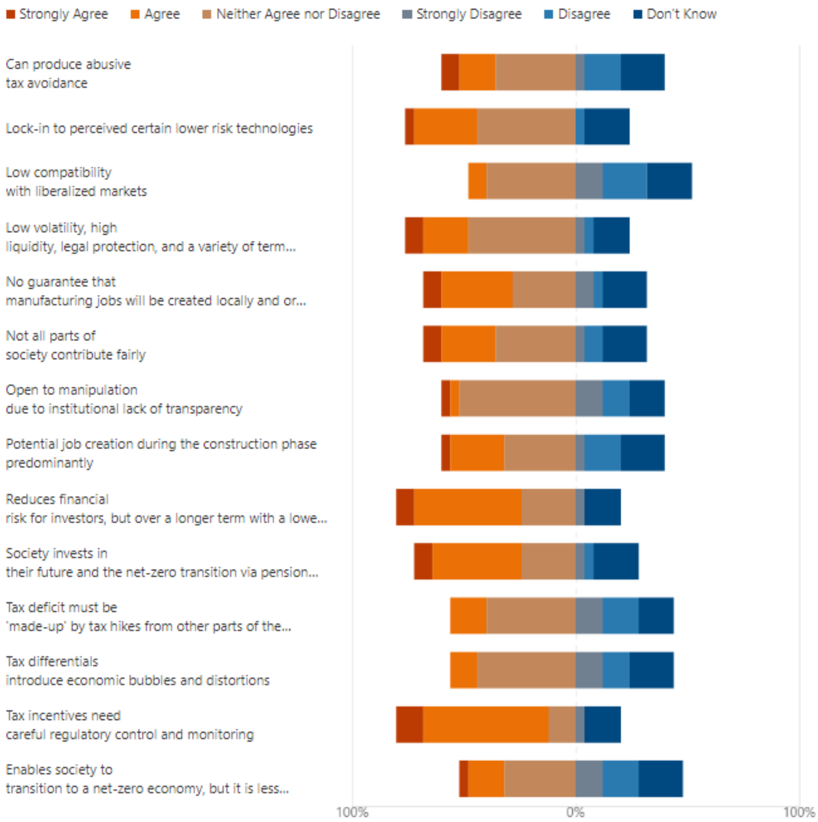
Q14 Strengths, opportunities, weaknesses and threats exist for Feed-in Premiums and Feed-in Tariffs. Evaluate each statement.



Q15 Strengths, opportunities, weaknesses and threats exist for Green Certificates and Renewable Obligation Certificates. Evaluate each statement.



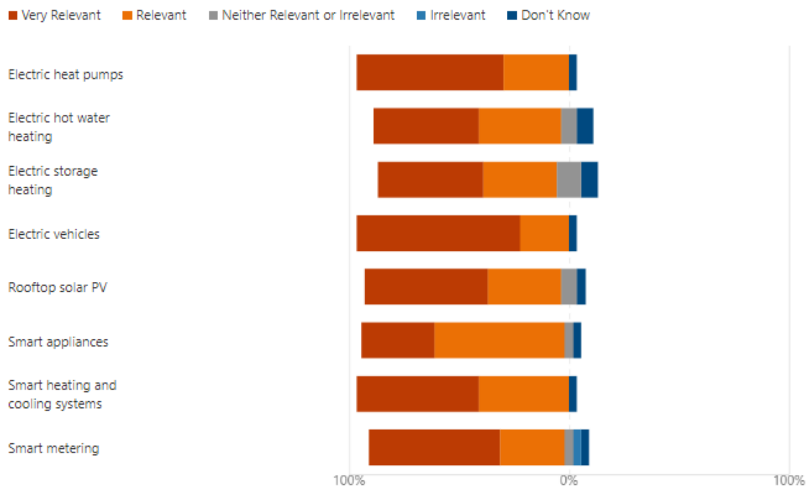
Q16 Strengths, opportunities, weaknesses and threats exist for Investment Bonds and Tax Incentives. Evaluate each statement.



Q17 Identify and discuss any other strengths, opportunities, weaknesses and threats to any of the supports schemes not stated in Questions 13, 14, 15 and 16.

"the costs, risks, benefits, fairness and control or any Energy support schemes needs to be clearly defined and transparent"
"The answers to these questions are very dependent on the design of any scheme. As per my response to question 12 there are different components to any scheme and some of these are interchangeable. For instance there is not reason you cannot use a competitive allocation process with a FiT or FiP."
"Some of these are statements of fact e.g. a regulated scheme such as ROCs will of course carry a regulatory burden. Surely the question is whether such a burden is worth the benefit or whether the burden is excessive."
"More local climate/green bonds support and local authority innovation needed (NI wide between the 11 councils in Northern Ireland given its small market size)"
"Felt all areas have been covered
"I would recommend investigating the Renewable Electricity Support Scheme (RESS) structure which has been implemented as a CfD scheme in ROI following years of consultation. It is functioning well and delivering excellent value for the electricity consumer for new renewable electricity."
"Ease of implementation and administration a key factor. Lessons should be learned from the operation of schemes in other jurisdictions."
"I think the question is too broad to really capture the nuances of the different product. For example does xxx have "Low compatibility with liberalized markets"..... the real answer is that it depends on what the market structure is, what are the rules around xxx etc. If the goal is to get to net zero by 2050 then what market do we need and what incentives do we need to get there. If the design is thought through then the goal can be achieved"
"Q14 needs to be more aware of the scope e.g. GIRONA for enabling FIT etc. to support broadly-based societal involvement and economic benefit. Q15 assumes public sector administrative burdens but does not keep it's mind open for a more 'lean' approach within the public sector or alternatives. Q16 seems to have a slight bias/assumption that tax schemes are not capable of being efficient, effective and transparent. There may be scope in Northern Ireland for doing something new, better and local under Northern Ireland Assembly potential tax raising powers, perhaps."

Q18 Other technologies exist outside of power generating technologies that can enable a transition to a low-carbon future through decentralization and electrification of electricity, transport and heating loads. Evaluate these technologies.

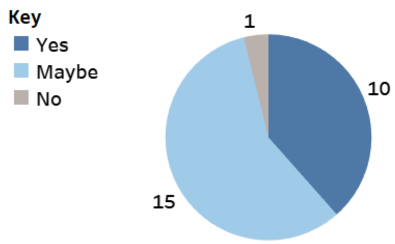


Q19 List, describe and evaluate any other low carbon transition technologies not identified in Question 18.

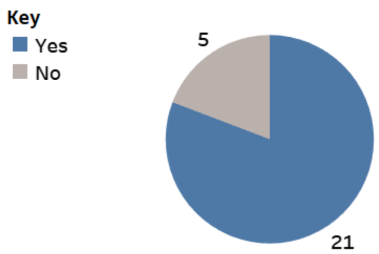
"Solar hot water; compressed air storage, wave/tidal"
"Network developments and smart management systems. Hydrogen & carbon capture technologies"
"Electricity and energy reduction, conservation and efficiency technologies; also need more focus on non-technological innovations - behavioural change"
"All relevant but some have more utility than others in delivering net zero. First 4 possibly the most useful."
"Green Hydrogen"
"V2G capability from EVs Electricity network monitoring and control Fit for purpose telecoms network SMART investment solutions as complementary to conventional reinforcement System support technologies e.g. rotational stabilisers and synthetic inertia"
"Rooftop solar water heaters, for hot water demand or as a pre-heat option"
"Hydrogen solutions should be considered here. Biogas solutions. Synthetic fuels to offset airline fuel use."
"Geothermal energy for heat (both low enthalpy and high enthalpy)"
"Energy efficiency, especially building envelope. Transport initiatives - public transport and LCT transport, Work from home, Ruminant herd numbers, Agri-environment policies, Carbon taxes. CBAM."
"This is all electricity - there is a raft of green gas technologies needed to ensure security of energy supplies"

"Behind the meter smart electricity storage e.g. Project GIRONA has very great relevance to Net Zero transition. It increases generation of renewables, increases and optimises the actual usage of generated energy and enables a community to participate, directly benefit and control their transition."
"Biomethane for heat/thermal, and transport"
"District Heating, Hydrogen (for both power generation and transport)"

Q20 Do you feel this survey has been useful in sharing your views to inform Northern Ireland's net zero transition to it's 2030 and 2050 emissions targets?



Q21 Do you wish to participate in any future expert panel of this DELPHI Study?



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