Our Zero eMission Future

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ELECTRICITY ASSOCIATION OF IRELAND

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About us

MaREI is the world-leading Science Foundation Ireland Research Centre for Energy, Climate and Marine, coordinated by the Environmental Research Institute (ERI) at University College Cork. MaREI has over 200 researchers across 13 partner institutes in Ireland working with 75 industry partners focussing on the energy transition, climate action and the blue economy. MaREI delivers excellent research with societal impact by supporting industry, informing policy and empowering society.

This report was prepared by Laura Mehigan and Dr Paul Deane.

Summary

A decarbonised All-Island electricity system is key to achieving climate ambition on the island of Ireland. This study takes a closer look at the future All-Island power system through the lens of decarbonisation by focusing on the year 2030 where over 70% of the annual electricity on the system will be renewable. While this requires a significant level of renewable energy build out, it also demands a resilient power system capable of absorbing and storing fluctuations in weather driven generation and at the same time meeting the demand of new electricity loads from electric cars, residential heating and data centres. Ireland's location on the edge of Europe presents a limited diversity of interconnection options and so our role within a greater interconnected European power system is also considered.

A reliable electricity supply is integral to our modern economy and while climate policy is often based on average values, power systems must be resilient to extremes to maintain the continuity of supply that society has become accustomed to. Our analysis examines over 250,000 hours of weather data across the island of Ireland and highlights how remarkably flexible the future All-Island power system will have to be to deal with a wide and diverse variation in weather events. At times, the system will produce more renewable generation than can be used, stored, or exported. Yet, it must be sufficiently resilient to deal with periods of low regional wind generation and extremes such as periods where there is very little power being supplied by renewables. Conventional generators and interconnectors meet the bulk of electricity demand during periods of low regional wind availability helped with smart loads, demand side response units and batteries.

Today the All-Island electricity sector is responsible for approximately 20% of final energy use and 16% of greenhouse gas emissions. The challenge of a fully decarbonised economy will require a greater contribution from electricity to final energy to assist wider system decarbonisation, coupled with a strong reduction in emissions from the sector. It also requires us to look not only at how we supply electricity but how it is integrated into the grid and managed in demands.

To align with the objectives of the Paris Climate Agreement, we find that a 2030 system with a minimum of 70% renewable electricity generation is correct in terms of ambition for the All-Island power system in addition to huge changes across other sectors, but today's grid is not adequately flexible to deliver this ambition. This goal can only be fully realized with actions that increase the capability of the grid to absorb the greatest amount of renewable generation. In the absence of such actions the power system will be outside the upper bound of what is required in terms of emissions reduction.

Clear Climate Policy provides clarity on the pace of emission reductions required and reduces the risk of carbon lock in for new investments. A greater effort in decarbonisation today will reduce the burden of effort post 2030 and this report also reviews options for different technologies that could further assist decarbonisation in the future. While these options all have implicit uncertainty, they share a requirement for significant capital commitment[1], long lead times for construction, decades-long operational lifetime and a need for investment decisions to be made well in advance of 2030. A dialogue on the future pathways for the power system is required to ensure the correct policy signals are provided to stakeholders that best position the sector to meet our decarbonisation obligations in the long term.

However, this progress cannot be taken for granted and in particular we highlight the following key messages:

- Achieving a high renewable ambition across the **All-Island power system requires the System Non-Synchronous Penetration (SNSP) level to increase to over 85%, grid constraints removed and continued investment in flexibility and grid infrastructure**. Without this, emissions will increase, and a lower ambition will be realized.

- Electrification of new loads in heat and transport plays an important role in wider system decarbonisation**. To maximise the benefit of renewable generation for emissions reduction, the rate of electrification of new loads,**

[1] The cost and the source of funding for the capital investment required is outside the scope of this report.

particularly in switching from high-carbon fossil fuel, must keep pace. Slower uptake on technologies such as heat pumps and electric vehicles has a net increase on wider energy system emissions.

- **While wind energy will be the main driver of decarbonisation, the reliable delivery of electricity requires conventional generation to play a necessary role providing energy, system services and flexibility.** The required gas fired capacity in 2030 is similar to today, but gas fired generation will operate less [~20% less energy compared to 2019 (or ~ 4 TWh less)]. Options to decarbonise conventional generation beyond 2030 need to be examined now to ensure investment and action in a timely manner.

- **All-Island power system emissions should not be greater than 6.2 million tonnes in 2030 to be in line with obligations under the Paris Climate Agreement.** The modelled All-Island 2030 system is just on the outer envelope of this range [~6.3 million tonnes]. Efforts to reduce emissions should be pursued to bring the system in line with expectations and reduce the burden of decarbonisation post 2030.

- Significant investment must be made across both the power system and wider energy system to achieve ambitious levels of emissions reduction on the All-Island system. Based on public data, **we estimate an 'overnight' cumulative investment of ~32€ billion for the All-Island power system with 90% of costs on physical infrastructure such as wind turbines and grid delivery and 10% on system services to facilitate the operation of the power system with high levels of renewables.** This level of investment requires strong and stable policy signals to deliver on climate ambition.

- **As policy across the UK, Ireland and Europe shifts from a renewables target focus to an emissions reduction focus there is a need to promote decarbonisation across the full system including supply, grid and demand side measures**. Policy coordination in the All-Island System and cooperation mechanisms across the UK and Europe will help maximize the benefit of decarbonisation across the full energy system.

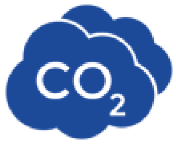
Decarbonisation Options compared to All Island 2030 Base Scenario 6.3 Mt CO2			
Remove Min Units Requirement	**Additional Wind Capacity**	**Additional Wind Capacity + remove Min Units**	**Carbon Capture and Storage Plant**
			
Would remove an additional 0.8 Mt CO2	**Would remove an additional 1.3 Mt CO2**	**Would remove an additional 2.9 Mt CO2**	**Would remove an additional 1.1 Mt CO2**
Investment would likely be needed in synchronous condensers, flywheel storage, or novel synthetic inertia schemes. Capital cost is uncertain	Investment in extra interconnection (+2.8GW), Batteries (+2.4GW) and offshore grid infrastructure. Deployment timelines and supply chain must be considered. Policy on carbon credits of exported power should be developed	Combining increased deployment of wind and removal of min units requirement would deliver significant emissions reduction and would require significant and sustained investment	Investment is required in plant and storage capacity as well as long term stable policy and likely political support. Residual emissions of CCS in a long-term energy system must be considered in wider decarbonisation context

Figure 1: Decarbonisation options examined and emissions reduction compared to Base Scenario. Note that measures are not additive.

1 The role of electricity in climate action

Our planet is warming and this is changing our climate in dangerous ways. Every 1 second over 1,000 tons of carbon dioxide (CO_2) is released into our global atmosphere, trapping the sun's heat, and warming our environment. Now more than ever, there is political and societal recognition for the need to reduce our emissions and decarbonize our complete energy system. The Paris Climate Change Agreement has the objective of holding the increase in the global average temperature to well below 2 °C above pre-industrial levels and pursuing efforts to limit the temperature increase to 1.5 °C above pre-industrial levels [1]. The science underpinning this ambition demonstrates a uniquely important role for a decarbonized electricity sector as a vector for clean energy but also as the backbone to a resilient and secure energy future.

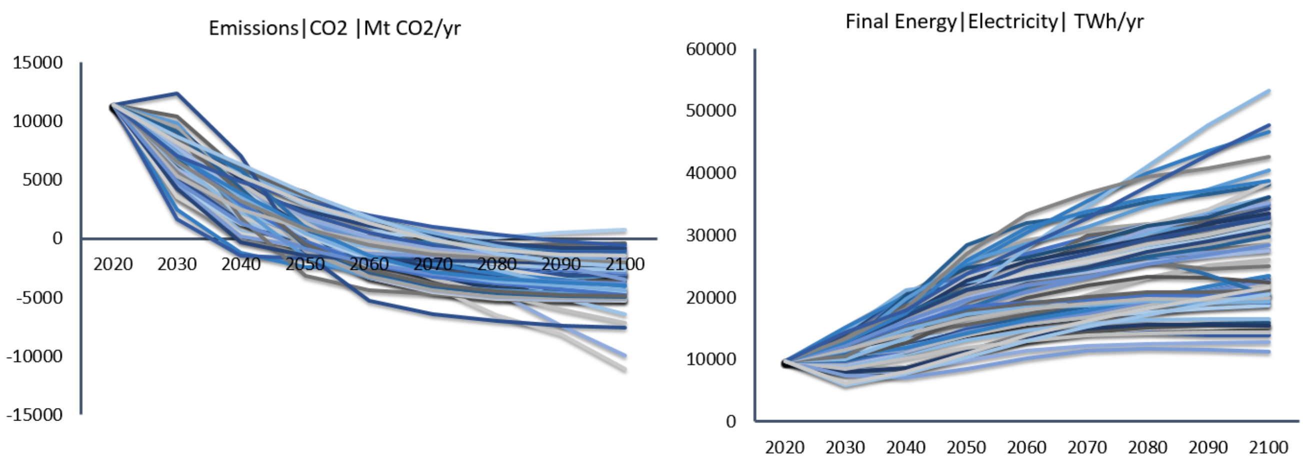


Figure 2: Pathways for CO_2 reduction and electricity demand in IPPC Pathway that meet the global ambition of 1.5 degrees for the EU and OECD region ["IAMC 1.5°C Scenario Explorer and Data hosted by IIASA, release 1.1"]

The Intergovernmental Panel on Climate Change (IPCC) Special Report on 1.5 degrees presents an overview of emissions reduction and the associated quantity of electricity required in our global energy system in pathways that limit future temperature increase [2]. Today, the global electricity system meets 20% of our final energy needs and under scenarios that meet the Paris Climate Agreement this is projected to increase to 50% by 2050 and even higher in some regions. In fact, all modelled future scenarios that meet the 1.5 °C target share a number of robust findings for the electricity sector, including a growth in the share of energy derived from low-carbon-emitting sources, a steep decline in the overall share of fossil fuels without Carbon Capture and Storage (CCS), a rapid decline in the carbon intensity of electricity generation simultaneous with further electrification of energy end-use such as mobility, heating and industrial processes. While the All-Island system is much smaller in scale and magnitude, these core findings are fundamentally relevant in efforts to meet climate obligations.

2 All-Island energy and climate policy

Despite variances in climate and energy policy, the All-Island electricity market is a story of success. Almost 13 years ago the Single Electricity Market was established, operating across two jurisdictions and with dual currencies (Euro and Sterling), it was the first market of its kind in the world when it opened. Today, the system is a world leader in the integration of variable renewables with almost 40% of electricity generated to come from clean renewable sources in 2020. This section presents the policy drivers for decarbonisation on the island and sets the context for the role of electricity as the main vector for decarbonisation.

2.1 Northern Ireland Policy Context

Northern Ireland has devolved responsibility for energy policy, excluding Nuclear Energy and Carbon Capture and Storage. The decarbonisation of the energy system will be vital to ensuring Northern Ireland meets its contributions to the UK's target of net-zero emissions by 2050.

Currently, Northern Ireland does not have any legally binding emissions reduction targets; however, it will contribute to the UK's stated aim to achieve net-zero emissions by 2050. In May 2019, the United Kingdom's Committee on Climate Change concluded that it is "*necessary, feasible and cost-effective for the UK to set a target of net-zero Green House Gas (GHG) emissions by 2050*" [3]. Following this, the Climate Change Act 2008 (2050 Target Amendment) Order 2019 came into effect on the 27 June 2019 [4]. The revised legally binding target towards net zero emissions covers all sectors of the economy. This update to the Order demonstrates the UK's and Northern Ireland's commitment to targeting a challenging ambition in line with the requirements of the Paris Agreement. The 'New Decade New Approach' deal also specified Northern Ireland's commitment to the Paris Agreement: *"The Executive will introduce legislation and targets for reducing carbon emissions in line with the Paris Climate Change Accord"* [5]. Furthermore, the Department for the Economy is currently preparing a new long-term strategy for decarbonisation of the Northern Ireland energy sector by 2050 at least cost to the consumer [6].

Northern Ireland has witnessed significant reductions in overall GHG emissions and in 2018 were almost 18% below 1990 levels. By contrast, Ireland's GHG emissions in this period have grown by 10% and UK GHG emissions have reduced by 42%. Currently, the energy sector is responsible for two thirds of Northern Ireland’s GHG emissions, but the bulk of emissions reduction have taken place in the electricity and industry sectors. Electricity is still a significant source of emissions and decarbonisation of the energy system is therefore critical to mitigate the impact of climate change. The Strategic Energy Framework (SEF) 2010-2020 sets a target of 40% of electricity consumption in Northern Ireland to be met from renewable generation by 2020 and significant investment in renewable generation enabled Northern Ireland to achieve the 40% target in 2019 [7].

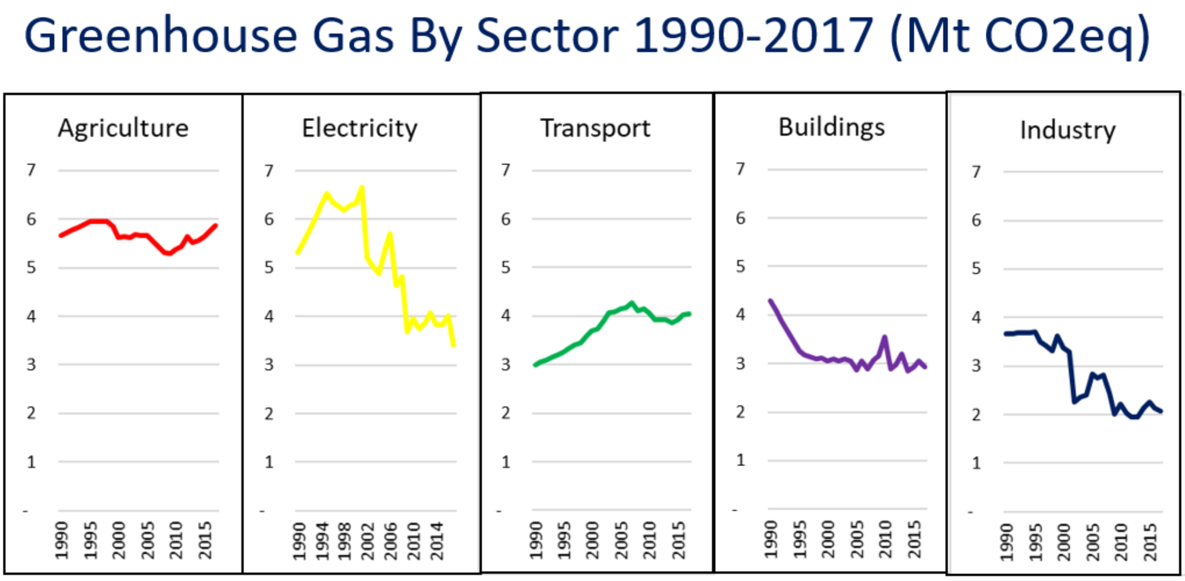


Figure 3: Northern Ireland Greenhouse gases from 1990-2017 for major sectors of the economy

2.2 Ireland Policy Context

Ireland has a complex set of overlapping national and European targets that have important relevance for the electricity sector. The ambition is broken out between emissions reduction for certain sectors and renewable energy targets for others. We present these separately below. The Irish Government published its Climate Action Plan in 2019 [8]. The objective is to enable Ireland to meet its European targets to reduce its carbon emissions by 30% between 2021 and 2030 in sectors not included in the EU Emissions Trading Scheme (i.e. all sectors apart from large industry and electricity) and lay the foundations for achieving Net Zero carbon emissions by 2050.

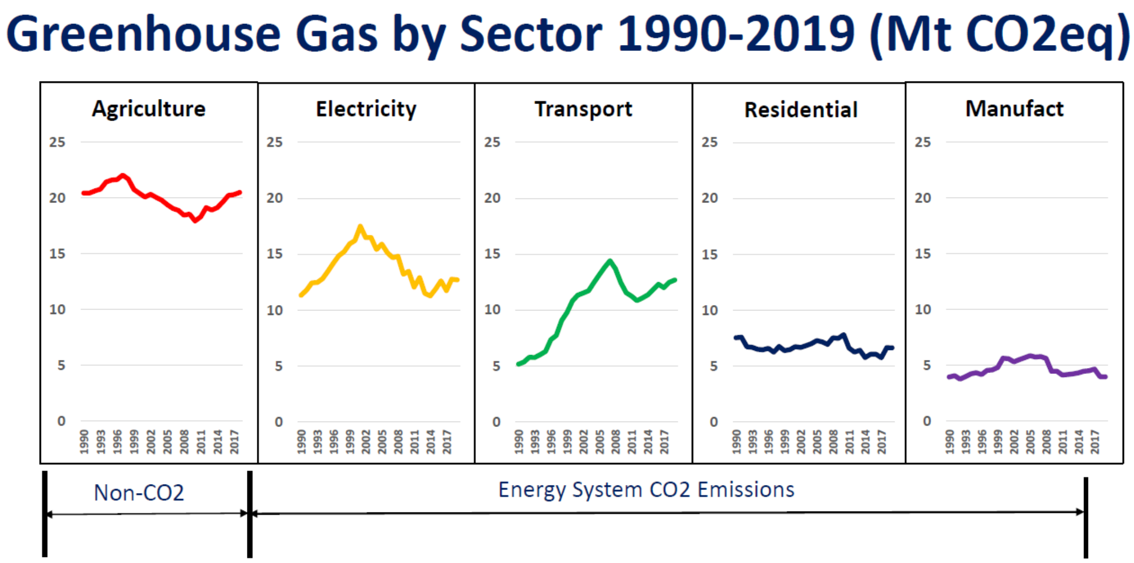
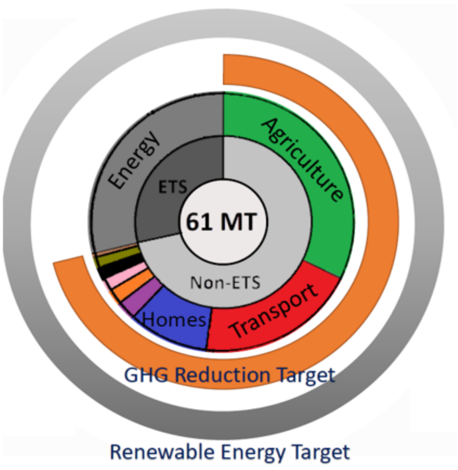


Figure 4: Ireland Greenhouse Gases from 1990-2019 for major sectors of the economy

<u>Emissions Reduction Targets:</u> Ireland's 2020 target is to achieve a 20% reduction of non-Emissions Trading Scheme (non-ETS) sector emissions (i.e. agriculture, transport, residential, commercial, non-energy intensive industry, and waste) on 2005 levels with annual binding limits set for each year over the period 2013-2020. New 2030 targets for EU Member States were adopted by the European Council in 2018. Irelands 2030 target under the Effort Sharing Regulation (ESR) is a 30% reduction of emissions compared to 2005 levels by 2030 [9]. There will be binding annual limits over the 2021-2030 period to meet that target.

In relation to 2020 EU targets, Ireland is set to miss its target for compliance for emissions reduction. Ireland's non-Emissions Trading Scheme emissions are projected to be between 2% to 4% below 2005 levels in 2020 and will have to purchase compliance to meet its obligations.

<u>Moving Emissions from Non-ETS to ETS Sectors:</u> Ireland does not have emission reduction targets for electricity, as these are within the European Union Emissions Trading Scheme, however there is an important interplay between the ETS and Non-ETS sectors in relation to the electrification of new load that has policy consequences. When electrification of new transport or heating loads take place (for example through EVs or electrification of residential home heating) this reduces the emissions burden for the State as it shifts the emissions responsibility to companies in the ETS sector. Thus, the electrification of new loads offers an important policy benefit.



Policy Overview
Emissions: EU Effort Sharing Decision
20% reduction (rel 2005) in Non ETS GHG Emissions to 2021
30% reduction (rel 2005) in Non ETS GHG Emissions to 2030

Renewable Energy Directive
16% RES by 2020 of Gross Final Consumption
-RES T 10%
-RES H 12%
-RES E 40%
Electrification of Transport and Heating benefits Irelands Non ETS Target
Decarbonisation of electricity contributes to National Ambition

Figure 5: Ireland Emissions and European renewable and climate obligations

Over the longer term, Ireland's National Policy Position on Climate Action and Low Carbon Development has set a target of an aggregate reduction in carbon dioxide (CO_2) emissions of at least 80% (compared to 1990 levels) by 2050 across the electricity generation, built environment and transport [10]. The long-term vision of low-carbon transition is also based on, in parallel, an approach to carbon neutrality in the agriculture and land-use sector, including forestry, which does not compromise capacity for sustainable food production. This policy position is evolving. The Programme for Government states that *"We are committed to an average 7% per annum reduction in overall greenhouse gas emissions from 2021 to 2030 (a 51% reduction over the decade) and to achieving net zero emissions by 2050. The 2050 target will be set in law by the Climate Action Bill, which will be introduced in the Dáil within the first 100 days of government, alongside a newly established Climate Action Council"* [11].

2.2.1 Renewable Energy

The Renewable Energy Directive (RED) sets out two mandatory targets for renewable energy in Ireland to be met by 2020 [12]. The first relates to overall renewable energy share (RES), commonly referred to as the overall RES target. For Ireland, the overall RES target is for at least 16% of gross final energy consumption (GFC) to come from renewable sources in 2020.

The second mandatory target set by the RED relates to the renewable energy used for transport. This is commonly referred to as the RES-T target. The RES-T target is for at least 10% of energy consumed in road and rail transport to come from renewable sources. In addition to these EU mandatory targets, Ireland has two further national renewable energy targets for 2020. These are for the electricity and heat sectors and are designed to help Ireland meet the overall RES target. The renewable electricity target is commonly referred to as the RES-E target. The RES-E target is for 40% of gross electricity consumption to come from renewable sources in 2020. The renewable heat target is commonly referred to as the RES-H&C target. The RES-H&C target is for 12% of energy used for heating and cooling to come from renewable sources in 2020.

Ireland is projected to miss its 2020 Renewable energy target of 16% and will have to purchase statistical transfers from other EU Member States to meet compliance.

At the time of writing, the European policy landscape is in a state of flux and overall renewable energy targets for Member States are yet to be formally decided. The recently published National Climate and Energy Plan 2021-2030 has indicative targets for Ireland as 34% for 2030, with a target of 70% for RES-E, 13% RES-T and 24% for RES-H&C with only the RES-E target formally committed to in the program for government [11,13].

3 The All-Island power system

The power system on the island of Ireland is one of the most agile in Europe. Wind generated electricity on the system frequently meets up to 65% of instantaneous electricity demand and approximately 40% annual renewable electricity generation is expected in 2020. In contrast with other EU member states, the power system has limited interconnection to neighbouring countries, has low levels of storage and low levels of hydropower.

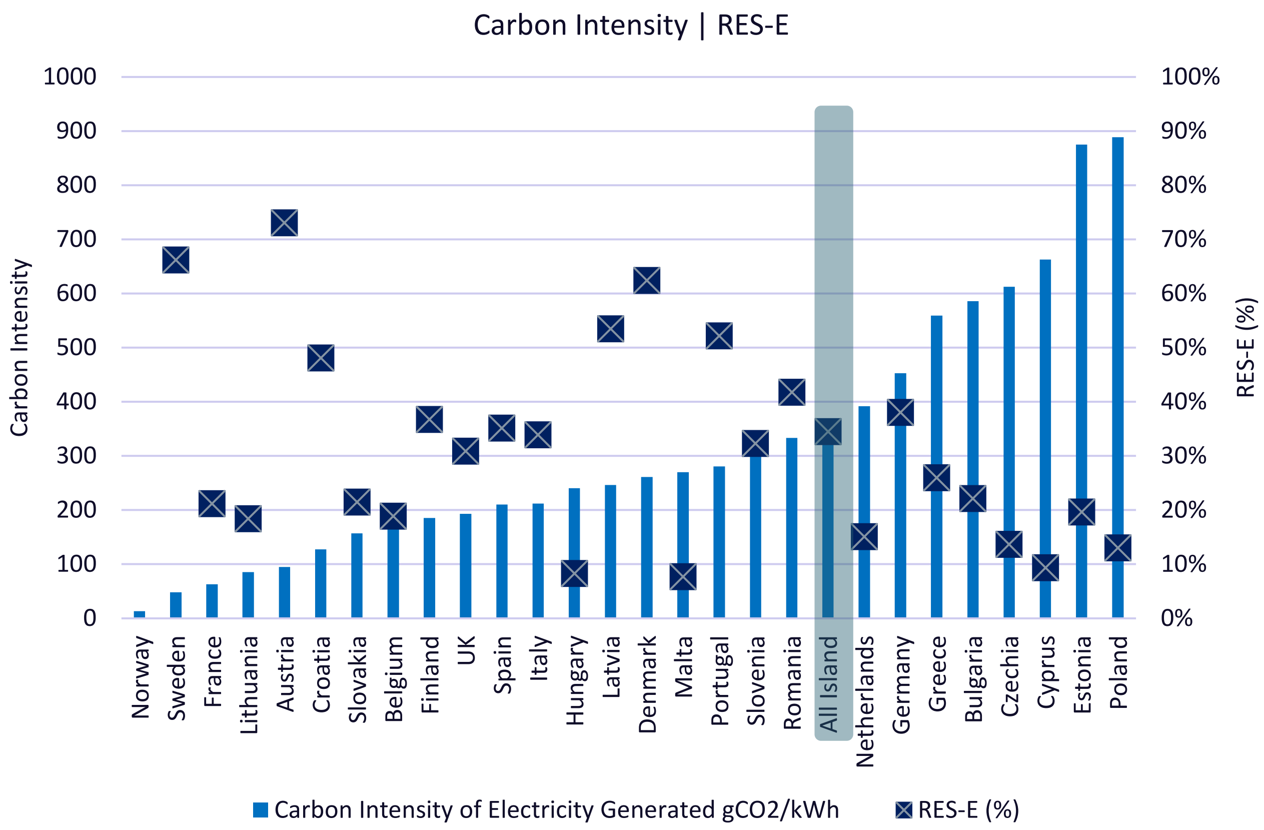


Figure 6: Carbon Intensity (left axis gCO_2/kWh) and Renewable Electricity Penetration (right Axis %) in 2018 for European countries. The All-Island System is highlighted in blue.

The All-Island system has a level of renewable electricity above the EU average (ranked 12th in the EU 28 in 2018) and the carbon intensity of the All-Island system is estimated at 340 gCO_2/kWh for 2018, this is above the EU average for countries shown in Figure 6 of 280 gCO_2/kWh.

Due to its isolated grid, the current level of wind generation is limited to ensure system strength is maintained. Achieving a minimum of 70% renewable electricity by

2030 will require significant infrastructure investment as well as capacity to integrate new storage technologies. According to the government's Climate Action Plan in Ireland, the level of wind capacity may have to increase by up to 300% to achieve the higher level of ambition but also to absorb new electricity loads from electric cars, electric heat pumps and significant growth in Ireland's data centre industry.

The EU has set an interconnection target of at least 10% by 2020 (Ireland's level was 7% in 2017), to promote security of supply and encourage countries to connect their installed electricity production capacity to share resources. There are already two interconnectors between the island of Ireland and the UK, one in Ireland and one in Northern Ireland. An additional two interconnector projects are at a preliminary stage: Greenlink between Ireland and the UK and the Celtic Interconnector the first planned interconnector between Ireland and France. Ireland's location on the periphery of Europe limits its diversity in terms of interconnection options. This challenge can be addressed to a degree through the introduction of storage technologies and flexibility solutions into the energy system.

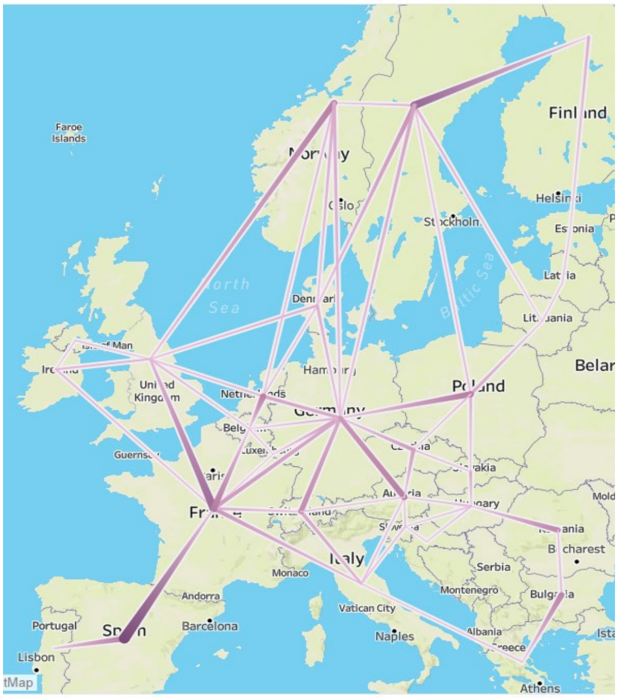
The power system on the Island is one of the most reliable power systems in Europe. The total system minutes lost (SML)[2] due to faults on the main system for 2019, attributable to SONI was 0.92 and EirGrid was 0.17. Significant reductions in outages for customers have also been achieved by increasing network reliability and storm resilience [14].

[2] System minutes lost is a measure of the energy not supplied for a disturbance. The metric takes account of the load lost (MW), duration of disconnection (minutes) and peak system demand (MW).

4 Methodology

4.1 Pan European Model Development

To understand the future 2030 All-Island Power System, MAREI has developed an extensive Pan-EU power market model covering EU 27, United Kingdom and Norway for the purpose of this study. The model uses the PLEXOS Integrated Energy Software that is widely used in the power and utilities industry for market price projections, asset dispatch modelling, and other purposes. The model takes key inputs and scenario assumptions such as hourly demand profile, fuel prices, generation portfolios and hourly wind and solar profiles, and has representations of generator technical parameters and interconnection between countries. The model undertakes a least cost optimization to produce hourly dispatch for the generators and hourly prices for the markets taking full consideration of the operational constraints (ramp rates, start time, availability etc.).



Why model all the EU

Ireland's location on the edge of Europe means the dominant influence on Ireland's climate is the Atlantic Ocean but we experience a range of air masses with different sources and tracks, giving us our variable weather. As the EU power grid becomes more interconnected fluctuations in weather driven electricity generation can be absorbed by interconnectors and transmitted across Europe meaning that what happens elsewhere in Europe matters.

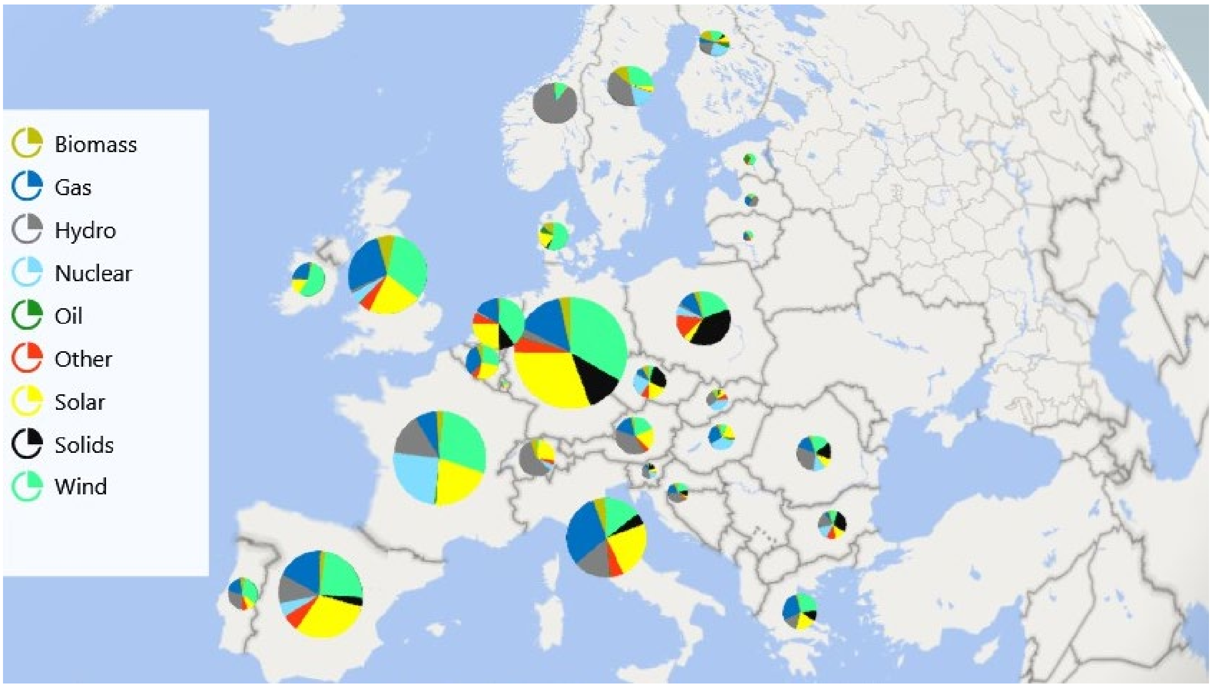


Figure 7: EU wide power system portfolios considered in this analysis. Portfolios and interconnection capacities (except the All-Island System) are from ENTSO-E 2018 TYNDP

4.1.1 2030 Power System Portfolio

Due to differing political, economic, social and technology drivers in Northern Ireland and Ireland, there are no unified official policy scenarios across both jurisdictions. A large number of published studies exist in the public domain with various projected portfolio for the year 2030. Some studies, like the Government of Ireland Climate Action Plan, do not present an All-Island overview.

Figure 8: Studies considered for 2030 analysis

The EU SysFlex project is a Horizon 2020 project with a wide range of European partners including EirGrid and SONI. Part of the work thus far involved the analysis of system stability for the All-Island power system for the year 2030. Our analysis follows a similar make-up in 2030 conventional portfolio to the EU SysFlex study [15] with modifications to remove generators that were not in use. The resulting 2030 portfolio is compared to the existing 2020 All-Island system in Figure 9. The portfolio was checked to be in line with the current All-Island loss of load expectation (LOLE) standard of 8 hours and all scenarios are tested for robustness to ensure adequacy of supply across multiple weather years.

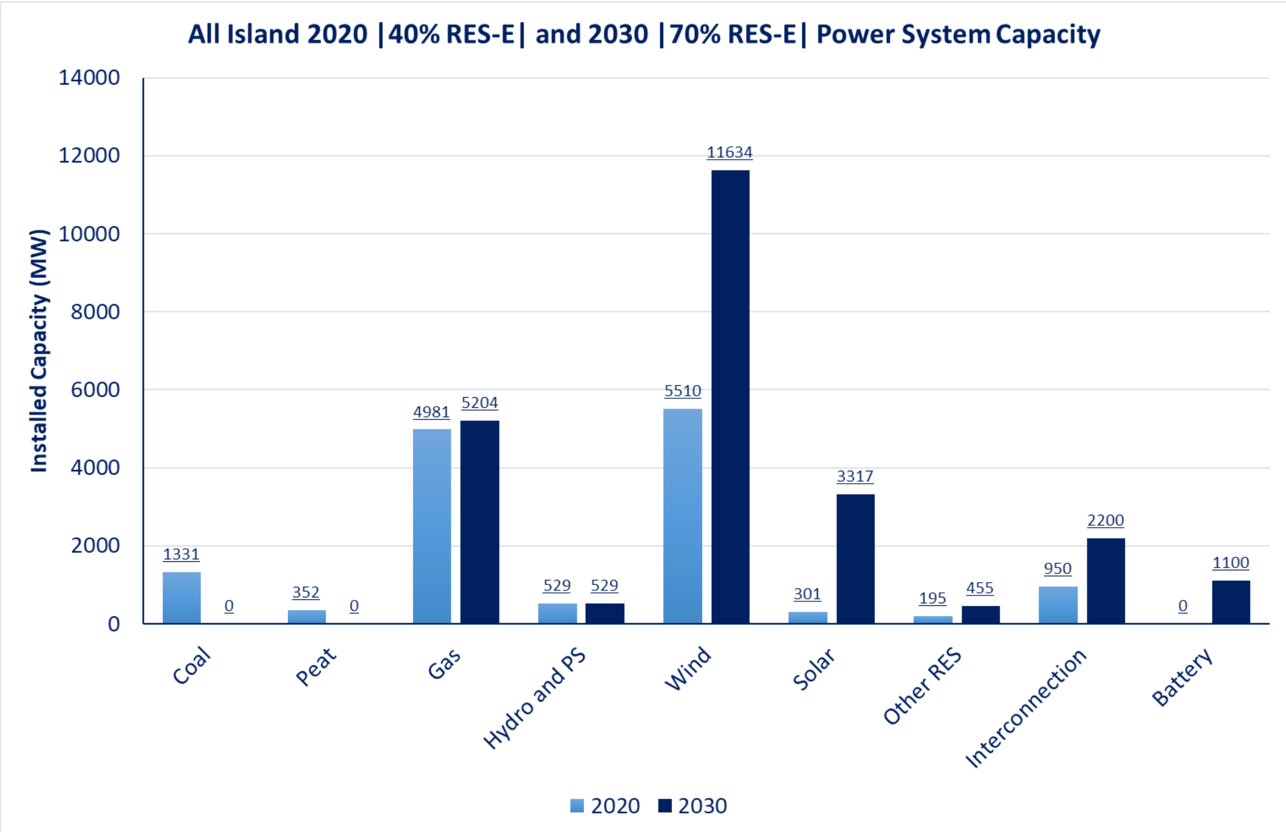
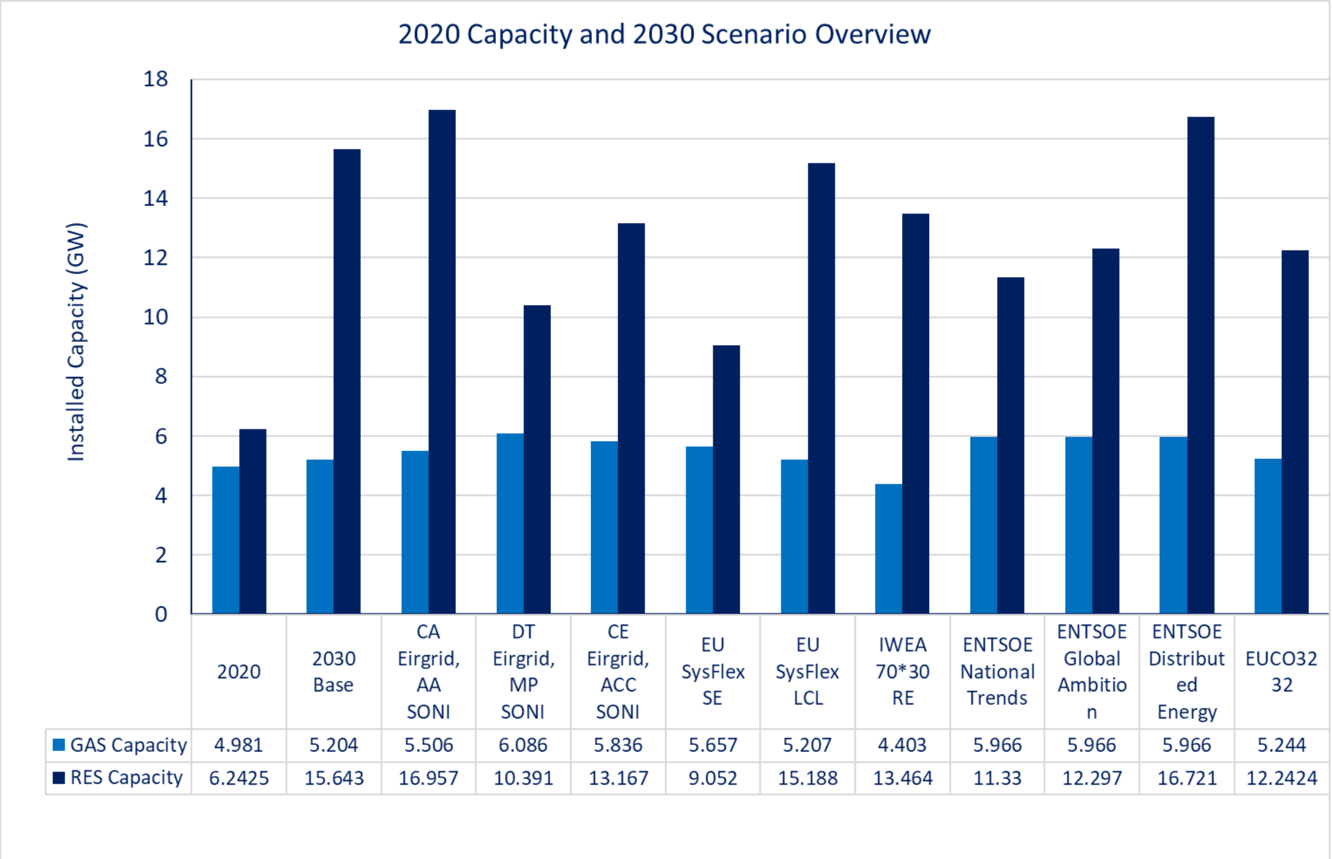


Figure 9: Comparison of 2020 and 2030 All-Island Power System portfolio

The resulting portfolio is also compared to other published studies from SONI and EirGrid, ENTSO-E, IWEA and the European Commission for the All-Island system for context in Figure 10. There is a consensus across studies that significant levels of gas fired generation will be required.



	2020	2030 Base	CA Eirgrid, AA SONI	DT Eirgrid, MP SONI	CE Eirgrid, ACC SONI	EU SysFlex SE	EU SysFlex LCL	IWEA 70*30 RE	ENTSOE National Trends	ENTSOE Global Ambition	ENTSOE Distributed Energy	EUCO32 32
GAS Capacity	4.981	5.204	5.506	6.086	5.836	5.657	5.207	4.403	5.966	5.966	5.966	5.244
RES Capacity	6.2425	15.643	16.957	10.391	13.167	9.052	15.188	13.464	11.33	12.297	16.721	12.2424

Figure 10: Comparison with other published studies and 2020 capacity. Our portfolio is the 2030 Base

In line with the findings of the EU SysFlex study [15], it has been assumed in this study that the FFR requirement is 100% of the largest single infeed (generator or interconnector import) as is Primary Operating Reserve (POR). SOR, TOR1, TOR2 are assumed to remain the same as they are at present. All batteries are considered for reserve and energy.

4.2 Heat and EV Profiles

One of the recommendations by the Committee on Climate Change [16] concerning heat decarbonisation in Northern Ireland is to replace oil heating in the off-gas grid area with low carbon heat supply, mainly heat pumps. The main energy policy document for Northern Ireland, Strategic Energy Framework (SEF 2010-2020) set a target of 40% of electricity consumption and 10% of heat supply from renewables by 2020 [7]. By June 2020, Northern Ireland had exceeded the 2020 electricity target, however, the goal for renewable heating will most likely not be achieved[3]. Similarly, in Ireland, the Climate Action Plan sets ambitious goals for the deployment of heat pumps in the residential sectors and these are included in the analysis as extra loads on the electricity system.

There is currently limited public availability of annual electric vehicle charging profiles that are based on actual charger use. To model the impact of the deployment of electric vehicles on the All-Island system we use normalized hourly charging demand profiles which consider residential, work, slow/fast public and rapid public charging from National Grid UK. In the analysis we assume that 75% of EVs are charged at home, 15% at work and the remainder is split between slow and fast charging.

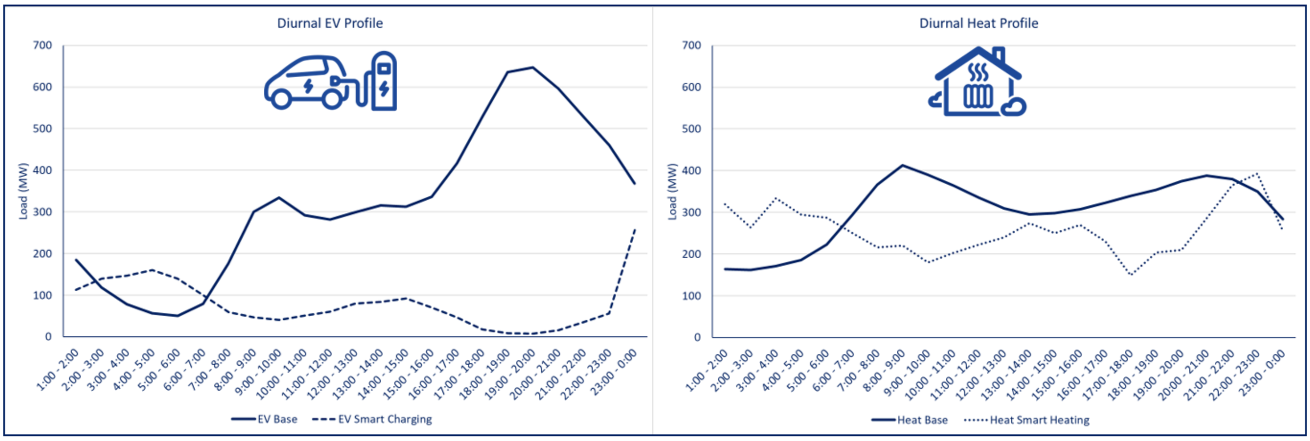


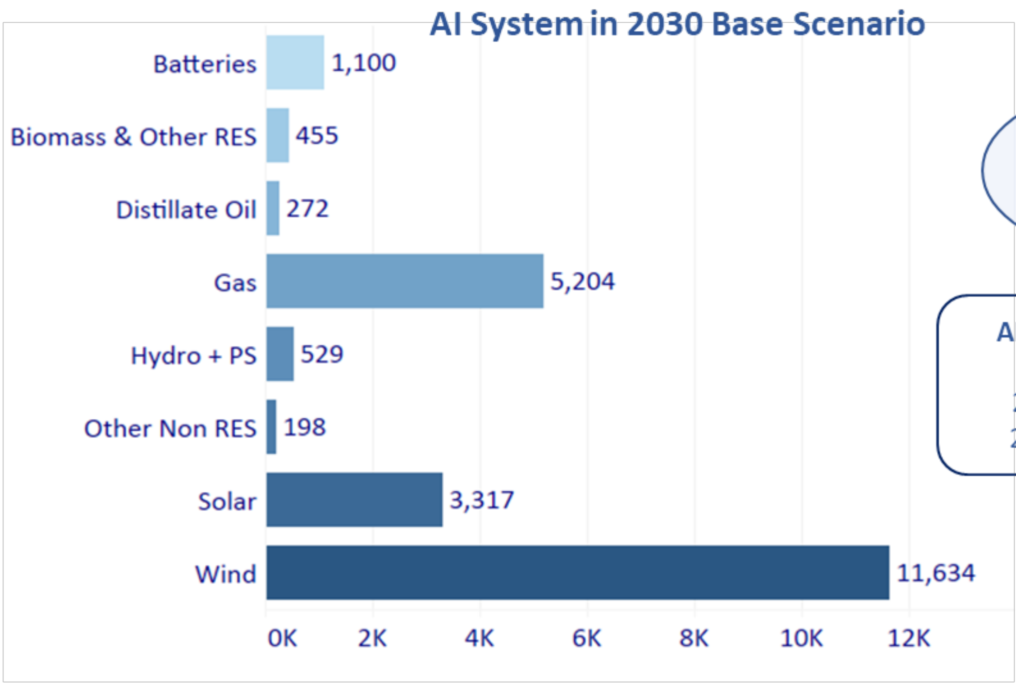
Figure 11: Diurnal EV and Heating profiles used in the study

To model the impact of smart charging and smart meters for home heating and home EV charging use, we assume that 20% of the gross daily load is ‘smart’ and movable to hours in the day where the overall costs of the system is lowest. The resulting smart profiles are also shown in Figure 11 as dashed lines. Note that these are an output rather than an input to the model.

[3] A recent overview of heating in Northern Ireland by Ulster University can be found here [17]

4.3 Core Scenarios and Narratives

2030 Base: This is the core scenario which assumes the All-Island System meets a 72% renewable electricity ambition. We assume Northern Ireland hits a 73% RES-E target and Ireland meets its 70% RES-E target. In developing renewable portfolios, we add variable renewable capacity such as wind and solar to the system until the level of ambition is reached and then iteratively adjust battery storage capacity to limit the overall level of variable renewable curtailment to ~7%. The values we use are indicative only and the exact level of offshore wind, onshore wind, solar and other renewable technology will be determined by competitive auctions and technology development. The renewable portfolios are 'frozen' for all scenarios unless specifically stated. All scenarios assume 750MW of demand side response units.



DSU Capacity
750 MW

AI Interconnection Capacity
2200MW Export
2200MW Import

AI Demand 53.7 GWh	1,000,000 EVs · 750,000 ASHP	**Smart Moveable Load** 20%
Min Inertia Level None	**Min No of Synchronous Generators ('Min Units')** 4	**SNSP Limit** 95%
AI RES Target 72%	**No local constraints**	**VRE Curtailment** ~7%

Figure 12: Overview of 2030 Base scenario

Lower Flexibility: This scenario explores the importance of flexibility in the system and we deliberately model a SNSP limit of 75% within a system that is inherently less flexible than the 2030 Base Scenario. The generation portfolio is the same as the 2030 Base Scenario.

	Min Inertia Level	Min No of Synchronous Generators (‘Min Units’)	SNSP Limit
2030 Base	None	4	95%
Lower Flexibility	17,500 MWs	6	75%

Table 1: Differences between Lower Flexibility Scenario and 2030 Base Scenario

Lower Electrification: In this scenario, we explore the relationship between the electricity system and wider energy system decarbonisation and in particular we model a 20% reduction in the uptake of electric vehicles and heat pumps.

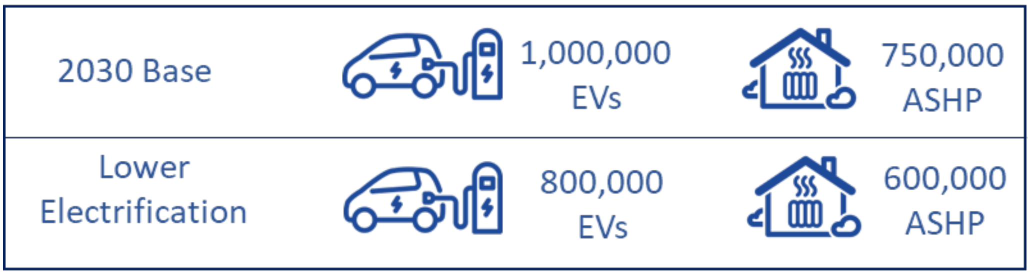


Figure 13: Differences between Lower Electrification scenario and 2030 Base Scenario

Weather Years Scenario: We undertake a ‘*Dunkelflaute*’ analysis (cold and calm snap) where we simulate a large number of historic weather years to understand how the electricity system operates in long periods of cold and calm weather.

Within each scenario a number of sensitivities are introduced to determine specific impacts around the 2030 Base Scenario. These sensitivities include:

1) An increase in wind capacity
2) Removal of Min Units constraint on All-Island System
3) Increased levels of 'smartness' (i.e. flexibility) in EV and Heating loads
4) The impact of a Carbon Capture and Storage (CCS) plant on All-Island emissions
5) The impact of varying generation portfolios in France and the UK

	2030 Base	Lower Flexibility	Lower Electrification	Weather Years
All-Island Electricity Demand (TWh) Includes HP and EVs	53.7	53.7	53.7*	53.7*
Interconnection (MW)	2200	2200	2200	2200
% All-Island RES-E Target	72	72*	72*	72*
% SNSP Limit	95	75	95	95
Min Inertia (GWs)	None	17.5	None	17.5
Min units required online	4	6	4	4
Electrification of heat and transport	1 million EVs 750k ASHP[4]	1 million EVs 750k ASHP	0.8 million EVs 600k ASHP	1 million EVs 750k ASHP
Wind Power (GW)	11.6	11.6	11.6	11.6
Solar Power (GW)	3.3	3.3	3.3	3.3

Table 2: Core scenarios

*some values will vary with scenario and sensitivity.

[4] ASHP refers to Air Source Heat Pump

4.4 Constraints and Curtailment

The current All-Island system has a number of system wide constraints. When a system wide constraint restricts the output of a generator or group of generators it is known as curtailment. When the output restriction is caused by a local network issue where the physical infrastructure of the grid cannot accommodate all of the generation it is a local constraint. In 2019, the combined amount of curtailment and constraint (also known as dispatch down) for the All Island power system was 7.7% with 4% attributed to constraints and 3.7% attributed to curtailment [18]. In this study, local constraints are not considered and only system wide constraints (i.e. curtailment) are examined. This includes reserve provision in addition to the other constraints such as SNSP, Min Units and min inertia and are specified in Table 2. Other EirGrid/SONI operational policies are not included. Where there is no inertia constraint prescribed it is assumed that inertia is provided from other sources such as synchronous condensers and/or new technologies. These were not explicitly modelled.

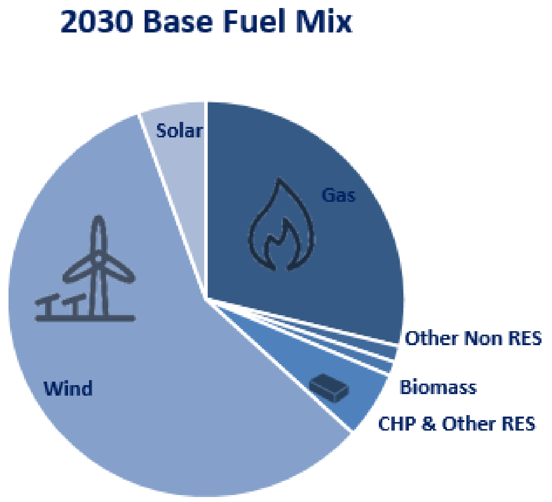
5 Results and Discussion

High level results for each scenario are introduced followed by a comparison of scenarios and insights from individual sensitivities.

Key messages:

- **Achieving a high RES-E ambition across the All-Island system requires the SNSP to increase to over 85%, grid constraints removed and continued investment in flexibility and infrastructure. Without this, emissions will increase.**
- **Conventional generation plays a necessary role in generation, system services and flexibility. The required Gas fired capacity is similar to today but will run for fewer hours and produce less energy.**
- **Electrification of new loads in heat and transport play an important role in wider system decarbonisation. Slower uptake on technologies such as heat pumps and electric vehicles may reduce power system emissions, but has a net increase on energy system emissions.**

The modelled 2030 system is different in scale and configuration from the system we see on the Island today. Despite the expected retirement of some generators, the system is 60% larger in capacity. In 2030, the All-Island system is essentially a dual fuel system (natural gas and wind). However, smaller elements of other renewables play an important role in offering technology diversity. A significant driver of decarbonisation is not only the increase in renewable generation, but also the exclusion of peat and coal from the fuel mix. These units typically met up to 15% of generated power and accounted for up to 40% of emissions (2018 figures). In the scenarios, we assume that 1 of the peat generation is fired on 100% sustainable biomass in 2030 and this contributes 2 percentage points to the RES-E ambition and reduces emissions by 0.25kt CO_2eq. Other renewable elements include existing hydro, landfill gas, combined heat and power with biomass and the biodegradable portion (50%) of waste from waste to energy plants.



Sources				
Coal	Gas	Peat	Var Renewable	Other RES
0%	30%	0%	63%	7%
% Change from 2019				
-100%	-20%	-100%	160%	180%

Figure 14: 2030 Base Scenario Fuel Mix and comparison to 2019 system

5.1 2030 Base Scenario

The 2030 Base scenario achieves a 72% target across the system and sees a significant reduction in CO_2 emissions, reducing from an estimated 13.0 Mt in 2018 to 6.3 Mt in 2030 giving a carbon intensity of electricity generated of 118 gCO_2/kWh. Variable renewable curtailment is 7.1% for the year. Achieving the RES ambition requires significant flexibility and improvement in grid infrastructure across the system. In this scenario, all grid constraints are removed, the second North-South tie line is in full operation and an SNSP level of 95% is assumed by 2030.

Conventional generation plays a necessary role in generation, system services and flexibility. The system has a similar level of gas capacity to today's system (circa 5.2GW), but these generators will operate at reduced levels. While there is a **significant increase in renewable ambition across the island, the level of energy produced by gas fired generation reduces by 20% relative to 2019** (or ~ 4 TWh less). highlighting the importance of gas and associated delivery infrastructure to the system. Gas generators will operate in a technically and economically more challenging environment with more ramping events and longer hours at minimum generation. In the modelled scenario, CCGTs[5] operate for an average of 6,000 hours per year with 23% of these hours at minimum generation and averaging at ~70 starts per year. It should be noted that only 'generic' CCGT are modelled and individual generator characteristic will cause this to vary. OCGTs[6] on the other hand will operate at much lower levels but provide important capacity at times of system stress when weather driven generation is low and interconnector flows are limited. Average running hours across the fleet is approximately 87 hours with ~60% of these hours at minimum generation.

What drives the level of Gas Fired Generation in 2030?

It might seem unexpected that such a significant increase in renewable generation results in a relatively modest reduction in electricity generated from natural gas (20%). The key here is understanding the interaction between electricity demand and renewable targets.

In general, renewable targets are a poor proxy for overall emissions reduction because they don't capture the impact of increasing or decreasing energy demand. In 2030, over 70% of annual electricity must come from renewables such as wind, solar, hydro and biomass. This means that 30% of electricity load is met by gas fired generation, however this is 30% of an electricity load that is bigger than today. EirGrid estimate total electricity demand over the next ten years is forecast to grow by between 19% and 50%, largely driven by new large users, many of which are data centers. In our analysis, we assume electricity demand is 33% larger than today driven in part by electrification of new loads such as electric cars and electric heating (accounting for 50% of the increase) and new loads from Data Centers (the remaining 50% of the increase). The net impact of increased renewable ambition and increased growth in demand is a modest reduction in overall thermal generation.

[5] Combined Cycle Gas Turbine
[6] Open Cycle Gas Turbine

Battery and other storage play an important role in absorbing weather driven variability. Batteries provide benefits in terms of reserve provisions, storage and reduce ramping across the system. Batteries operate at an annual capacity factor of approximately 16%.

5.2 Lower Flexibility Scenario

With lower levels of system flexibility, we are unable to reach a RES-E ambition of 70%. It results in a level of 66% RES-E but with significant levels of variable curtailment (16%) making the financing of renewable projects highly challenging. All-Island emissions are 7.2 Mt, 14% higher than the 2030 Base Scenario**. In this analysis, we find that an SNSP level of at least 85% across the Island must be achieved to meet a RES ambition of at least 70%.**

5.3 Lower Electrification Scenario

We model a lower uptake of EVs and Heat Pumps (200,000 less EVs and 150,000 less ASHPs) in the All-Island System in 2030. Lower uptake of EVs and Heat Pumps naturally leads to a lower electricity demand and results in lower emissions of 0.1 Mt in the electricity system. However, the resulting emissions in the wider energy system are higher by 0.9 Mt[7]. The net system wide impact is that these lower levels of electrification lead to a net increase of 0.8Mt.

From a climate policy perspective, the impact is more nuanced for Ireland as it has obligations to reduce emissions in the non-ETS sectors by 30% relative to 2005. The impact on Ireland's Non-ETS targets are the gross emissions (rather than net) as once new loads are electrified, they transfer to the ETS sector regardless of whether net emissions are lower or not.

[7] The underlying assumptions here are that an ASHP replaces an oil-fired boiler (3.5t CO_2) and an EV replaces a petrol car (1.8t CO_2).

	2030 Base	Lower Flexibility	Lower Electrification
All-Island RES-E (%)	72%	66%	73%
CO_2 Emissions (Megatonnes)	6.3	7.2	6.2[8]
Carbon Intensity (g/kWh)	118	135	115
Variable RES Curtailment	7%	16%	8%
Conventional Gas Generation (GWh)	15942	18117	15471
Wind and Solar Generation (GWh)	34971	32008	34742
Other Generation (GWh)	4403	4377	4397
Average Running hours per CCGT	5971	7279	5825
Average Hours at Minimum per CCGT	1390	2449	1349
Net Exports from All-Island	1344	2780	2055

Table 3: Overview of Main Scenarios

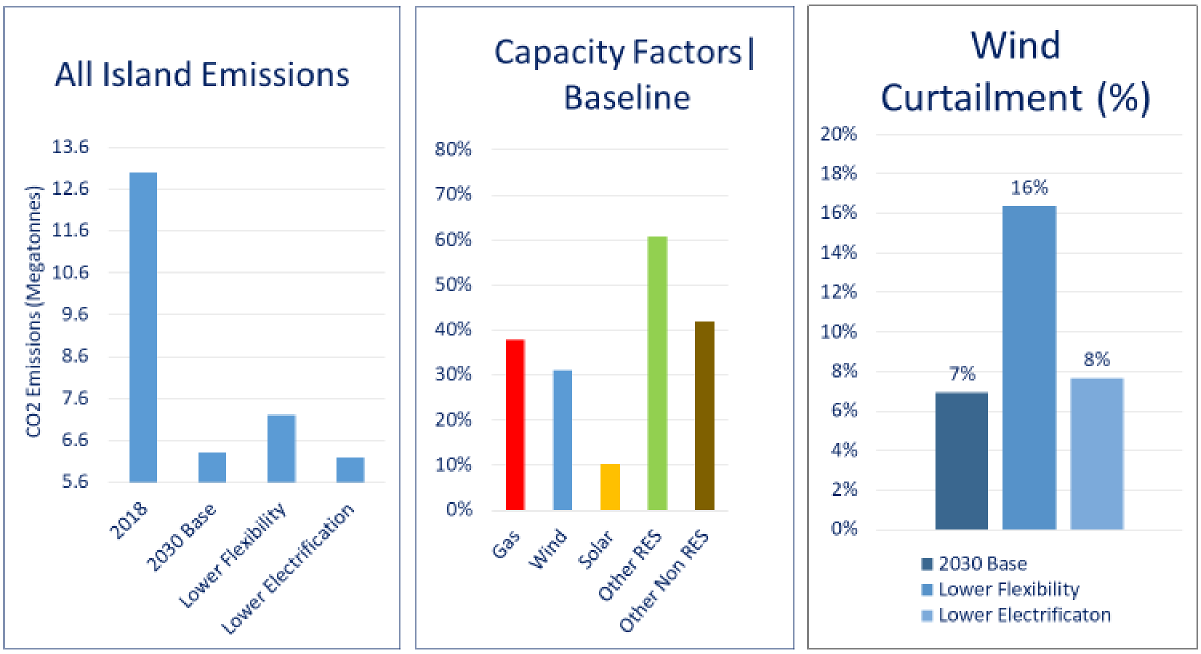


Figure 15: CO2 Emissions, Capacity Factors and wind curtailment for presented scenarios

5.4 Weather Years Scenario

The so called “Kalte Dunkelflaute” (German for “cold dark doldrums”) describes an extended period with very low outside temperature as well as low production of wind and solar energy. This weather phenomenon is frequently seen, e.g. in Germany from 16 to 26 January 2017, with up to 90% of the generation coming from conventional power generators at peak demand. With higher electrification of final demand

[8] The energy system wide impact is a net increase of 0.8Mt.

sectors, especially the residential and tertiary sector, and high penetration of renewables in the power market, the “Kalte Dunkelflaute” becomes an important security of supply test for an evolving energy system. **In this analysis, we simulate the EU Wide Power System with over 250,000 hours of weather data (30 years) to examine how the All-Island System operates during 2-week periods of low generation from wind and solar.**

In general, across the island of Ireland Atlantic low-pressure systems are well established in our weather systems by December, and depressions move rapidly eastward in December and January, bringing strong winds with rainfall. Occasionally a cold anticyclone over the UK and Europe extends its influence westwards to Ireland, giving dry cold periods lasting several days. Very cold winter temperatures accompanied by low wind speeds are often attributed to persistent high-pressure systems over the British Isles, described as a ‘low wind cold snap’. Cradden et al examined the prolonged cold spells which were experienced across the island of Ireland in the winters of 2009–10 and 2010–11. While electricity demand was relatively high at these times, wind generation capacity factors were low. There still remains a high degree of variation within individual seasonal results and the most useful aspect is in identifying the potential for more unusual extreme events in a given season [19].

While these occurrences are infrequent, they profoundly impact the design of a robust and reliable electricity system, not only for the All-Island system but for the wider north western European region as they tend to impact a wider geographic region which has knock on consequences for flows on interconnectors.

In this analysis, we examine 30 historical years of hourly European weather data and simulate the full system with individual weather years. In particular, we focus on 4 specific events all over 2-week periods: A) maximum generation of variable renewables. B) minimum generation of variable renewables. C) highest generation of conventional gas fleet and D) period with lowest capacity margin.

The analysis highlights how remarkably flexible the All-Island system will have to be to deal with a wide and extreme variation in weather events. At times the system will produce more renewable generation (Pane A) than can be used, stored or exported, while it must also be resilient and reliable to deal with periods (Pane C) when gas, conventional generators and interconnectors will provide the bulk of weekly generation and demand side response units and batteries help on shorter timescales. There will also be short periods of system stress where all available conventional generation is called upon (Pane D) to ensure supply is met.

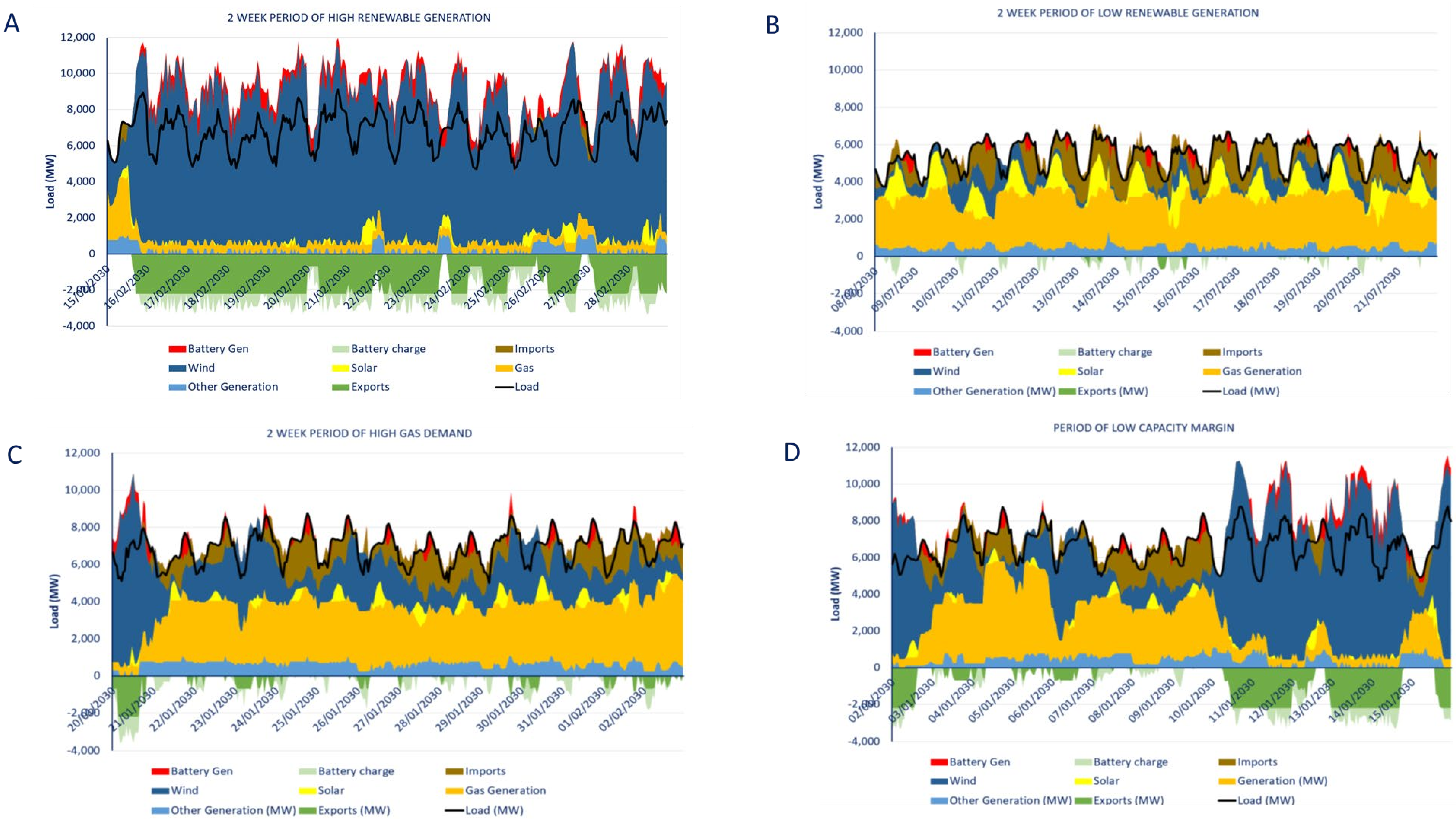


Figure 16: Weather Years Scenario: A) High wind period, B) Low wind period, C) High gas generation period and D) Low capacity margin.

Dealing with prolonged periods of low weather driven generation in the All-Island system is not trivial, and while conceptual solutions involving batteries, large scale storage and increased interconnection are appealing, the issue is not an easy one to solve.

A challenge with using electrical storage, such as batteries, in conjunction with weather driven renewable generation is the scale required to store enough energy for a prolonged period with low weather availability. Storage technologies such as batteries have many uses over short time scales and can provide important services to the grid, but current technologies cannot economically provide the scale of capacity to operate an electricity system on variable renewable generation alone. For example, if we consider the 2-week window of low wind speeds in Pane C, approximately 65 million Tesla Power walls (assuming 13.5kWh per unit) would be required to provide energy for this period.

We also examine the role of interconnectors and in particular we focus on the direction of flows in terms of export and import to the All-Island system at individual hours of the days across the sample of 30 years of weather data.

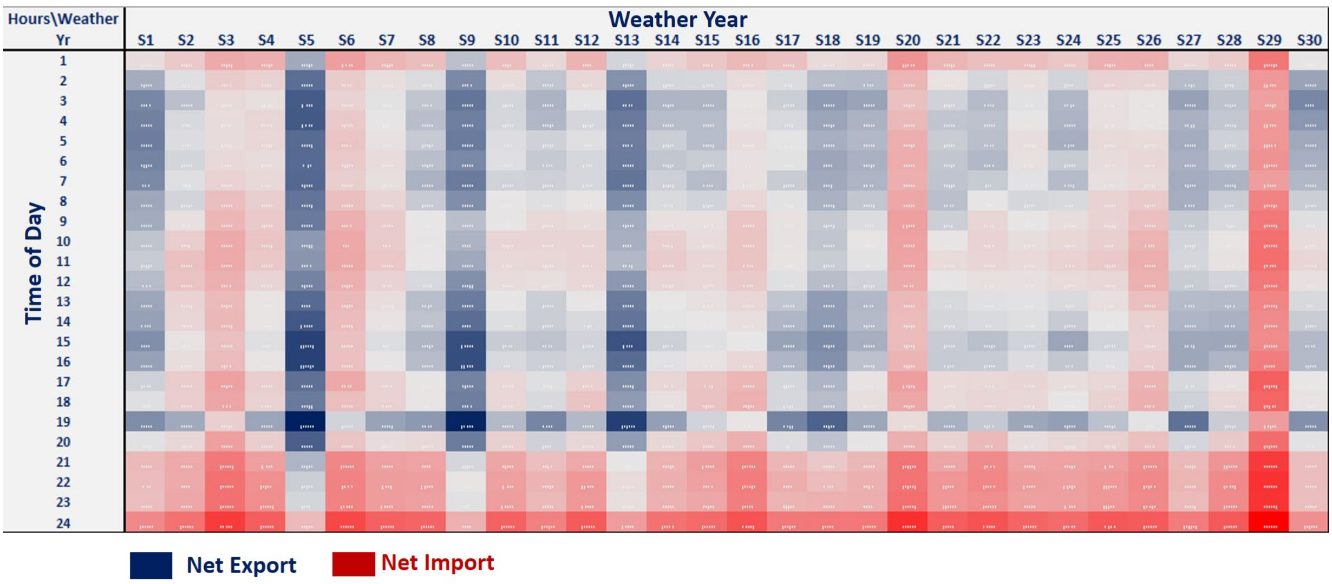


Figure 17: Average hourly direction on interconnector flows for hours of the day (y-axis) and 30 different weather years (x-axis). The stronger the colour (blue or red) the larger the magnitude of flow.

The analysis of interconnector flow shows that an individual weather year has an important impact on the direction of flow (net import or net export) and magnitude of flow. On balance the All-Island system is a net exporter of power, but low wind years change this (for example S29). It can also be seen that at time of peak demand (18:00) the flow on the interconnector is again influenced by the overall weather year.

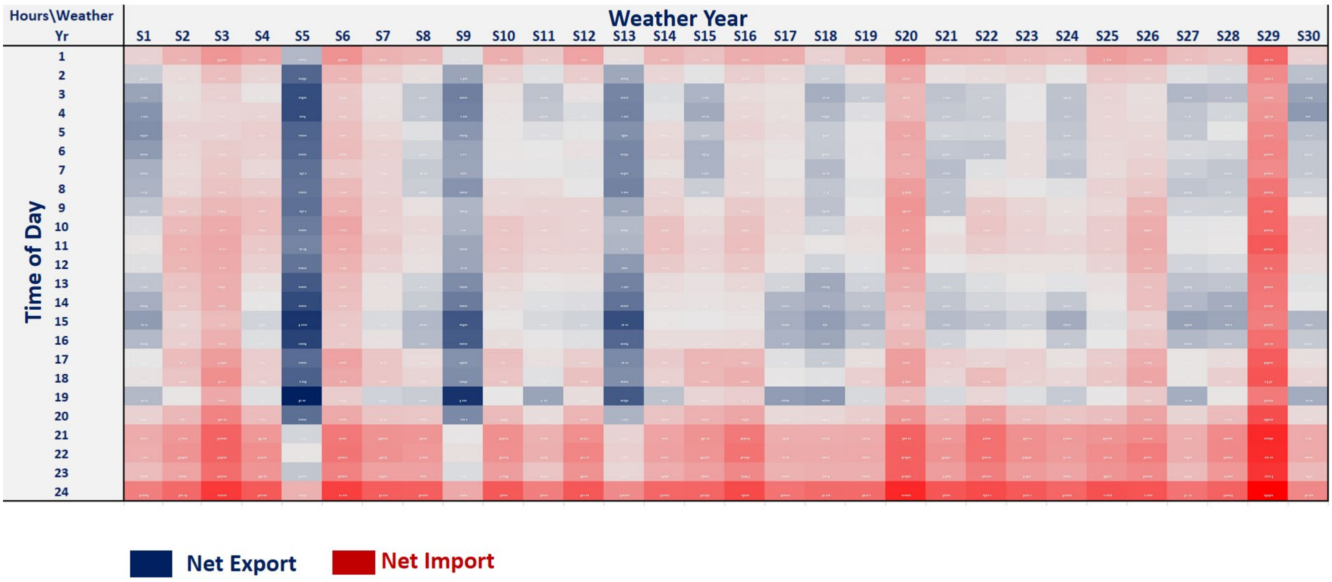


Figure 18: Sensitivity on average hourly direction on interconnector flows for hours of the day (y-axis) and 30 different weather years (x-axis). The stronger the color (blue or red) the larger the magnitude of flow. In this scenario GB and UK have 10% more wind

A further scenario was considered (above) where the level of wind capacity in France and Great Britain was increased by 10%. The impact of this change was the increase the overall level of net import in to the All Island system and decrease the overall net exports. However, the dominant driver of net interchanges was the weather year with overall hourly flows seeing smaller changes.

5.5 Sensitivities

The following sensitivities are considered in the next section:

1) Removal of Minimum Units (Min Units) constraint on All-Island System
2) An increase in wind capacity
3) Increased levels of 'smartness' in EV and Heating loads
4) The impact of a CCS plant on All-Island Emissions and
5) The impact of varying generation portfolios in France and the UK

Note: In all sensitivities the 2030 Base Scenario portfolio remains static.

5.6 Removal of Min Units constraint on the All-Island System

To enable the secure and reliable operation of the All-Island power system the system operator needs to apply some operational constraints. In 2020, this means that a number of conventional generators in various locations are required to run to assist the system with inertia, voltage stability, reserve and other technical elements. For 2030 we have assumed that some of these operational constraints are required, including a requirement for a minimum number of generation units referred to as the Min Units constraint. Within the scenarios modelled for 2030, curtailment of weather driven generation is largely influenced by system constraints such as Min Units and the SNSP limit. With substantial renewable capacity additions required to achieve 2030 targets, there is likely to be continued stress on curtailment unless steps are taken to relieve these constraints. We assume a Min Units constraint of 4 units (unless stated) across the system, and in this sensitivity, we remove the constraint to understand the impact on emissions and the system.

While Ireland is leading the world in research in this area, it is not yet clear what the cost and technical implications would be of removing this constraint. Investment would likely be needed in synchronous condensers, flywheel storage, or novel synthetic inertia schemes needed for scenarios where conventional generation is not meeting the inertia constraint to maintain ROCOF at 1Hz/s. Therefore, this sensitivity should be seen as a contribution to the conceptual understanding of outcomes rather than a clear indication of what will happen.

Removing the Min Units constraint of 4 units in the 2030 Base Scenario reduces All-Island emissions by 0.8Mt (6.3Mt→5.5Mt) and reduces variable renewable curtailment to 5.8%. The impact on conventional generation is significant with average annual running hours for a CCGT reducing from nearly 6,000 hours to just over 4,300 hours with 10% of these hours at minimum level.

5.7 Increased wind capacity

This sensitivity explicitly explores increased wind capacity levels from the 2030 Base scenario. This scenario fully incorporates the Irish government's plan to deploy up to 5GW of offshore wind by 2030. To limit curtailment a subsequent increase in battery capacity from 1.1GW to 3.5GW and an increase in interconnection capacity from a base case of 2.2GW to 5.0GW is required. The gas capacity remains the same as the base case to ensure that demand can be met during periods of system stress or low wind generation.

The increase in wind capacity makes a strong contribution to the All-Island renewable energy level from 72% to approximately 97% and the associated emissions reduction is ~1.3Mt from the 2030 Base scenario. This scenario sees significant exports of power and presents a challenge for policy makers as it highlights a divergence in outcomes between renewable energy policy and decarbonisation policy. In the absence of a cooperation mechanism which accounts for providing decarbonized electricity to other countries, the All-Island system will only realize marginal carbon reduction benefits of being a major exporter of power.

The increased wind capacity has an impact on the conventional generation fleet, reducing annual average operating hours from approximately 6,000 hours to approximately 5,100 hours with 27% of this time at minimum generation. A further sensitivity was undertaken where in addition to the extra wind capacity the full relaxation of the Min Units requirement for 4 units is also assumed thus simulating a remarkably flexible system. In this ambitious sensitivity, All-Island emissions reduce to 3.4Mt (6.3Mt → 3.4Mt) and the average running hours for conventional generators (CCGT) reduce to below 2,600 hours. The average fleet wide capacity factor for conventional generators (CCGT and OCGT) is 30%, a reduction from the 40% capacity factor reported in 2019.

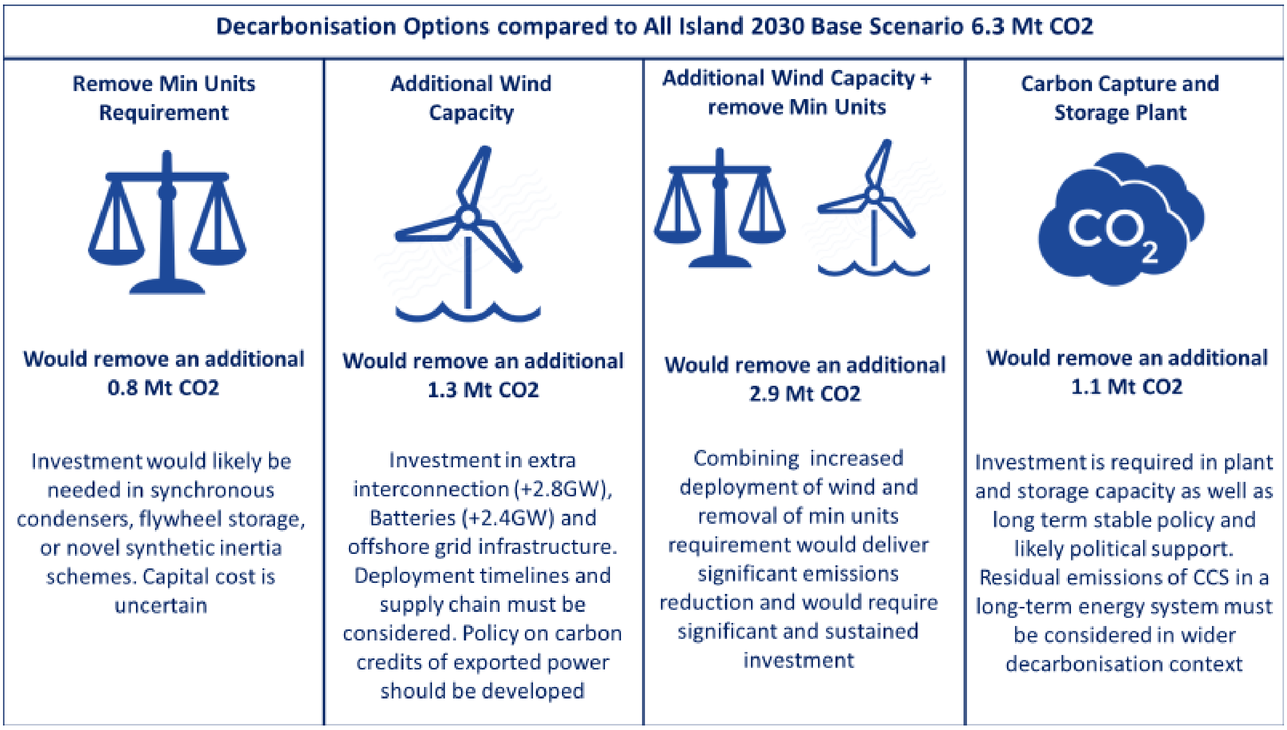
5.8 Increased levels of ‘smartness’ in EV and Heating loads

In this sensitivity, we examine the impact of increased levels of ‘smartness’ in demand side loads for residential heating and EVs. In the 2030 Base scenario, it is assumed that 20% of the daily demand is movable and within the optimization framework these loads are placed at periods of the day that lead to the most efficient operation of the systems in terms of costs and emissions. Constraints are applied, however, to reduce unrealistic outcomes such as a very high volume of a smart load in one-time period thus creating a significant ramp event within the system. In this sensitivity the level of smart load is assumed to increase to 40%. Results show that the impact is relatively small in terms of emissions reduction with a reduction of 0.1Mt relative to the 2030 Base Scenario.

5.9 The impact of a Carbon Capture and Storage plant on All-Island Emissions

Carbon capture and storage (CCS) is a uniquely important technology that features strongly in global scenarios that achieve Net Zero emissions in line with the Paris Climate Agreement [20]. The Committee on Climate Change in the UK has recommended that carbon capture technology is investigated as a potential method for decarbonizing Northern Ireland’s power sector and the Climate Action Plan in Ireland has established a Steering Group to examine and oversee the feasibility of the utilization of CCS in Ireland.

In this sensitivity, we assume that a gas fired generator is converted to CCS with a capture rate of 85% (a plant carbon intensity of approximately 60 gCO_2/kWh) and carbon is removed (post combustion) from the exhaust and injected deep below the ground, so it cannot enter the atmosphere and contribute to climate change. Results of the sensitivity indicate that All-Island emissions would reduce from the 2030 Base scenario of 6.3Mt to 5.2Mt. The impact on conventional power generators is relatively benign as the CCS plant is assumed to be a ‘must run’ unit and so overlaps with the Min Units requirement of 4 units to be online.



Decarbonisation Options compared to All Island 2030 Base Scenario 6.3 Mt CO2			
Remove Min Units Requirement	**Additional Wind Capacity**	**Additional Wind Capacity + remove Min Units**	**Carbon Capture and Storage Plant**
Would remove an additional 0.8 Mt CO2	**Would remove an additional 1.3 Mt CO2**	**Would remove an additional 2.9 Mt CO2**	**Would remove an additional 1.1 Mt CO2**
Investment would likely be needed in synchronous condensers, flywheel storage, or novel synthetic inertia schemes. Capital cost is uncertain	Investment in extra interconnection (+2.8GW), Batteries (+2.4GW) and offshore grid infrastructure. Deployment timelines and supply chain must be considered. Policy on carbon credits of exported power should be developed	Combining increased deployment of wind and removal of min units requirement would deliver significant emissions reduction and would require significant and sustained investment	Investment is required in plant and storage capacity as well as long term stable policy and likely political support. Residual emissions of CCS in a long-term energy system must be considered in wider decarbonisation context

Figure 19: Summary of decarbonisation options for sensitivities undertaken. Note that measures are not additive.

5.10 System Services

System services are required to ensure secure and reliable operation of the power system to the required standards. Such services include frequency response, reserve, system inertia and so on. Across all the 2030 scenarios we have assumed some level of advancement of technologies which leads to the relaxation of the SNSP and Min Units requirements from where they are today. This results in a reduction in run hours for conventional generation. It is inevitable that opportunities for conventional generation to gain income regularly from some system services will diminish with the reduction in run hours.

Figure 20 shows the duration curves of available operating reserve[9] from conventional generation for the 2030 base scenario. This is significantly different to the situation in 2020 where a minimum level of these categories of operating reserve are always available from conventional generation. When the Min Units constraint is removed the available provision of these reserves from conventional generation reduces even further. The additional interconnectors to France and the UK, provide system service benefits in addition to the import/export potential. In 2030, batteries, interconnectors and DSM[10] will dominate the provision of reserve in operating reserve categories such as Fast Frequency Response (FFR), Primary Operating Reserve (POR), Secondary Operating Reserve (SOR), Tertiary Operating Reserve 1 & 2 (TOR1 and TOR2).

[9] Operating reserve refers to additional power that is required following a system disturbance. The timeframe in which the Megawatts are delivered determines the category of reserve. FFR is provided between 2-10 seconds, POR between 5-15 seconds, SOR between 15-90 seconds, TOR1 between 90 seconds and 5 minutes, TOR2 between 5 – 20 minutes.
[10] Demand Side Management

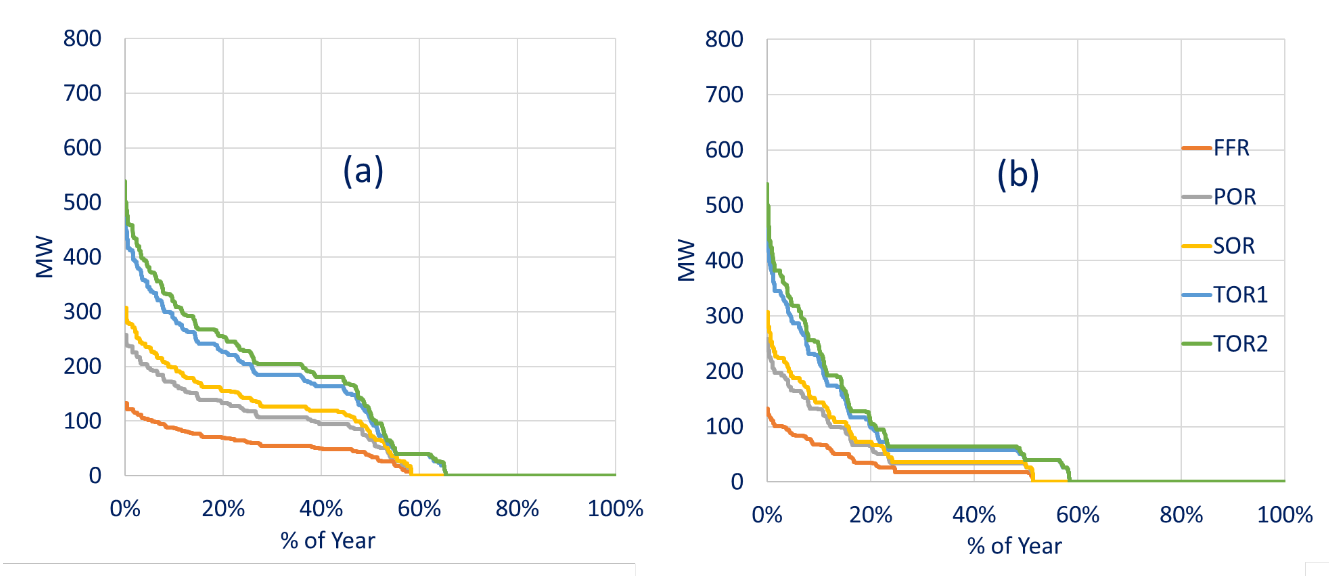


Figure 20: Reserve available from conventional generation for (a) 2030 Base scenario and (b) 2030 Base scenario with Min Units constraint removed

Ramping margin is another type of system service. It is designed to ensure that the system is capable of coping with variability, particularly that caused by wind generation, and the risk that the levels of wind forecasted may be under or over estimated. There are currently 3 categories of ramping margin that have different time horizons and durations[11]. Conventional generation remains important year-round for the longer horizon ramping margin Ramping Margin 8, as battery technology is not expected to extend beyond a 4-hour storage duration by 2030.

The reduction in run hours for conventional generation also indicates that there will be less inertia and therefore less synchronous inertial response (SIR) available from conventional generators compared to 2020. However, the requirement to limit the rate of change of frequency (ROCOF) to 1Hz/s is not expected to be relaxed any further by 2030. Therefore, to reduce the Min Units requirement, additional low or zero carbon sources of inertia will be required. Proven technologies such as synchronous condensers and flywheel storage may form part of the solution, but new and innovative technologies will also be required. Appropriate market arrangements or incentives will be required to encourage investments in these technologies. The "*Dunkelflaute*" analysis demonstrated that conventional generation is still required in 2030 to provide generation and system services at times of system stress or low

[11] The system services Ramping Margin 1, 3, 8 refer to the increased megawatt output that can be delivered with a good degree of certainty for the given time frame of 1, 3 or 8 hours and maintained for a duration of 2, 5 or 8 hours respectively.

wind and so any market arrangements or incentives will have to be designed in a way that is mindful of this reality.

5.11 Expenditure and Investment Required

Significant investment must be made across both the power system and wider energy system in order to achieve ambitious levels of emissions reduction on the All-Island system. Here we estimate the 'overnight' investment required to achieve the level of emissions reduction presented in the 2030 Base scenario. Reaching this level of emissions reduction will require additional related expenditures of ~32€ billion. This is broken into the categories power plant such as wind turbines and solar panels, infrastructure such as electricity grid and non-grid system services costs in Figure 21.

Public data is available for the estimation of system services costs for the early years of the next decade. The methodology used to estimate the system services costs for the year 2030 is based on the methodologies adopted in the EU SysFlex Project [21]. Interpolation is then used to estimate the system costs for the remaining years up to 2030. Note that while all the costs in Figure 21 are simplified and draw on existing information in the public domain [14, 22-25] (see also Appendix for more detail), they give an important sense of the investment required. An in-depth analysis is necessary to assess more accurately the total cost related to high penetration of renewables in the All-Island system.

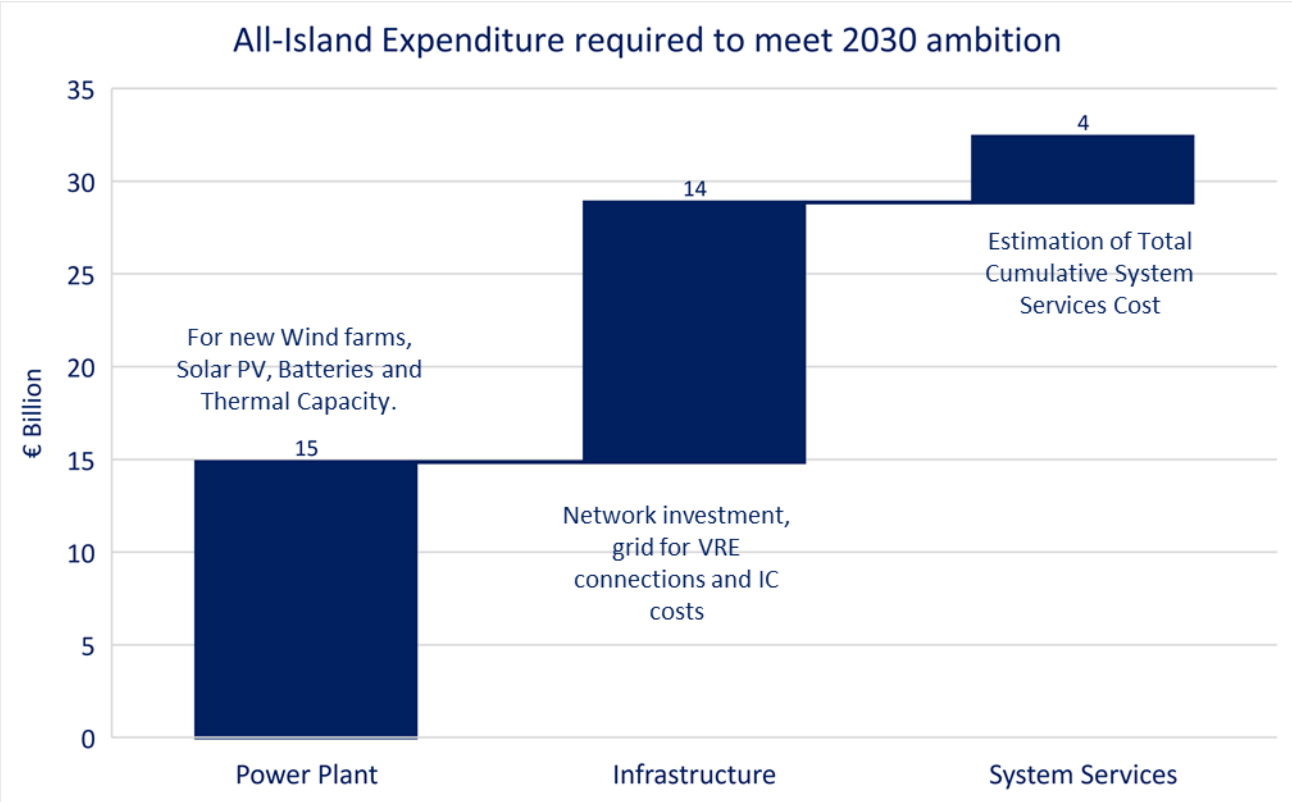


Figure 21: Investment and capital expenditure required for the 2030 Base Scenario

The figure above excludes investment in the wider energy system such as the need for retrofitting homes, the installation of heat pumps and charging infrastructure for EVs which is also estimated at a further 30€ billion (this excludes EV vehicle costs and associated subsidies). These costs are important as they allow the wider energy system to leverage on the accelerated decarbonisation and improved efficiency of electricity as a decarbonisation vector. The cost of bringing a home to a cost optimal standard is determined by a number of factors including the size and type of home as well as the starting condition of the home. A cost-optimal analysis commissioned by the Department of Housing, Planning and Local Government in Ireland estimated the cost to achieve a B2 rating from a starting point of a D or E rating to be in the range of €21,000-€39,000. The costs considered in this study were focused on the system and investment costs. The cost to the consumer is another important aspect that needs to be studied and may form part of future work.

6 Post 2030 and Pathways to Net-Zero

A number of countries such as the United Kingdom, Sweden and France have set ambitious targets of net carbon neutrality (also known as Net Zero) by 2050 or earlier. The EU along with several countries, including Ireland are also considering a Net Zero target. Net Zero means that total greenhouse gas emissions would be equal to or less than the emissions removed from the environment. This can be achieved by a combination of emission reduction and emission removal.

Decarbonising electricity production is integral to achieving a Net Zero energy system and has already been made a primary goal in the strategies of key All-Island stakeholders such as the Commission for Regulation of Utilities, Water and Energy (CRU), the Utility Regulator in Northern Ireland, and the Transmission System Operators (TSOs) EirGrid and SONI.

In Northern Ireland, the Department for the Economy, began the process of developing a new energy strategy to identify potential pathways to reach a Net Zero 2050 target for the energy sector in Northern Ireland while meeting the energy needs of the population sustainably and in a cost-effective manner. Results of a stakeholder analysis were published in June 2020 [6] and an Energy Intelligence Branch has recently been formed within the Department to focus on energy systems modelling and analysis. This will provide insights on the costs and benefits of different choices from across the whole energy sector on pathways to Net Zero.

In Ireland, the support of a Net Zero economy by 2050 has been reaffirmed in the 'Programme for Government – Our Shared Future' report published in June 2020 [11]. The report states that the government is committed to reducing annual emissions by 7% in the next decade followed by a number of new carbon budgets which will be set out by a newly established Climate Action Council that will enable the 2050 target to be achieved through proposed decarbonisation pathways.

The end point for a Net Zero ambition is a significant reduction in emissions in all elements of the All-Island economy. In particular, the role of land use, land use change, and forestry (LULUCF) and emissions removal technologies becomes important for achieving the final goal of Net Zero because some emissions will remain in hard to decarbonise areas such as heavy transport, agriculture and heavy industry.

An example below is from the European Commission's analysis of pathways to Net Zero for the EU as a whole. In the analysis, the EU power system is carbon neutral by 2040 and emissions removal are required thereafter to compensate for residual emissions in other sectors.

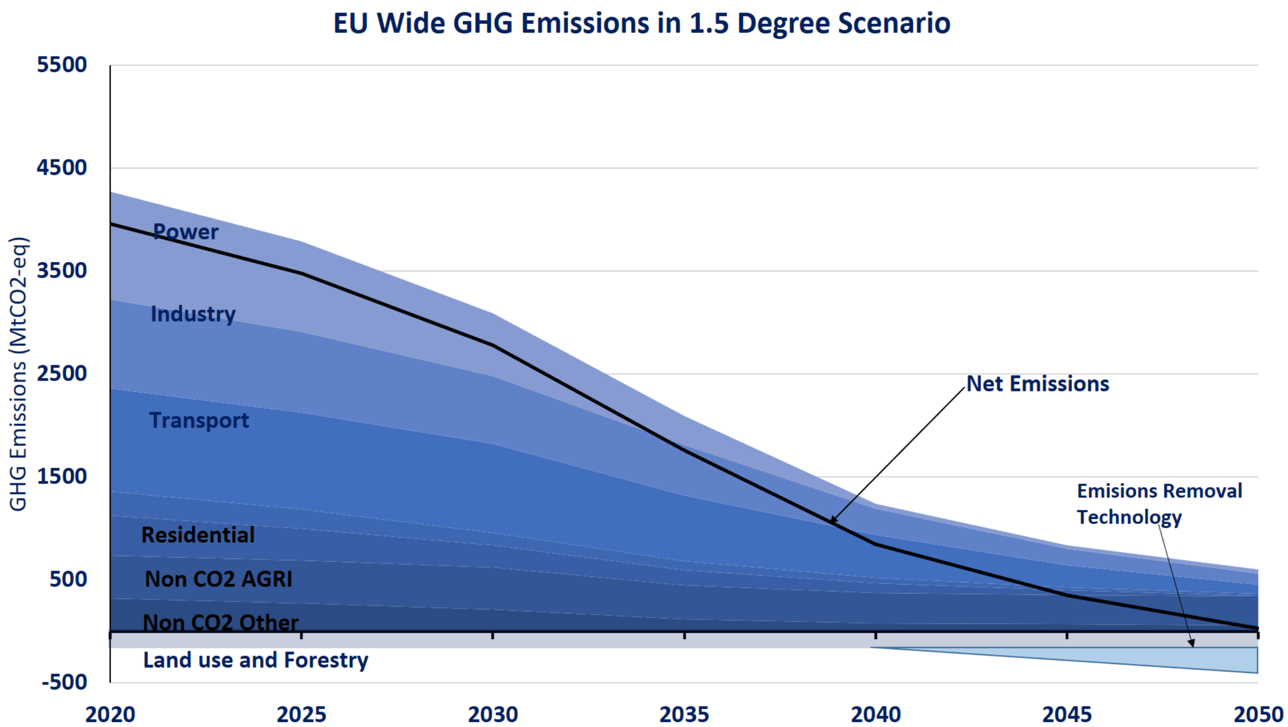


Figure 22: Emissions reduction trajectory for carbon neutral European economy.

Researchers from MAREI (Glynn et al) [26] have previously investigated the implications for the electricity system of a Paris Agreement compliant power sector in Ireland under varying assumption of carbon budgets reflecting different levels of historic responsibility. Note that the analysis was undertaken for Ireland and not the All-Island system. To date, no All-Island analysis has been undertaken.

The cumulative carbon budgets for Ireland utilised in the MAREI analysis range from 766 $MtCO_2$ to 128 $MtCO_2$ from 2015. They are derived from the Irish population share of 0.064% of the global population and the same 0.064% share of the remaining global carbon budgets. These carbon budgets relate to a 66% probability of achieving a 2°C limit, to a 50% probability of reaching a 1.5°C limit, and are chosen to span the technically feasible range of territorial mitigation. This approach can be justified by the fact that Irish population as a percentage of the global population has been remarkably stable over the last 50 years and is projected to remain so. In all, 38 scenarios explored the range of potential energy system changes under differing effort-sharing carbon budgets based on equitable per capita shares of the remaining global carbon budgets.

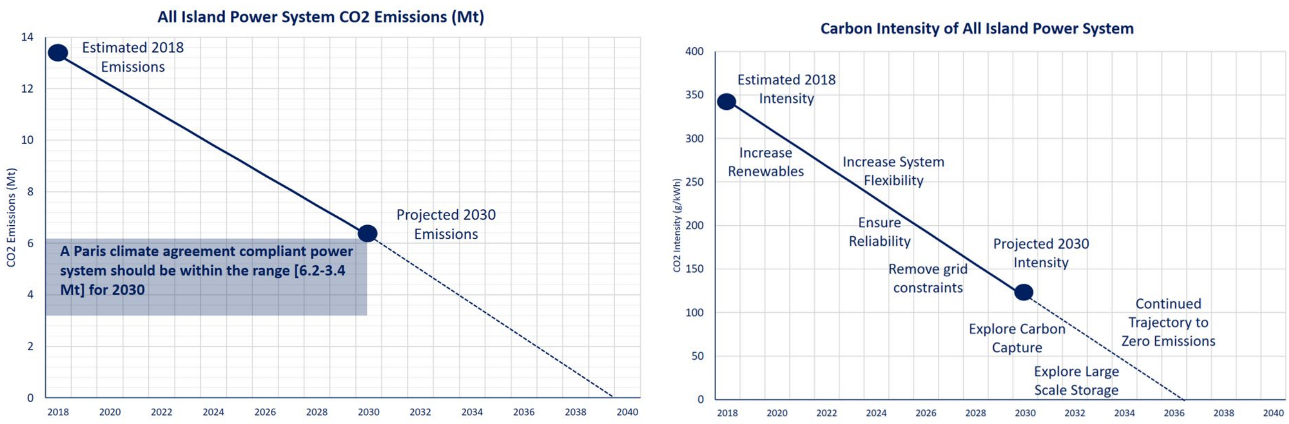


Figure 23: All-Island Absolute Emissions and Emissions Intensity projected to 2030. Note measures in RHS figure are indicative only and are not presented in any specific order

Results show that All-Island power system emissions should not be greater than 6.2 Mt in 2030. This is assuming that the distribution of CO_2 emissions between Northern Ireland and Ireland remains at the same level as 2018 (i.e. 24% attributed to Northern Ireland and 76% attributed to Ireland). The overall carbon envelope for the power system is between 6.2 Mt and 3.4 Mt and current projections show that the future All-Island 2030 system is just on the outer envelope of this range. Efforts to reduce emissions as outlined in Figure 23 should be explored to bring the system in line with expectations and reduce the burden of decarbonisation post 2030.

Beyond 2030 there are a number of technology choices that could offer further decarbonisation potential and it is not clear which option (or mixture) is most appropriate for the All Island system. What is clear however is the need for further decarbonisation. Several technologies could be considered for assisting in the decarbonisation of the conventional fleet beyond 2030. Some technologies may be more suitable than others. Due to the time it takes for such projects to be developed, it is recommended that a cost benefit analysis of the options is completed in the short-term to identify which technologies are best suited to the All-Island power system, Ireland and Northern Ireland.

6.1 The role of negative emissions technologies in the power system

While the climate science of mitigating energy related emissions is often complex it can be distilled into simple elements which reflect the overarching implications for the power sector. Namely:

- The less mitigation that takes place in areas outside of electricity, the more the electricity sector will have to do in terms of emissions reduction and net removals.

- The more we change and reduce patterns of consumptions, the less we will have to rely on negative emissions technologies to reduce and remove emissions from the atmosphere.

There are uncertainties about the scale of negative emissions that may be possible in the future, and about their impacts and costs. However, 88 of the 90 scenarios in the IPCC SR1.5 report which have at least a 50% chance staying below 1.5 °C warming in 2100 rely on net negative emissions. Recent research by MAREI (Gaffney et al) [27] has also highlighted the important role of negative emissions technologies deployed in conjunction with high volume of renewables to achieve, not only emissions reduction, but also to contribute to the stable and reliable operation of the European power system. Negative emissions could particularly help offset emissions from hard-to-abate sectors, such as aviation or the manufacturing of iron, steel and cement. However, the future of such technology options is still an open question with significant uncertainty.

6.2 Hydrogen and the future All-Island Power System

In July 2020 the European Commission published its hydrogen strategy for a climate-neutral Europe [28]. This strategy brings different strands of policy action together, covering the entire value chain. It also brings the industrial, market and infrastructure angles together with the research and innovation perspective in order to create an enabling environment to scale up hydrogen supply and demand for a climate-neutral economy.

According to the EU Strategy, the share of hydrogen (H_2) in the energy mix is estimated to grow from 2% today to 14% by 2050. Large-scale deployment of clean hydrogen is required and two 'flavours' are most likely. 'Blue' H_2 is produced from natural gas and most emissions are captured with CCS while 'Green' H_2 is produced via electrolysis and renewables. Blue H_2 is cheaper but its price is dependent on gas prices and its environmental performance is linked to the success of CCS and reduction in upstream gas emissions. Green H_2 is currently more expensive and its future price is linked to reduction in costs of electrolysers and cheap renewable electricity. Both have challenges to overcome in terms of deployment rates, cost reduction and technologies advances and it is likely that both types will be required to achieve significant cumulative emissions reductions required by the Paris Agreement.

Across the island of Ireland, there is important activity in hydrogen research and development with a number of studies providing cost estimates and financial analysis [29-31]. Importantly, hydrogen must be delivered to its intended end uses, unless production and consumption are co-located. In literature, levelized cost of hydrogen (LCOH) is often reported but a difference must be made between production cost and delivered cost of hydrogen.

MaREI's EirWind project estimates that hydrogen production costs of less than €150/MWh are possible in an integrated production system which couples a 500MW wind farm to a large scale hydrogen production facility [32]. The additional delivery costs result in a final cost to customers of €240-€270/MWh of hydrogen. A challenge to understanding hydrogen potential is often the units used are non-standard and Figure 24 presents delivery costs in €/MWh and benchmarks the costs again the price of petrol (without taxes). Lifecycle emissions are also shown for comparison.

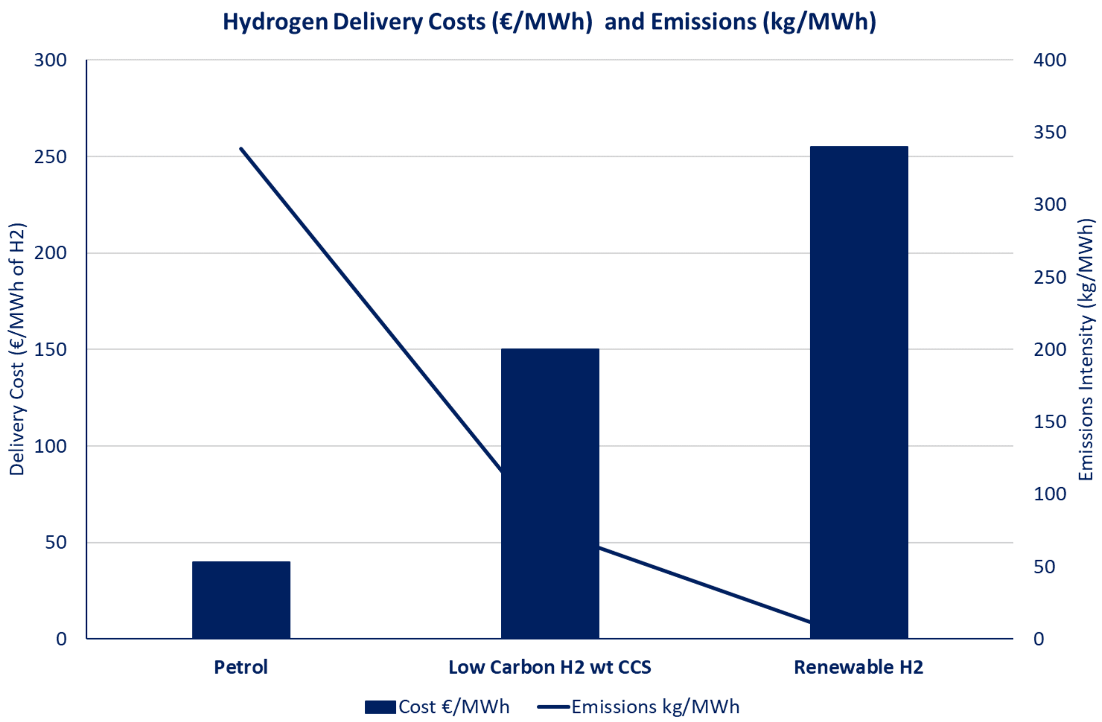


Figure 24: Hydrogen Delivery Costs compared to petrol (ex tax) and associated lifecycle emissions (right axis)

6.3 The Potential for Hydrogen in the All-Island System

Using a simplified analysis, we explore the potential for hydrogen production from the All-Island system in 2030 using **only curtailed energy from variable renewables**. This is not intended as a detailed analysis but rather an exercise to understand the potential resource available.

In the Base 2030 Scenario modelled, 2.4TWhs of renewable curtailment takes place in the All-Island system, however, much of this takes place over short periods of time with sharp spikes and the level of this curtailment that can be captured for hydrogen production is related to the size of the available electrolysis capacity. In this simplified example, we examine the potential production for increased capacity up to 500 MW. We find that in this example with 300MW of Electrolysis Capacity approximately 246 GWh of H_2 can be produced.

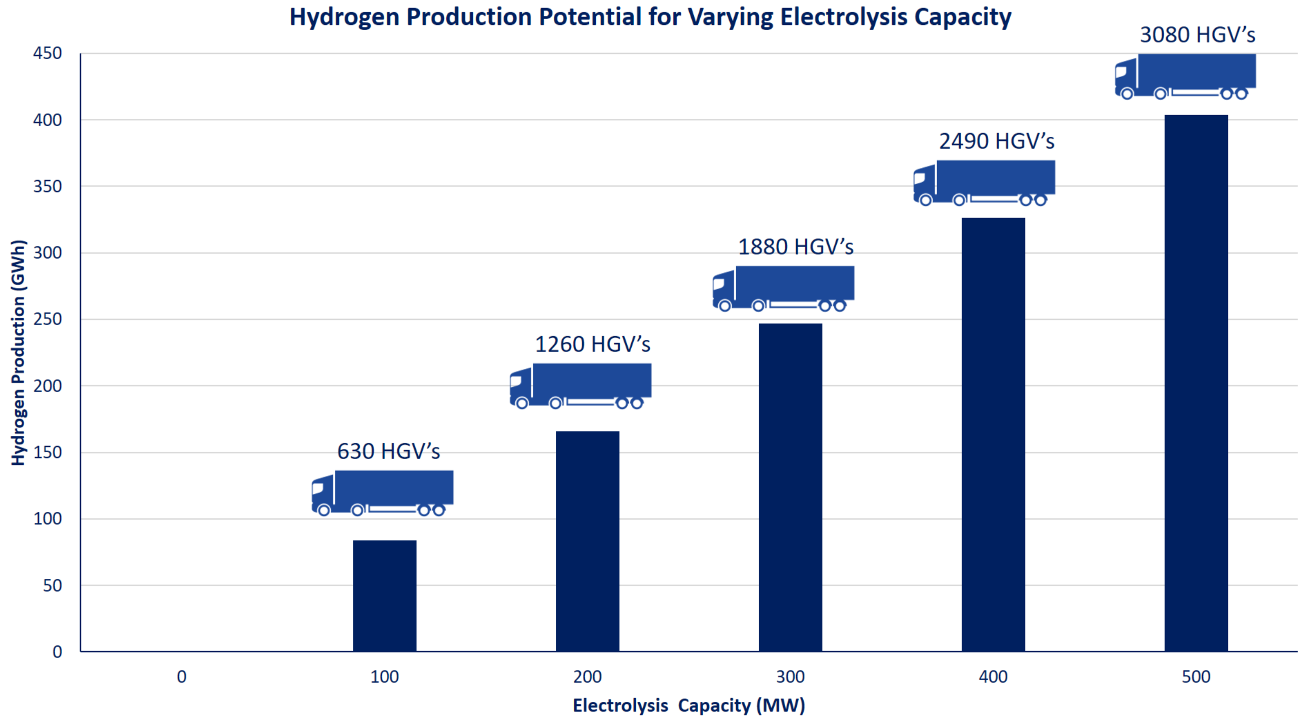


Figure 25: Simplified Hydrogen Production Potential from curtailed renewable production in 2030

This would be equivalent to the needs of 1,800 heavy good vehicles (assuming 130 MWh/pa). While the potential for hydrogen will grow with increased variable renewable production, significant research and pilot scheme deployment is required to reduce costs and fully understand the role of hydrogen in the future All-Island system. Hydrogen could also play an important role in long term energy storage on the island to provide energy in time of low wind availability. However, the economic and technology feasibility of this is not yet understood.

7 Appendix

7.1 The All-Island System and the Rest of Europe

This graphs below present the outcomes of the All-Island System in terms of carbon intensity and resulting wholesale electricity prices in comparison to other EU countries modelled.

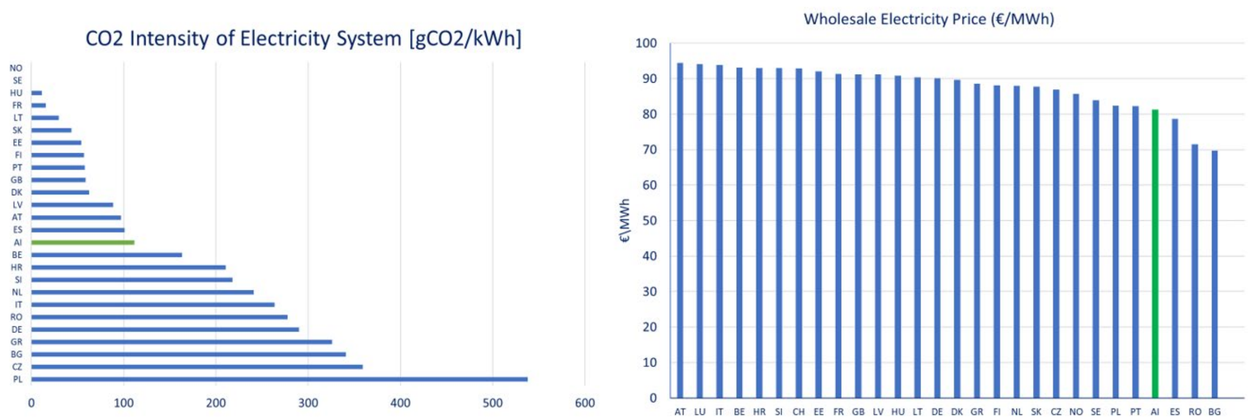


Figure 26: How the 2030 All-Island System compares in Carbon intensity and wholesale electricity prices to other modelled EU countries.

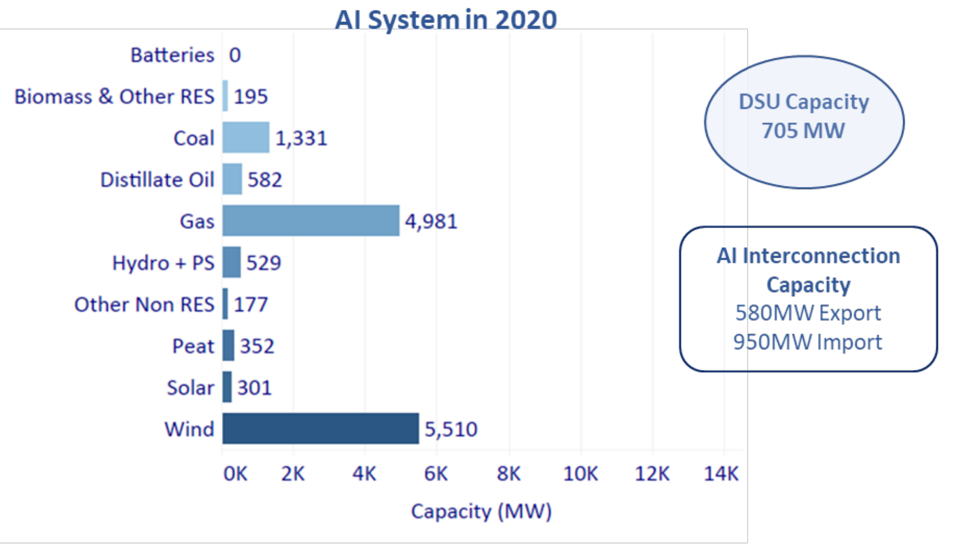
7.2 Scenario Inputs and Assumptions

	2030 Base	Lower Flexibility	Lower Electrification	Weather Years	S1 - Min Units Removed	S2 - Increased Wind	S3- Increased Smartness	S4 - CCS	S5 Varying GB + FR RES
Demand (includes EVs and HPs)	53.7 TWh	53.7 TWh	52.3 TWh	53.7 TWh	53.7 TWh	53.7 TWh	53.7 TWh	53.7 TWh	53.7 TWh
No of EVs	1,000,000	1,000,000	800,000	1,000,000	1,000,000	1,000,000	1,000,000	1,000,000	1,000,000
No of HPs	750,000	750,000	600,000	750,000	750,000	750,000	750,000	750,000	750,000
EV & HP Smart Moveable Load	20%	20%	20%	20%	20%	20%	40%	20%	20%
AI Generation Capacity (MW)									
Biomass & Other RES	455	455	455	455	455	455	455	455	455
Gas	5204	5204	5204	5204	5204	5204	5204	4754	5204
Gas CCS	0	0	0	0	0	0	0	450	0
DO	272	272	272	272	272	272	272	272	272
Wind	11634	11634	11634	11634	11634	15584	11634	11634	11634
Solar	3317	3317	3317	3317	3317	3317	3317	3317	3317
Battery	1100	1100	1100	1100	1100	3500	1100	1100	1100
Other Non RES	198	198	198	198	198	198	198	198	198
Hydro + PS	529	529	529	529	529	529	529	529	529
DSU	750	750	750	750	750	750	750	750	750

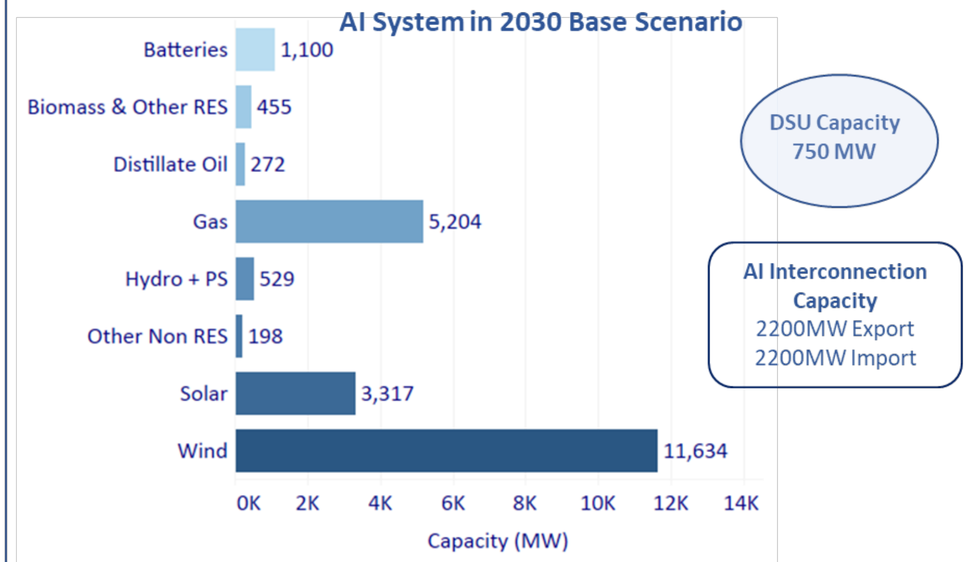
	2030 Base	Lower Flexibility	Lower Electrification	Weather Years	S1 - Min Units Removed	S2 - Increased Wind	S3- Increased Smartness	S4 - CCS	S5 Varying GB + FR RES
AI Interconnection Capacity (MW)	2200	2200	2200	2200	2200	5000	2200	2200	2200
Moyle Import/Export	500	500	500	500	500	500	500	500	500
EWIC Import/Export	500	500	500	500	500	500	500	500	500
Greenlink Import/Export	500	500	500	500	500	500	500	500	500
Celtic Import/Export	700	700	700	700	700	700	700	700	700
Additional Interconnection	0	0	0	0	0	2800	0	0	0
System									
SNSP Limit	95%	75%	95%	95%	95%	95%	95%	95%	95%
Min Inertia Level	None	17.5 GWs	None	None	None	None	None	None	None
Min synchronous generators required ('Min Units')	4	6	4	4	0	4	4	4	4
10% More GB/FR Wind	No	No	No	No	No	No	No	No	Yes
Carbon Tax €/tCO2	33.5	33.5	33.5	33.5	33.5	33.5	33.5	33.5	33.5
Fossil Fuel Price €/GJ Coal Gas Oil	 3.6 9.9 16.4	 3.6 9.9 16.4	 3.6 9.9 16.4	 3.6 9.9 16.4	 3.6 9.9 16.4	 3.6 9.9 16.4	 3.6 9.9 16.4	 3.6 9.9 16.4	 3.6 9.9 16.4

Table 4: Scenario inputs

7.3 Comparison of 2020 to 2030 Base Scenario



AI Demand ~40.2 GWh	~20,000 EVs; ~45,000 ASHP	**Smart Moveable Load** N/A
Min Inertia Level 23,000MWs	**Min No of Synchronous Generators ('Min Units')** 8	**SNSP Limit** 65%
AI RES Target ~40%	**Local constraints**	**VRE Curtailment** ~7%



AI Demand 53.7 GWh	1,000,000 EVs; 750,000 ASHP	**Smart Moveable Load** 20%
Min Inertia Level None	**Min No of Synchronous Generators ('Min Units')** 4	**SNSP Limit** 95%
AI RES Target 72%	**No local constraints**	**VRE Curtailment** ~7%

7.4 Overview of Expenditure and Investment Required

Category	Item	Cost	Units	Source	Total Costs (Million €)
Residential Requirements	Air Source Heat Pumps	11000	€/unit	SEAI	8,250
Residential Requirements	Residential Retrofits	30000	€/unit	Government of Ireland	22,500
Power Plant	Onshore Wind	1434	€/kW	IWEA 70*30 Study	7,463
Power Plant	Offshore Wind	2949	€/kW	IWEA 70*30 Study	4,129
Power Plant	PV	732	€/kW	IWEA 70*30 Study	2,428
Power Plant	Batteries	380	€/kW	IWEA 70*30 Study	836
Infrastructure	Offshore grid connections	496	€/kW	IEA Task 26	694
Infrastructure	ESB Networks 'Strategy to 2027'	10	Billion €	ESB Networks 'Strategy to 2027'	10,000
Infrastructure	Interconnection costs	1000	€/kW	UCC Own Estimation	1,200
Infrastructure	Network Costs	2.1	Billion €	IWEA 70*30 Study	2,100
System Services	DS3 Costs	3.5	Billion €	IWEA 70*30 Study/UCC Own Calculation based on EU SysFlex methodology	3,548

Table 5: Overview of Expenditure and Investment Required

7.5 Overview of results from scenarios and sensitivities

				Sensitivities			
	2030 Base	Lower Flexibility	Lower Electrification	Removal of Min Units	Increased wind capacity	Increased 'smartness'	CCS
All-Island RES-E (%)	72%	66%	73%	72%	97%	72%	72%
CO2 Emissions (Megatonnes)	6.3	7.2	6.2	5.5	5.1	6.3	5.2
Carbon Intensity (g/kWh)	118	135	115	103	95	117	94
Variable RES Curtailment	7%	16%	8%	6%	6%	7%	7%
Conventional Gas Generation (GWh)	15942	18117	15471	13759	12736	15677	19516
Wind and Solar Generation (GWh)	34971	32008	34742	35309	48513	35114	35000
Other Generation (GWh)	4403	4377	4397	4421	4396	4408	4407
Average Running hours per CCGT	5971	7279	5825	4339	5105	5861	5890
Average Hours at Minimum per CCGT	1390	2449	1349	447	1350	1309	1637
Net Exports from All-Island	1344	2780	2055	-260	11359	1248	1477

Table 6: Overview of results from scenarios and sensitivities

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