eirgrid.ie soni.ltd.uk

Tomorrow's Energy Scenarios 2023

Consultation Report

Disclaimer

While all reasonable care has been taken to prepare this document, we can make no guarantee to the quality, accuracy and completeness of the information herein. We do not accept responsibility for any loss associated with the use of this information. Use of this document and the information it contains is at the user's own risk.

Information in this document does not amount to a recommendation as regards to any possible investment. Before taking a business decision based on the content of this document, we advise that interested parties seek separate and independent opinion in relation to the matters covered by this document.

For queries relating to this document or to request a copy contact info@eirgrid.com or info@soni.ltd.uk.

EirGrid

The Oval, 160 Shelbourne Road,
Ballsbridge, Dublin 4, D04 FW28,
Ireland

SONI

Castlereagh House, 12 Manse Rd,
Belfast, BT6 9RT,
Northern Ireland

Document structure

This document is intended to provide potential future scenarios in order for EirGrid and SONI to perform a future System Needs Assessment. This document is for information purposes only and does not supersede any policies or regulatory approved documentation. The document represents the scenarios for both Ireland and Northern Ireland and is split into five sections:

Section 3 – Scenario planning

This section explains the reasoning behind using scenarios as a planning methodology as well as the publications and policies that have influenced and shaped the report.

Section 4 – Scenario storylines

Building on the previous section, Section 4 details each of the four scenarios, including aspects such as RES-E generation mix, demand growth and decarbonisation targets. There is also a discussion on the economic model used and some of the assumptions we have applied to the scenarios.

Section 5 – Electricity demand

Demand serves as a key input for TES 2023. This section provides the reasoning behind the growth in demand, consisting primarily of electrification while also discussing factors, such as energy efficiency and flexibility that will help manage peak demands.

Section 6 – Electricity generation

The generation portfolio will transform from a conventional hydro-carbon based fuel mix to primarily renewable sources. This section discusses the renewable technology mix, the dynamic role that flexible thermal generation may play in the future and the potential of new negative emissions technologies.

Section 7 – Conclusions and next steps

This report has been released as part of the TES2023 development process. In this section, we summarise the conclusions from our analysis and how to provide your feedback to the consultation.

Abbreviations and terms

Abbreviation	Term	Description
BECCS	Bioenergy with Carbon Capture and Storage	An electricity generator running on biogenic fuel(s) where CO_2 is captured and permanently stored. This is a negative emissions technology.
	Capacity Factor	A measure of energy production which states total electricity actually produced during a period of time as a percentage of total potential production if the technology was running at full output.
CCS	Carbon Capture and Storage	The process of capturing, transporting and storing the carbon dioxide produced from the combustion of fossil fuels before it is released into the atmosphere.
CAP	Climate Action Plan	The Irish government's climate plan that sets out a roadmap to halve Ireland's emissions by 2030 and reach net zero no later than 2050.
	Climate Change Act	This is a Northern Irish Act to set targets for the years 2050, 2040 and 2030 for the reduction of greenhouse gas emissions.
CO_2	CO_2 Emissions	Carbon dioxide emissions stemming from the burning of hydrocarbon fuels and from other manufacturing processes. They include carbon dioxide produced during consumption of solid, liquid, and gas fuels as well as gas flaring.
COP	Coefficient of Performance	The efficiency of a heating system: the ratio of energy output to energy input.
CCGT	Combined Cycle Gas Turbine	An electrical generator that utilises waste heat from a gas turbine to create steam that drives a secondary turbine, thus increasing overall efficiency compared to an OCGT.
	Curtailment	Curtailment refers to the dispatch-down of generation for system-wide reasons (where the reduction of any or all generators would alleviate the problem).
	Decarbonisation	Decarbonisation is the term used for removal or reduction of carbon dioxide (CO_2) output into the atmosphere.
DSM	Demand Side Management	The modification of normal demand patterns, usually using incentives and/or control actions.
DSU	Demand Side Unit	A Demand Side Unit consists of one or more individual demand sites that can be dispatched to reduce demand by the Transmission System Operator as if it was a generator.
	Dispatchable Generation	Sources of electricity that can be used on demand and dispatched at the request of power grid operators, according to market needs. Does not include wind and solar generation which are non-dispatchable generation.
DACC	Direct Air Carbon Capture	Direct air carbon capture technologies extract CO_2 directly from the atmosphere which can then be stored, thereby achieving carbon dioxide removal.
ESBN	Electricity Supply Board Networks	ESBN is the Transmission Asset Owner of the Irish electricity transmission system. They also build, operate, and maintain the distribution system in Ireland.
EED	Energy Efficiency Directive	The Energy Efficiency Directive is a European Union directive which mandates energy efficiency improvements.

Abbreviation	Term	Description
	Electrification	The substitution of electricity for other fuels, such as oil and gas, used to provide similar services, for example heating and transport.
	Electrolysis	Electrolysis refers to the splitting of water molecules into Hydrogen and Oxygen, for the production of green Hydrogen.
ENTSO-E	European Network of Transmission System Operators for Electricity	The European Network of Transmission System Operators, represents 43 electricity transmission system operators from 36 countries across Europe.
EV	Electric Vehicle	A vehicle powered by an electric motor.
	Flexibility	The ability to respond to both expected and unexpected changes in demand and generation.
	Final Energy Use	The total energy from the power system consumed by end users, such as households, industry and agriculture. It is the energy which reaches the final consumer's door and excludes that used by the energy sector itself. It is also referred to as total final consumption.
	Green Hydrogen	Hydrogen that is produced by splitting water into hydrogen and oxygen using renewable electricity.
HVDC	High-Voltage Direct Current	A HVDC electric power transmission system uses direct current for the bulk transmission of electrical power.
	Interconnector	A transmission line which crosses or spans a border between countries and which connects the transmission systems of those countries.
LEU	Large Energy User	An industrial plant directly connected to the Transmission System that uses a significant amount of energy.
LCOE	Levelised Cost of Energy	A metric used to compare the cost competitiveness of different technologies. LCOE measures lifetime costs divided by energy production.
NECP	National Energy and Climate Plan	Regulation on the governance of the energy union and climate action to meet the EU's 2030 energy and climate targets for each member state.
NTL	New Tech Load	A Large Energy User consisting of significant amounts of data servers for support of cloud computing etc.
NIEN	Northern Ireland Electricity Networks	NIE Networks owns the electricity transmission and distribution network and operates the electricity distribution network which transports electricity to customers in Northern Ireland.
NIRO	Northern Ireland Renewable Obligation	NIRO is the main policy measure for supporting the development of renewable electricity in Northern Ireland.
OCGT	Open Cycle Gas Turbine	Open-cycle gas turbines are the simplest application of gas combustion for electricity generation. OCGTs consist of a gas turbine only and do not recover any waste heat.
PV	Photovoltaics	Technology for conversion of light into electricity.
	Pumped Hydro Energy Storage	Hydroelectric energy storage that uses the flow of water between an upper and lower reservoir to generate power or store energy for later use.

Abbreviation	Term	Description
RED	Renewable Energy Directive	EU directive which is the legal framework for the development of renewable energy across all sectors of the EU economy, supporting clean energy cooperation across EU countries.
RES-E	Renewable Energy Sources for Electricity	Electricity from renewable energy sources, i.e. the electricity generated from clean energy sources such as photovoltaic, hydro, wind, renewable biomass etc.
SEAI	Sustainable Energy Authority of Ireland	SEAI is Ireland's national sustainable energy authority.
SOEF	Shaping Our Electricity Future	An EirGrid and SONI publication which outlines a pathway towards meeting 2030 government electricity ambitions in Ireland and Northern Ireland. It also provides a foundation to support the broader transition to net zero by 2050.
	Smart Meter	A meter that employs digital technology to transmit information, such as the electricity consumption of appliances, to relevant actors, for example the consumer and supplier.
	Surplus Renewable Generation	This is a component of dispatch down which occurs at times when there is more generation than the market needs to meet consumer demand, including exports. It is also known as oversupply.
SONI	System Operator for Northern Ireland	SONI is the Electricity Transmission System Operator for Northern Ireland.
SNSP	System Non-Synchronous Penetration	A real-time measure of the percentage of generation that comes from non-synchronous sources, such as wind generation, PV, batteries, and HVDC interconnector imports, relative to the system demand, and expressed as a percentage.
TER	Total Electricity Requirement	The sum of annual electricity demand for residential, tertiary, transport, industrial sectors, including electricity demand met by privately operated and owned micro-generators, as well as losses.
TAO	Transmission Asset Owner	The entity that owns the transmission assets. In Ireland ESB Networks owns the transmission assets and in Northern Ireland NIEN owns the transmission assets.
	Transmission Grid	The typically meshed network of high voltage (400 kV, 275 kV, 220 kV and 110 kV) circuits and other equipment used to transmit bulk electricity supplies. The terms grid, network, and system can be used interchangeably.
TSO	Transmission System Operator	The licensed entity that is responsible for transmitting electricity from generators to regional or distribution operator.
VRES	Variable Renewable Energy Sources	Sources of electricity generation that are non-dispatchable and which use weather-based renewable processes, such as wind, waves, tidal flows, or solar radiation to produce electricity.

Contents

1. Executive summary

Welcome to the consultation report for Tomorrow's Energy Scenarios 2023 (TES2023). In this document you will find our latest thinking on long term energy scenarios for Ireland and Northern Ireland. Our scenarios consider how electricity demand and generation might evolve from 2035 to 2050. The report explains what this could mean for electricity demand, generation, storage and interconnection supported by different technologies.

We present these scenarios cognisant of the fact that the SEAI will shortly report to the Department of the Environment, Climate and Communications on an evidence-based decarbonisation pathway for the electricity system to reach net zero. The process of developing and publishing a TES report is biannual and is part of the commitment we give to our stakeholders to involve them in how we plan the future transmission grid.

Executive Summary

For TES 2023, we have developed four distinct scenarios for consultation. These represent boundary conditions and the future power system is likely to combine elements of each scenario. The scenarios we are seeking views on are titled Self-Sustaining, Offshore Opportunity, Gas Evolution and Constrained Growth. Each scenario considers a different pathway to decarbonise our power system, the pace of change and how we might achieve the energy transition in terms of energy demand, transmission and generation. The scenarios are summarised as follows:

Self-Sustaining follows a fast paced transition away from fossil fuels to electrification in all sectors. This scenario is focused on meeting Ireland's and Northern Ireland's domestic electricity needs, increasingly through renewable generation supported by other technologies such as battery storage and carbon capture and storage. Self-Sustaining shows a net zero power system from 2040.

Offshore Opportunity also follows a fast paced transition to a decarbonised power system. This sees a faster and larger development of offshore wind and results in the power system becoming a significant net electricity exporter through interconnections. Offshore Opportunity also shows a net zero power system from 2040.

Gas Evolution follows a steadier pace to the energy transition with electrification supported by increasing demand for green hydrogen in some sectors. The scenario includes significant renewable generation capacity to produce both electricity and power electrolysis plant to produce green hydrogen. Gas Evolution shows a net zero power system from 2045.

Constrained Growth is the slowest of the four scenarios to decarbonise. This relates to both the rate of electrification of demand and the development of decarbonised generation capacity. With slower development of renewable generating capacity, it shows greater reliance on electricity imports when domestic supplies are not sufficient to meet demand. Constrained Growth shows a net zero power system from 2050.

The four scenarios have been analysed using economic expansion modelling software. The results presented in this report show how our forecasts for electricity demand can best be met in each scenario. In summary our key messages for Ireland and Northern Ireland are:

1. TES 2023 scenarios show electricity demand more than doubling by 2050

Electricity demand is forecast to increase significantly due to a growing population[1,2] and increasing electrification in all sectors of the economy as per Ireland's Climate Action Plan 2023 targets and the Climate Change Act in Northern Ireland.

1 Population and Labour Force Projections 2017 - 2051
2 2021 Census

2. In a renewables dominated power system, demand will need to follow renewable output to a greater extent than at present

Measures to improve energy efficiency and demand flexibility will be vital to help reduce pressure on the electricity system and manage peak loads – we anticipate requiring 20–50% demand flexibility.

3. Our scenarios show a net zero power system for Ireland and Northern Ireland being achieved from 2040–2050

Achieving a net zero power system will be challenging and assumes very significant development of network capacity and zero carbon system services.

4. A balanced portfolio of generation technologies will be required, with renewables supported by energy storage, firm dispatchable capacity and interconnection

Decarbonising the electricity system will require:

- A large and rapid rollout of **renewable generation** capacity, particularly offshore wind as well as utility-scale and domestic solar PV.
- Significant growth of **energy storage capacity**, including short, medium and long duration batteries.
- The acceleration of **green fuels** (hydrogen, biomass and biomethane) to offer reliability and flexibility to the power system.
- **Negative emissions technologies** to capture and store carbon and balance emissions from remaining conventional plant.
- Significant increases in **electricity interconnection** to continental Europe and Great Britain to enable energy imports and exports.

Tomorrow's Energy Scenarios 2023 has an important role to play in stimulating debate and we want to hear your feedback as part of this consultation.
https://consult.eirgrid.ie
https://consult.soni.ltd.uk

With your feedback on board, we will update our analysis and publish a final report for TES 2023. We will use the findings to guide our technical assessments of the electricity system going forward to plan what we need to prioritise to enable a sustainable, secure and affordable energy transition for Ireland and Northern Ireland.

2. Introduction

Welcome to the consultation report for Tomorrow's Energy Scenarios 2023 (TES 2023). In this document, you will find our latest thinking on long term energy scenarios for Ireland and Northern Ireland. Our scenarios consider how electricity demand and generation might evolve from 2035 to 2050. The report explains what this could mean for electricity demand, generation, storage and interconnection supported by different technologies.

Sustainability, climate change and the transition to Net Zero have become key topics of debate in all corners of society. Government commitments to achieve net zero by 2050[3,4] have highlighted the need for a transition away from carbon-emitting technologies. Similarities have been drawn between this challenge and that of electrifying rural Ireland and Northern Ireland, however, the scale of change necessary is unprecedented in today's world. Cooperation and collaboration will be a fundamental aspect of this change.

In the energy sector, we are exploring how we best meet society's needs for energy security and affordability alongside taking positive action to help decarbonise our power supply. With Shaping Our Electricity Future v1.1[5], EirGrid and SONI have published a roadmap on the work which needs to be carried out on the transmission system to reach 2030 climate targets. TES 2023 takes this thinking further to consider what our power system might look like over a longer horizon to 2050. This report sets out a range of credible pathways that Ireland and Northern Ireland can take to achieve a Net Zero power system. Underpinned by EirGrid's and SONI's technical research and modelling, each scenario considers how much electricity we might need and how it can be provided.

TES 2023 has an important role to play in stimulating debate and we want to hear your feedback as part of this consultation. We will consider stakeholder feedback, update our analysis and publish a final report for TES 2023. We will use the findings to guide our technical assessments of the electricity system going forward in order to determine what we need to prioritise to enable a sustainable and secure energy transition for Ireland and Northern Ireland. They will also enable EirGrid and SONI to continue to support Governments and Regulatory Authorities in the development of energy policy and market design development required to achieve net zero.

3 Climate Action Plan 2023
4 Climate Change Act (Northern Ireland) 2022
5 Shaping Our Electricity Future Roadmap Version 1.1

2.1 Our role

EirGrid and SONI, as Transmission System Operators (TSO), play critical roles in the economies of Ireland and Northern Ireland. Through the provision of a secure electricity supply, EirGrid and SONI are responsible for planning and operating the electricity transmission system to ensure that electricity is transported securely from where it is generated to where it is needed. Sustaining a reliable supply of electricity is not just important for existing consumers, it is also crucial for attracting investment. To ensure a continued safe, secure, economic and sustainable electricity supply, EirGrid and SONI must continue to identify the future needs of Ireland's and Northern Ireland's transmission grid and plan the investments needed to address these requirements. EirGrid has also been appointed as the Offshore TAO which will enable the efficient planning and development of offshore grid assets.

Since the launch of Tomorrow's Energy Scenarios Ireland 2019[6] and Tomorrow's Energy Scenarios Northern Ireland 2020[7], there have been significant updates to electricity policy in Ireland and Northern Ireland, as well as at a European level and in the United Kingdom. These changes have had a direct impact on both Ireland's and Northern Ireland's roadmap to become net zero by 2050.

There has been a distinct shift in the focus of policy measures moving away from looking solely at the amount of renewable electricity generation, towards a more holistic view of carbon emissions reductions. Crucially, there is a clear focus now on decarbonisation across all sectors, not only through increasing renewable electricity penetration but also by means of energy efficiency and emissions reduction.

Ireland's government policy is aligned with the ambitious targets set out by the EU. Likewise, Northern Ireland's Climate Act 2021 has put in place regional legislation aligned with wider UK legislation in order to reach its climate targets. These targets include the development of carbon budgets, annual emission reductions, accelerating delivery of renewable electricity generation, and enhanced interconnection.

As TSOs, EirGrid and SONI are responsible for planning and operating the transmission system to support delivery of government policy targets for the energy sector. As such, we have considered policy change across many sectors with the aim of producing the most informed report as is possible.

6 Tomorrow's Energy Scenarios Ireland 2019
7 Tomorrow's Energy Scenarios Northern Ireland 2020

2.2 The transmission grid

The backbone of Ireland's and Northern Ireland's power system is the transmission grid. Made up of a network of high voltage lines and cables, efficiently delivering large amounts of power from where it is generated to where it is needed. The deployment of renewable generation, with some projects locating in areas of the island with relatively little demand, has increased the importance of transmission infrastructure and requires a move to a more plan led approach. Electricity supply is essential to everyday life and the local economy, and a reliable electricity network is needed to move electricity around Ireland and Northern Ireland. EirGrid and SONI has responsibility for the real time operation and future planning of the transmission system.

ESB Networks is the Transmission Asset Owner (TAO) in Ireland and is independent from EirGrid. ESB Networks is responsible for maintenance, repairs, and construction of the transmission and distribution grid in Ireland. EirGrid has been mandated to develop, own, and operate Ireland's offshore grid as Offshore TAO.

Northern Ireland Electricity Networks (NIE Networks) is the owner of the electricity transmission and distribution networks in Northern Ireland and is independent from SONI. NIE Networks operates the distribution system and is responsible for maintenance, repairs and construction of the transmission and distribution grid in Northern Ireland.

To support the ambitious targets set out, it will be necessary to upgrade and develop the electricity grid to ensure the safe and secure transfer of electricity. The future needs of the electricity transmission grid will be outlined in the next step of TES, the System Needs Assessment (TESNA).

3. Scenario planning

A key role for EirGrid and SONI is to plan the development of the electricity transmission grid to meet the future needs of society. We use scenario planning to consider a range of possible ways that electricity supply and consumption may change in the future, given the long-term uncertainty over the economy and technological developments. We then consider the common threads across the different scenarios studied so that the grid can be developed to accommodate a variety of possible futures.

3.1 TES 2023 explained

TES 2023 sets out a range of pathways for the power system in Ireland and Northern Ireland to reach net zero emissions. The scenarios have been defined to provide different pathways for the future power system, in the expectation that what actually happens in the future will take elements of all the scenarios.

Our scenarios are reviewed periodically to take account of changes in policy, demand and technology. We will use the TES 2023 outputs as the starting point for testing the performance of the electricity transmission grid and how it will need to develop out to 2050. This consultation report represents Step 2 of the TES 2023 development process (see Figure 3.1 below).

3.2 Why do we use scenario planning?

Our long-term approach to the development of Ireland's and Northern Ireland's electricity infrastructure is set out in our Grid Development Strategy[8,9]. Scenario planning allows EirGrid and SONI to assess the performance of the electricity system against a range of potential energy transition futures. It assists us to meet projected demand levels, meet Government policy objectives, and ensure a long-term sustainable and competitive energy future for Ireland and Northern Ireland.

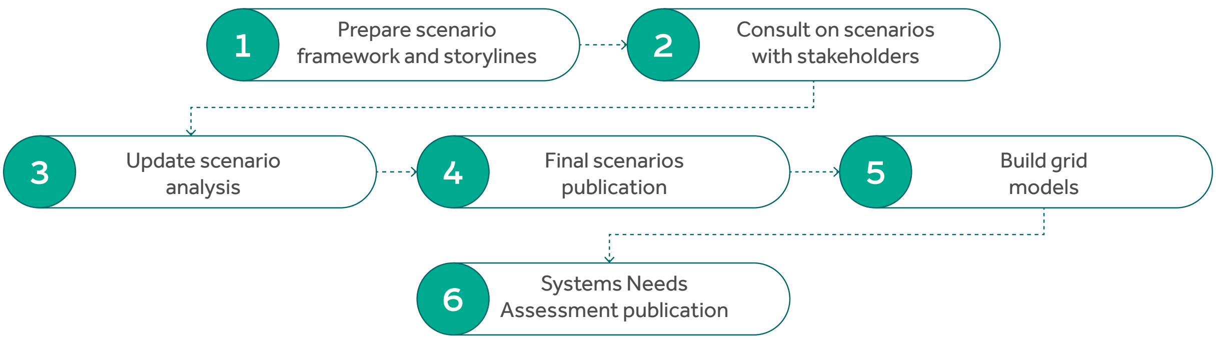

Figure 3.1: Overview of the TES 2023 development process

8 EirGrid and SONI Group, Strategy 2020–25
9 SONI strategy-2025

The grid development process commences with identifying the future needs of the electricity transmission system brought about by changes to electricity demand, generation, storage and interconnection. We use scenarios to understand the right balance of technologies for electricity generation and interconnection against known and anticipated future changes to electricity demand based on government policies and targets. The results of our scenario modelling are then explored in more detail in the TES System Needs Assessment which informs the projects taken forward for development of the grid.

3.3 Related EirGrid and SONI publications

EirGrid and SONI regularly produce documents associated with the transmission system. Since the most recent publication of TES, there have been multiple publications associated with generation, transmission and demand.

Shaping Our Electricity Future Roadmap Version 1.1[10] (SOEF) provides insights on achieving Ireland's and Northern Ireland's 2030 climate targets from a network, public engagement, operations and market perspective. The main objective of SOEF is to outline a secure transition path to deliver on the ambitious renewable and climate goals. TES 2023 scenarios take the SOEF endpoint in 2030 as their starting position and draws on the analysis performed for this publication.

The **Ten Year Network Development Plan**[11] (TYNDP) process of the European Network of Transmission System Operators (ENTSOs) for Electricity and Gas is an important reference for TES 2023. It provides guidance on the European-wide energy transition and is central to understanding Projects of Common Interest (PCIs)[12]. In addition, the revised TEN-E Regulation (2022) requires member states to collaborate on the development of Offshore Network Development Plans. EirGrid and SONI are currently collaborating with other TSOs and ENTSO-E in support of the Offshore Network Development Plan (ONDP) 2024.

The **All-Island Generation Capacity Statement**[13] (GCS) is an annual report from EirGrid and SONI detailing the balance between electricity demand and supply on the island for the coming 10 years. The GCS assesses the adequacy between supply and demand in order to allow the TSOs to signal for future needs and requirements. Elements of this report were used in scenario building and demand growth prediction.

The All-Island Ten Year Transmission Forecast Statement[14] (TYTFS) describes technical network data for Ireland and Northern Ireland, such as network configuration, parameters, and opportunities for connection.

10 Shaping our Electricity Future Roadmap Version 1.1
11 TYNDP 2022 Scenario Report
12 European Commission, Projects of Common Interest
13 All-Island Generation Capacity Statement
14 All-Island Ten Year Transmission Forecast Statement (2021)

3.4 Energy and climate policy

Energy and climate policies are at the heart of our scenario planning process. In 2022, electricity represented around 22% of final energy use[15] in Ireland, with the remainder split reasonably evenly between heat and transport. In Northern Ireland, the value was around 14%[16].

Increasing electrification is a key element of current energy policy – shifting energy use in the heat and transport sectors to electricity, through widespread use of electric vehicles and heat pumps, will allow decarbonisation targets to be achieved more readily.

Given the increasingly important role for electricity in the energy transition, energy and climate policies have provided the foundation for our scenario development in TES 2023. A large portion of energy and climate policies that have been published are focused on 2030 as a target date, however, we understand these policies are crucial on the path to net zero by 2050. The most relevant policies are summarised below.

3.4.1 EU policy

The ambition of carbon neutrality by 2050, as set out in the Regulation on the Governance of the Energy Union and Climate Action (EU/2018/1999) and the European Green Deal, remains the key driver for EU member states to decarbonise. In an effort to achieve this, in December 2020, the European Council committed to increasing the EU emissions reduction target to at least 55% by 2030 in the Fit for 55 package (compared to 1990 levels).

In September 2023, the European Parliament voted in favour of a 42.5% target for renewable energy in the EU's energy mix by 2030 (with the aim of achieving 45%) and faster approval procedure for deploying renewables, in line with the ambition of the Green Deal and RePowerEU. The new, recast Energy Efficiency Directive (EU) 2023/1791, which was adopted by the European Parliament and the Council in early 2023, establishes a target reduction on final energy consumption at EU level by 11.7% in 2030, compared with the energy consumption forecasts for 2030 made in 2020.

3.4.2 Ireland

Ireland has continued to firmly align itself with EU ambitions with the publication of the Climate Action and Low Carbon Development (Amendment) Act 2021, which commits to achieving a 51% reduction in Ireland's overall Greenhouse Gas emissions by 2030 relative to 2018 emission levels, and to achieving a climate neutral economy no later than 2050.

Overall carbon budgets for the periods 2020–2025, 2025–2030 and 2030–2035 came into effect in April 2022 and sectoral emissions ceilings were announced in July 2022.

Climate Action Plan 2023 (CAP23) was published in December 2022 and explicitly sets out updated emission reductions aligned with carbon budgets and sectoral emissions ceilings.

15 2022 National Energy Balance
16 Energy in Northern Ireland 2022

These include targets for the electricity sector of:

- Carbon Budget 1: 2020–2025: 40MtCO_2 equivalent.
- Carbon Budget 2: 2025–2030: 20MtCO_2 equivalent.
- Reduce electricity sector emissions to 3 MtCO_2 equivalent per annum.
- 80% of electricity generated from renewable sources.
- 9 GW of onshore wind capacity (6 GW by 2025).
- 8 GW of Solar PV capacity (up to 5 GW by 2025).
- At least 5 GW of offshore wind capacity (additional 2 GW for green hydrogen production).
- At least 2 GW new flexible gas plant.
- At least 500 MW of community based renewable energy projects.
- Ensure that 20–30% of system demand is flexible by 2030 (15–20% by 2025).
- Delivery of three new transmission grid connections or interconnections to Northern Ireland, Great Britain, and the EU and explore further interconnection.

These targets serve as the foundation that which we have used to explore possible future scenarios out to 2050 for Ireland.

3.4.3 The UK

In 2019, the UK updated its Climate Change Act to bring into law a requirement for net zero emissions by 2050. The UK also created strict carbon budgets for the coming years; the fifth carbon budget, covering the period 2028 to 2032, limits the total greenhouse gas emissions in the UK to an average 57% reduction in emissions relative to 1990. The sixth carbon budget has also been released and covers the years ranging 2033-2037. Energy policy is devolved to Northern Ireland, so how the country contributes to the carbon budgets and delivers net zero emissions will be set by the devolved administration.

3.4.4 Northern Ireland

In December 2021, the Northern Ireland Executive published its Energy Strategy ‘Path to Net Zero Energy’. The new strategy outlines a roadmap to 2030 aiming to deliver a 56% reduction in energy-related emissions relative to 1990 levels, on the pathway to the 2050 vision of net zero carbon and affordable energy.

In June 2022, the Climate Change Act (Northern Ireland) came into force. This legislation commits Northern Ireland to achieving emissions reductions of 48% from 1990/1995 level by 2030 and net zero carbon emissions by 2050. Part of this legislation updated the requirements of the Energy Strategy in setting a new target of achieving at least 80% RES-E in Northern Ireland by 2030. The legislation also requires Northern Ireland to introduce carbon budgets, with the first budget to cover the period 2023 to 2027, and also requires that Northern Ireland publish a Climate Action Plan by June 2024[17].

17 DAERA is consulting on carbon budgets for Northern Ireland

3.5 Challenges for electricity supply

Given the changes to legislation domestically and internationally, both Ireland and Northern Ireland are facing a significant transformation of the electricity system and also of the wider economy.

We now need to plan for an electricity system that can deliver a power system with up to 80% renewables by 2030 in both Ireland and Northern Ireland, 51% and 48% reduction in greenhouse gas emissions by 2030 for Ireland and Northern Ireland respectively, and a climate neutral economy by 2050 in Ireland and Northern Ireland.

Decarbonising at pace poses significant challenges for the electricity system. EirGrid and SONI have an obligation to plan and operate the power system in a reliable and secure way while also cognisant of legislated carbon targets. TES 2023 provides four scenarios that provide measured approaches to these future challenges and considers:

- Changes to electricity demand from society and all sectors of the economy.
- The range of renewable generation technologies that are available.
- Non-carbon emitting generation technologies.
- The role of flexible and renewable fuel-ready, thermal generators in a decarbonised power system.
- Interconnection with other countries enabling both electricity imports and exports.
- The importance of energy storage through batteries and other technologies.
- Ensuring electricity supplies meet demand, even during long periods of cold weather with little or no available wind resource.

EirGrid and SONI recognise cost is a key concern in a secure transition and we are committed to working with government and regulatory authorities to help ensure a safe, secure, reliable but also affordable electricity system out into the future. As regulated entities, we acknowledge the responsibilities of our regulators in ensuring that customers and network users receive value for money while providing the appropriate investment signals to enable the just transition in the most secure, reliable and effective manner. Those investments go towards the efficient operation, development, and maintenance of the power system and markets.

TES 2023 provides a high-level analysis of plausible scenarios for the power system showing how it could develop in alignment with government policies and targets. Cost assessment is not included the scope of TES 2023 and our analysis of the scenarios. Following TES 2023 and the System Needs Assessment, and working with government and regulators, cost assessment will be a part of transmission grid development planning informed by TES 2023.

4. Scenario storylines

In TES 2023, four scenarios are being studied:

Self-Sustaining

Offshore Opportunity

Gas Evolution

Constrained Growth

The scenarios attempt to provide a range of quite different, but plausible, pathways towards achieving the government's net zero targets. They take into account the uncertainty around factors such as demand electrification, the rate of build of new renewable generation capacity, system demand, and levels of interconnection. All of the scenarios start at a roughly similar starting point in 2030, based on the Shaping Our Electricity Future v1.1 roadmap, and end by 2050.

The scenarios will be used in a future study (TES System Needs Assessment) to assess the impact of the various government policies on the transmission network. We can then use those results to plan future developments of the network that will accommodate a variety of possible futures

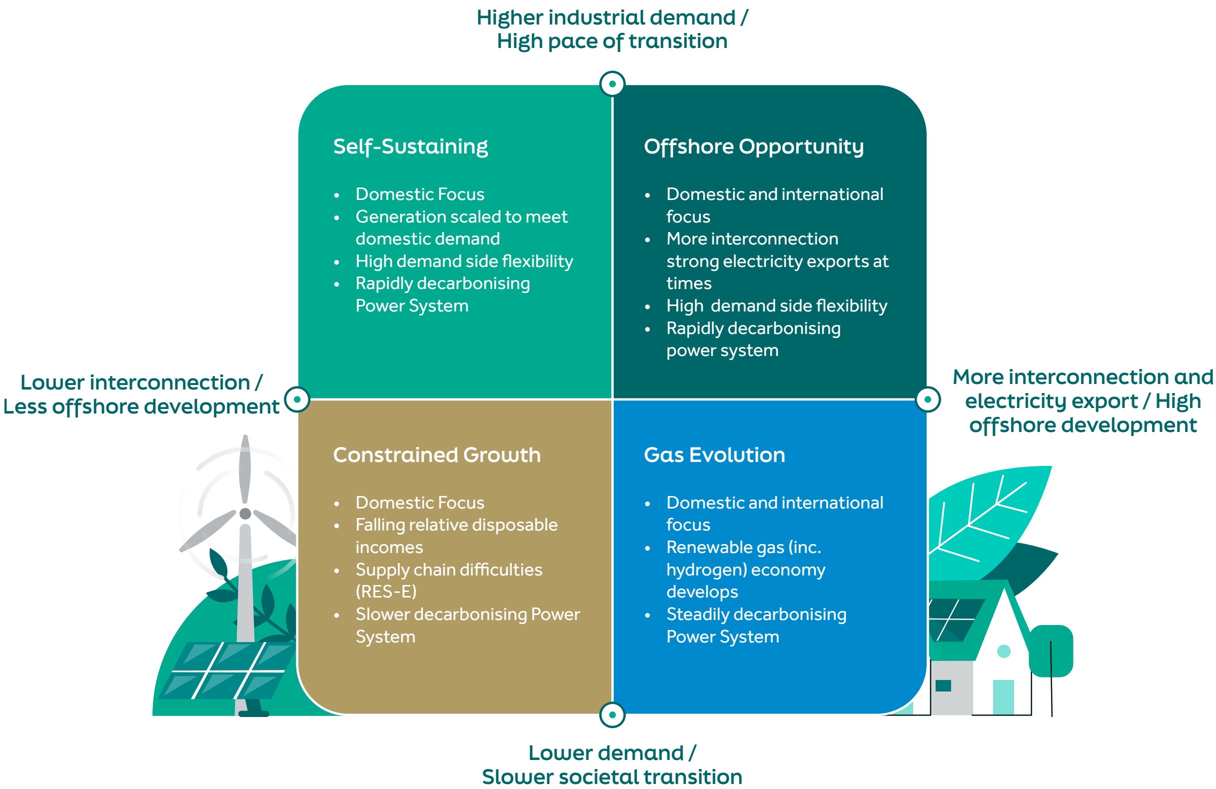

Figure 4.1: TES 2023 scenarios

Self-Sustaining

Self-Sustaining considers a future where there is very high penetration of renewables across all technologies – onshore and offshore wind, large scale solar, rooftop solar, and grid-scale energy storage – and this clean energy attracts new industry and development to Ireland and Northern Ireland. Targeting a net zero power system from 2040 and a fast pace of decarbonisation, there is also a very high penetration of electric vehicles, residential and commercial heat pumps.

Offshore Opportunity

Offshore Opportunity is similar to Self-Sustaining, it includes for very high levels of offshore wind capacity and interconnection to Great Britain and continental Europe. The large amount of clean electricity generated by offshore wind enables economic development, increasing energy exports and a portion of it is also used to create green hydrogen for power generation. Offshore Opportunity also features a fast pace towards a net zero power system from 2040.

Gas Evolution

Gas Evolution sees the energy transition being supplemented by a potential hydrogen economy. It features significant amounts of renewable power being converted at scale into green hydrogen. Due to more widespread use of hydrogen, the transmission system electricity demand is lower than in the previous scenarios. However, a portion of electricity demand will develop outside of the transmission system to produce green hydrogen. The pace of decarbonisation in Gas Evolution is steady, targeting a net zero power system from 2045.

Constrained Growth

Constrained Growth reflects a future where the energy transition proceeds more slowly and it takes longer to achieve climate targets for the power system and other sectors of demand. In Constrained Growth, offshore wind develops slowly, as does interconnection with other countries. Electric vehicle roll-out is slower, and electrification of heat and other demand progresses more slowly. In Constrained Growth, the net zero power system target from 2050.

4.1 Scenario development

Developing the TES scenarios and economic model is a complex process. We start out by considering the purpose of TES, and then looking at the policy landscape, as well as the main variables where we are uncertain how various factors will evolve over the next few decades. The TES scenarios feed into the TES System Needs Assessment – a detailed study of the power system, and how it will need to be developed and upgraded across those different future scenarios.

Thus it is important that the scenarios be distinct in order to help define an envelope of credible scenarios. This helps ensure that our future planning will capture the system needs for a variety of different pathways towards net zero, allowing us to plan and develop the network from a 'least-regrets' viewpoint.

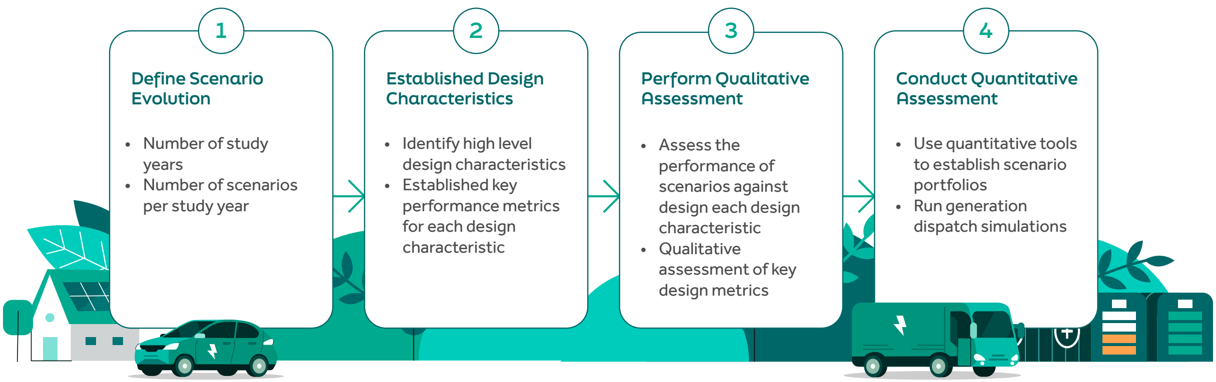

Figure 4.2: TES scenario building process

4.2 TES Economic model overview

We use economic modelling software for the TES 2023 studies (PLEXOS). A key input to the model is the hourly system demand from 2035 to 2050 for Ireland and Northern Ireland. These time series are created using an ENTSO-E demand forecasting tool called Trapunta. The economic model is an optimisation engine – it tries to meet the demand using the cheapest generation available, subject to certain constraints. As the system demand increases over time, the economic model is allowed to build new generation to meet that demand. All of the different technologies and their characteristics are available for the model to choose from[18].

For the CO_2 emissions constraint, we limit the emissions the model can produce over time. Depending on the scenario, this results in the model making decisions on investments that will minimise emissions over the time horizon being studied. So for example, in the Gas Evolution scenario, we force the model to reduce emissions down to zero from 2045. We also can allow the model to make decisions to drive different build rates according to technology, or we can set maximum or minimum yearly build rates. In this way, we can guide the model towards different storylines aligned to each scenario. This may result in more, or less solar, wind, batteries, or interconnection, while not specifying the exact amounts in each scenario.

For every hour of the study run across the fifteen year horizon from 2035 to 2050, the model will determine the most appropriate dispatch and build-out of generation to meet the constraints and emission limits that we have set in each scenario.

4.3 Model assumptions

TES 2023 analysis incorporates market-based electricity flows between the Single Electricity Market, Great Britain, France and continental Europe, based on the TYNDP 2022 model. Each jurisdiction is represented as a node. The Ireland and Northern Ireland electricity networks are not modelled in this stage of TES 2023 but will be analysed as part of the TES System Needs Assessment.

Technology types

Modelling has the potential to consider many different electricity generation technologies. For TES 2023, we have considered the following technologies:

- Renewables such as solar, onshore and offshore wind.
- Energy storage through pumped hydro, short-medium duration batteries and long-duration energy storage (LDES).
- Flexible thermal generation technology such as natural gas, hydrogen and biomass.
- Carbon capture and storage.
- Electricity interconnection between Ireland and Northern Ireland with Great Britain and continental Europe.

We have assumed that conventional gas generators may operate on methane or biomethane and that new generators post 2035 will be capable of running wholly on hydrogen. We have assumed that coal, peat and oil-fired generators will not be available by 2035, but that gas with carbon-capture and storage becomes feasible.

18 TYNDP 2022 Scenarios Report

We also consider the potential use of negative emissions technology – biomass with CCS – where carbon neutral biomass is supplemented with CCS to become a net absorber of CO_2. Apart from long and short duration batteries, we also assume pumped storage at Turlough Hill is available as well as the proposed pumped storage unit at Silvermines. The model can also build extra interconnection from Ireland and Northern Ireland to Great Britain and continental Europe.

Operational limits

In this analysis, no limit has been placed on system non-synchronous penetration (SNSP) within the economic model. Similarly inertia rules and minimum-set rules have not been modelled. Future operation of the system will be reviewed within the following TES System Needs Assessment. Real world constraints will always act as a counterweight against ambitious developments such as those outlined in TES 2023, and the results should be considered through that lens.

Emissions limits

The carbon dioxide emissions are constrained down from the initial level in 2035 to reach net zero from a set year, depending on the net zero date of each scenario. The rate at which the model reaches net zero and the technologies chosen to achieve this target are decided by the modelling software (PLEXOS). Negative emissions technologies are available to be chosen within the model.

Electricity market model

The model includes estimates (based on TYNDP data) of the fixed and operational costs of the different technology types, as well as other technical parameters. The fixed costs are used in the expansion modelling phase, where Plexos determines the appropriate build out of generation in the different scenarios, subject to applied constraints. For the hourly model runs, the model optimizes Ireland with all its neighbours and looks at the cost optimum solution as a whole, based on availability of renewable energy in each jurisdiction, and interconnector capacity. The price of electricity in a region is based on the cost of the marginal unit in that region at that point in time.

4.4 Limitations of TES modelling

While the findings from TES 2023 are important, it is necessary to recognise the limitations of the analytical approach:

Weather year

For the TES analysis an average weather year has been selected, in this case 2009. This particular year is recommended in TYNDP as a sensible representative weather year. Clearly, the weather experienced changes every year so in practice we may see more prolonged periods of cold, high or low wind speeds. Changes in weather will be experienced differently across Ireland, Northern Ireland and other countries.

Modelling choices

Modelling choices – Optimisation engines often struggle with mixed-integer problems where there is a mix of continuous data such as system demand, and 'lumpy' or discrete data such as whether to build a 500 MW interconnector.

Knife-edge choices may also be reflected by the model outputs where a particular technology is favoured because it is very marginally cheaper than an alternative. In reality, a more nuanced combination might be more appropriate. There is no simple solution to this other than to be aware of it, and to treat the model outputs accordingly.

Hydrogen and electrolysers

Lack of high quality data on electrolysers and their operation negatively impacted the accuracy and validity of the initial results. As a consequence, we removed the electrolysers from the PLEXOS model and included provisional figures allowing for projected demand and renewable capacity for electrolysers to produce green hydrogen. It should be noted that the future demand profile may be higher than forecast by TES 2023, and further additions to the renewable generation portfolio may be required to meet demands of an electrolyser integrated economy.

Future policy developments

TES 2023 analysis is based on current government policy and our best estimates about how the energy sector will evolve. It is important to note that changes to policy, or the emergence of disruptive technologies could weaken some of our assumptions and analysis.

5. Electricity demand

A key input into TES 2023 is electrical demand over the period 2035–2050. The first part of this section covers Ireland's electrical demand, with the second section covering Northern Ireland's electrical demand.

5.1 Introduction

Electricity demand forecasted in TES 2023 is significantly higher than that of the previous TES report in 2019. This is due to several factors, the most important factor being the increased government targets and ambitions on decarbonising the energy sector in both jurisdictions. Electrification will play a pivotal role in enabling these targets to be realised. The shift from fossil fuels to electric heat pumps, electric vehicles, and electrical heating processes in industry adds large amounts of electrical demand to the system. While increasing efficiency and flexible demand will help alleviate this strain on the system, the forecast growth in electricity demand is high throughout all scenarios. Each TES scenario aims for a carbon neutral energy sector (ranging from 2040 to 2050), and this is a key driver in the rate of increase of electricity demand seen in the analysis.

5.2 Demand forecast Ireland

Electricity demand is forecasted to significantly increase by 2050, ranging from 73 TWh to 86 TWh. This results in more than a doubling of demand from current levels.

Increasing demand is driven by the following factors:

- Ireland's projected population growth;
- Growth of data centres and New Tech Loads (NTLs);
- Electrification of heating and transport;
- Projected growth of industrial demand; and
- Electrification of industrial demand processes.

This section outlines the breakdown of electricity demand per final energy use sectors, namely residential, tertiary (also known as commercial), transport and industry. The growth assumptions used for the different demand input sectors are shown in Table 5.1. Growth rates take account of economic factors and personal consumption rates and have been informed by assumptions considered previously for the GCS[19]. These rates were then adjusted to fit each scenario storyline narrative. Please note, the growth rates in the below table do not include efficiency savings (see Section 5.2.3 Demand flexibility and energy efficiency).

19 Generation Capacity Statement 2022–2031

The forecasted population growth used in TES is based on the Central Statistics Office's Population and Labour Force Projections 2017 - 2051[20]. The high fertility scenario (F1M2) was used from these projections to forecast a growth in population from 5.4 million in 2030 to 6.2 million by 2050.

As a result of the projected population growth, the number of residences is set to increase significantly year on year. Thus, overall growth in residential demand is anticipated to outweigh energy efficiency improvements.

Table 5.1: Per annum growth assumptions (IE)

Scenario	Sector	2031–2040	2041–2050
Self-Sustaining	Industrial	1.50%	1.50%
	Residential	1.50%	1.00%
	Tertiary	2.00%	1.50%
Offshore Opportunity	Industrial	2.00%	2.00%
	Residential	1.50%	1.00%
	Tertiary	2.00%	1.50%
Gas Evolution	Industrial	0.80%	0.80%
	Residential	0.50%	0.00%
	Tertiary	1.00%	0.50%
Constrained Growth	Industrial	0.30%	0.30%
	Residential	0.25%	0.00%
	Tertiary	0.50%	0.00%

20 Population and Labour Force Projections 2017 - 2051

5.2.1 Total Electricity Requirement

Total Electricity Requirement (TER) is the sum of the annual electricity demand for the residential, tertiary, transport and industrial sectors. TER also includes power system losses that are calculated to be approximately 8% of final use demand. For TES 2023 analysis, TER does not include self-consumption (demand met by on-site generation). Micro generation is an output of the TES 2023 model.

Figure 5.1 illustrates how demand is built up from various components. Demand growth to 2030 is primarily driven by the data centres and NTLs in the industrial sector as per the GCS forecast. Demand growth from 2030 onwards is mostly caused by electrification of heat, transport, and industrial processes where electricity represented 22% of final energy use.

It is important to note that while there is electrolyser demand in Figure 5.1, this demand has not been included in our modelling. The electrolyser demand shown below is potential extra load that could be required for generating indigenous green hydrogen through electrolysers, however this load could be supplied by non-grid connected generators and therefore is not considered as part of the electricity load (TER and peaks) highlighted elsewhere in this report. Indicative renewable capacities that are required to supply this electrolysis load are outlined in Section 6 of this report.

Electrolyser demand was assessed and informed by the National Hydrogen Strategy[21] outlining the potential hydrogen demand levels there could be by 2050 in Ireland.

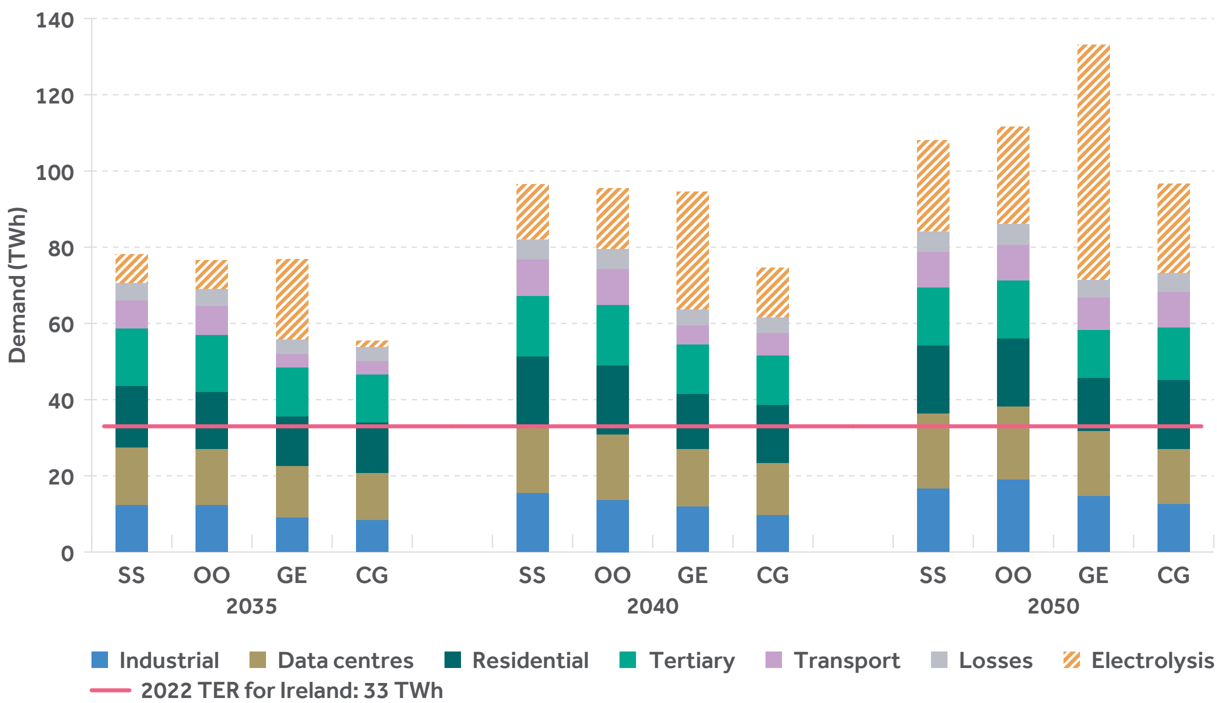

Figure 5.1: Annual Total Electricity Requirement (IE)

21 National Hydrogen Strategy

5.2.2 Peak electricity demand

Ireland's peak demand for electricity generally occurs on a weeknight in winter at approximately 6:00pm. Peak electricity demand is sensitive to weather conditions and typically varies depending on the ambient temperature. The peak demand forecasting methodology accounts for the effect of temperature using the concept of climate years. Peak demand for each scenario is forecast for an average ambient temperature by selecting the average historical climate year. The historical climate year used for all demand forecasting was 2009 as this has been deemed an average climate year for Europe in general.

Figure 5.2 below shows how peak electricity demand is forecast to change for each scenario. The timing and sectoral composition of peak demand varies across scenarios driven by adoption of new technologies such as smart meters and electric vehicles. The greatest increase in peak demand is seen in Offshore Opportunity and is driven by greater demand from electrified industrial processes and high uptake of EVs and heat pumps.

Constrained Growth shows a slower peak demand growth for electricity as this scenario takes longer to transition away from fossil fuels. Gas Evolution sees a transition to renewable gases such as green hydrogen, which tends to reduce demand growth on the electricity system. The increase to peak is most pronounced in Offshore Opportunity, as outlined below. The red line on the graph indicates the 2022 peak demand in Ireland.

Figure 5.2 shows the peak demand after smart EV charging is applied (see Section 5.2.5 for more details on the blended charging profiles for EVs). Self-Sustaining and Offshore Opportunity see increased flexibility and efficiency improvements while the majority of demand has already been electrified by 2040. The flexibility technologies that can potentially be developed for short duration peak mitigations are outlined in Section 5.2.3

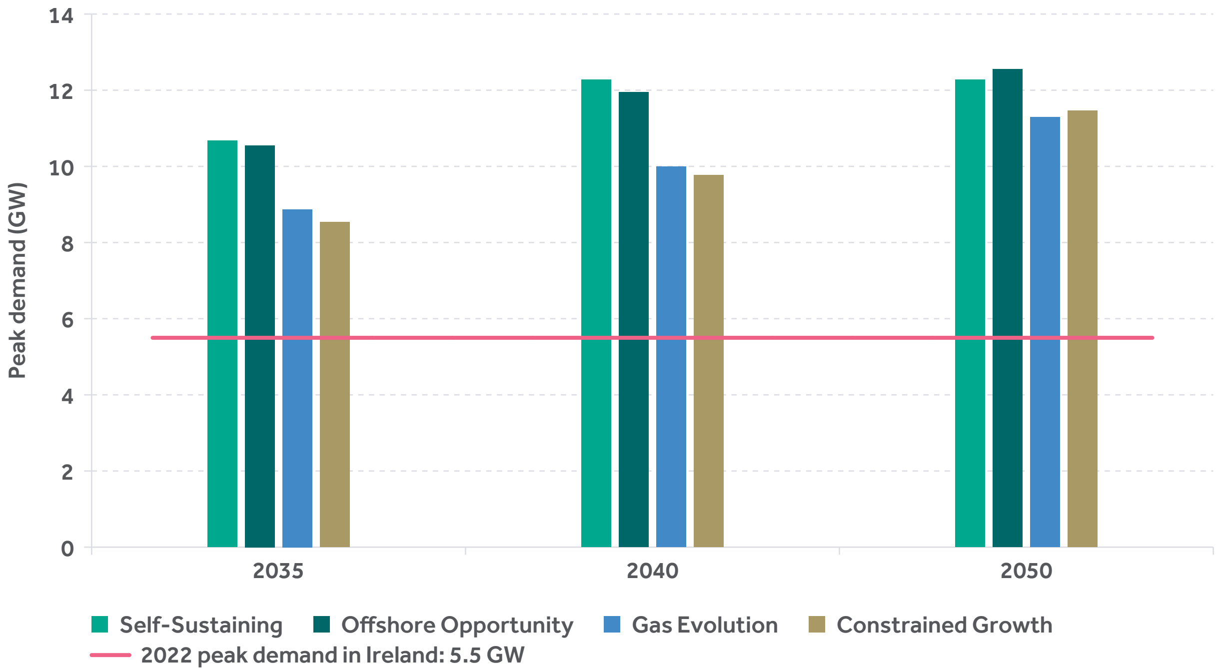

Figure 5.2: Forecasted peak demand (the red line on the graph indicates the 2022 peak demand in Ireland)

5.2.3 Demand Flexibility and Energy Efficiency

Demand Flexibility

Demand Flexibility will be key to allowing overall electricity demand to increase while maintaining system security. Managing peak demand on the system alleviates pressure on the power grid overall and may minimise the level of system reinforcements that are required, ultimately saving expenditure on new infrastructure. Shifting peak demand to times of high RES should allow for cheaper end-use electricity for the consumer. For TES 2023, we have included demand flexibility in all of the scenarios – the highest levels being in Self-Sustaining and Offshore Opportunity.

Flexibility measures included in TES modelling are as follows:

- As heat pumps are rolled out and electricity demand grows in that area, it is assumed that this will be flat across the day as Building Energy Ratings (BERs) from new builds and retrofits will allow efficient running of heat pumps across the day due to efficiency savings.
- Smart devices are expected to assist consumers to reduce their electricity demand at peak times when electricity prices are highest. This shifting of demand is incentivised by time-of-use tariffs and enabled by smart meter data. The ability to shift demand largely depends on the potential flexibility of new electricity demand.

- A share of traditional baseload demand ranging from 5% to 9% is assumed to be flexible by 2050. This is designed in the model in such a way that at times of high renewable availability, load will shift to this period when prices are low. This reduces curtailment of renewable electricity and enables the consumer to access cheaper electricity.
- There is significant potential to shift electric vehicle demand away from peak times depending on the location and sophistication of charging infrastructure and the price signals offered to consumers through time-of-use tariffs. All scenarios assume high electric vehicle adoption rates by 2050, but the level of smart charging vehicles that limit the peak demand differs between scenarios. The potential impacts of higher system peaks and the assumed charging profiles for electric vehicles are discussed in Section 5.2.5.
- Extensive rollout of vehicle-to-grid is assumed by 2050. This allows EVs to act as batteries and give electricity back to the grid at times of high demand and low renewable generation.
- Energy efficiency improvements are expected to reduce demand in all sectors as technology and homes become more efficient over time.
- Demand that is not considered to offer flexibility is modelled as flat (i.e. it does not vary at different times in the day). This includes data centre and New Tech Load (NTL) demand.

On average, approximately 8% of power produced is lost as it passes through the electricity transmission and distribution systems to homes and businesses, this is reflected as a percentage of additional demand in the demand profiles.

Potential additional demand flexibility impacts can be seen in the table below:

	2050 hourly demand shift potential (MW)			
	Self-Sustaining	Offshore Opportunity	Gas Evolution	Constrained Growth
Traditional baseload demand to provide flexible demand in some form	1,070	890	520	670
DSU	1,200	1,200	1,200	1,200
V2G	3,190	3,190	1,130	240
Total	**5,460**	**5,280**	**2,850**	**2,110**

Energy efficiency

Energy efficiency refers to the implementation of energy saving measures such as improvements in insulation, window glazing, lighting and heating, among others. Such measures can have other benefits including improved thermal comfort, long-term energy cost savings, as well as reduced CO_2 emissions and energy imports. As such, energy efficiency is a key part of the European Commission's climate and energy policy (see Section 3.4 Energy and climate policy).

Table 5.2 shows the range of year-on-year energy efficiency gains assumed in each scenario. In Offshore Opportunity and Self-Sustaining, more energy efficiency measures are adopted and embedded in each area of electricity demand. For Constrained Growth and Gas Evolution, lower levels of energy efficiency uptake are assumed. For energy efficiency gains to be realised they will need to be enabled by appropriate policy incentives and behaviour change.

Smart meters

Smart meter installations in Ireland are being carried out by ESB Networks under the National Smart Metering Programme and overseen by the Commission for the Regulation of Utilities (CRU). This started in 2019, and it is intended to have all 2.4 million electricity smart meters installed by the end of 2024. In October 2022, it was announced that over 1 million smart meters have been installed. Smart meters are represented in the form of the percentage of traditional baseload demand mentioned in the Demand Flexibility section above.

Table 5.2: Year-on-year energy efficiency gains

	Self-Sustaining	Offshore Opportunity	Gas Evolution	Constrained Growth
Residential	-1.5%	-1.5%	-1.0%	-0.8%
Tertiary	-1.5%	-1.5%	-1.0%	-0.8%
Transport – passenger EVs	-0.9%	-0.9%	-0.9%	-0.5%
Transport – all other EVs	-0.5%	-0.5%	-0.5%	-0.5%
Data centre and NTLs (%)	-0.3%	-0.3%	-0.3%	-0.3%
Industrial processes (%)	-1.0%	-1.0%	-0.8%	-0.5%

5.2.4 Residential and tertiary

Residential and tertiary electricity demand can be broken down into two components:

1. Lighting and power.
2. Electrified heating and cooling.

The main technologies we focus on are electric direct heaters, air source heat pumps, ground source heat pumps and hybrid heat pumps as these dominate growth in electrical demand in the residential and tertiary sectors.

It is also anticipated there will be growth in heating technologies using biomass as a source of fuel, but the majority of existing heating systems shift to electrical sources. While this does add significant load to the power system, the efficiency of electrical heat pumps will lead to reductions in overall energy demand in this sector.

Heat pumps

Increasing the uptake of heat pumps is a key target in the Irish government's Climate Action Plan 2023. This will have a significant impact on the electricity demand of Ireland as heating systems switch from fossil fuel heaters to electrical heat pumps.

The energy demand from a heat pump is a function of the average heat demand from a dwelling and the efficiency of a heat pump. This is known as the coefficient of performance (COP). The air source heat pump COP assumptions, which are fixed across scenarios, are given in Table 5.3. These COP assumptions were based on the SEAI National Heat Study Low Carbon Heating and Cooling Technologies Report[22]. Note that the COP for heat pumps has been assumed to be the same throughout the year, it is not based on seasonal temperature shifts.

Table 5.3: Heat pump Coefficient of Performance (COP)

Heat pump	COP
Air source	2.6
Ground source	2.94

22 National Heat Study, Low Carbon Heating and Cooling Technologies

To assess the level of electricity demand from heat pumps we took the following approach:

1. We reviewed existing demand by individual subsectors of heating, cooling, lighting and power. This was then further broken down into the individual fuel and technology sources for each subsector.
2. Demand was then forecasted for each sub-sector based on the increase in number of residences and the technology shift driven by decarbonisation goals.
3. Within our demand profiles, we have assumed that heat pumps output at a steady fixed rate over the day[23]. This provided a forecast of electrical heat pump demand in TWh.

Figure 5.3 below shows the development of electrical heating demand as a result of heat pumps. The variations seen across the scenarios reflect the increasing volume of heat being electrified and the adoption of efficiency improvements that ultimately act to slow and reduce the total electrical demand from heat pumps in Self-Sustaining and Offshore Opportunity in 2050.

Included in the demand figures in Figure 5.3 are heat pumps committed to district heating systems. We have assumed that a portion of electrical heating demand will be from district heating schemes. CAP23 outlines an ambition of up to 2.7 TWh of installed district heating capacity by 2030. We have adjusted our electrical heating demand to allow for this in our electricity modelling. Self-Sustaining and Offshore Opportunity hit this target, while Constrained Growth and Gas Evolution fall short of it.

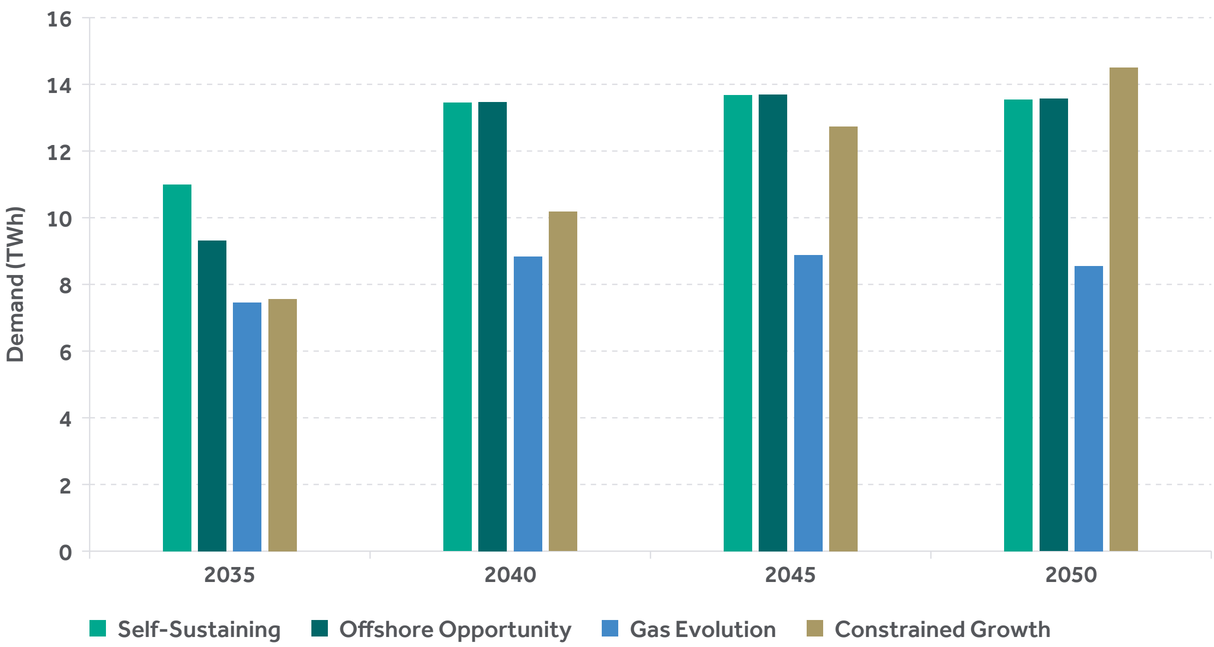

Figure 5.3: Residential and tertiary heat pump electrical demand (IE)

23 [How will heat pumps alter national half-hourly heat demands? Empirical modelling based on GB field trials]()

5.2.5 Transport

Electric vehicles

The electricity demand from transport is a function of which modes of transport are electrified (cars, motorcycles, vans, buses, freight, and rail), the distance of travel by citizens, and the efficiency of each electric transport mode.

CAP23 sets out targets with regard to the electrification of motor vehicles. Within the scenarios, a range of possible EV adoption rates are assumed in line with the degree of electrification in each scenario. Self-Sustaining and Offshore Opportunity share the same degree of electrification, showing a significant increase in the adoption of EVs. This increase may be promoted by falling EV costs, stronger economic growth, higher consumer appetite for decarbonisation, or a ban on the sale of new non-zero emissions vehicles post-2030.

Gas Evolution and Constrained Growth show a slightly more sluggish transition to EVs as is expected in these scenarios. Gas Evolution also includes for some transport demand to be met by alternative renewable fuels, such as green hydrogen.

As more electric vehicles enter general use, they will have an increasing impact on the operation of the electricity grid. The exact extent of this impact will depend on a wide range of factors such as the types of electric vehicles in use, vehicle usage trends, types and locations of vehicle chargers, and the charging patterns of vehicle owners. Electric vehicle adoption numbers are shown in Figure 5.4.

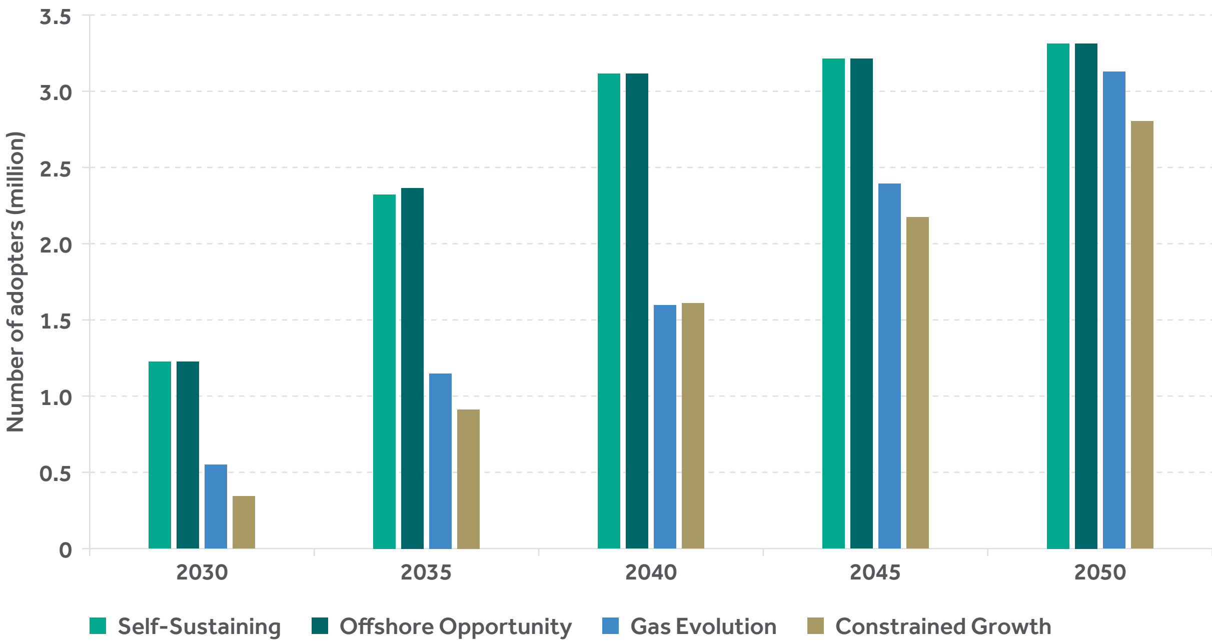

Figure 5.4: Projected number of EVs (IE)

The efficiency of EVs is assumed to improve over time, leading to a higher distance travelled per unit of electricity input, known as specific consumption.

Table 5.4 shows our assumptions for electric passenger vehicles (including plug-in hybrid electric vehicles) and electric delivery vans.

Table 5.4: Specific consumption rates (kWh/100km), electric passenger vehicles and delivery vans

	2035	2040	2050
Self-Sustaining	16.19	15.48	14.14
Offshore Opportunity	16.19	15.48	14.14
Gas Evolution	16.86	16.12	14.72
Constrained Growth	17.41	16.98	16.15

As the number of electric vehicles grows, they will have an increasing impact on the electricity grid and on electricity markets. The scale of this impact will depend on a wide range of factors such as the quantity and types of electric vehicles in use, vehicle usage, types and locations of vehicle chargers and the charging patterns of vehicle owners. Vehicle charger technology has the potential to minimise the potential impact of electric vehicle demand on the electricity system, and on electricity markets.

It is assumed that charger technology will evolve over time from simple chargers and patterns that are readily available today, to smart chargers with features such as programmable charge start times to smarter charging technology that optimise vehicle charging in line with dynamic electricity price signals.

The TES 2023 framework for electric vehicle chargers is shown in Table 5.5. It shows the different blended configurations of simple, smart, and smarter profiles that EVs can operate at. The ratio of simple to smart to smarter differs depending on the scenario and the year, indicating a behavioural change in vehicle charging and the development of policy to incentivise smart charging and vehicle-to-grid charging.

In scenarios with high uptake of electric vehicles, optimisation of charging demand is required to ensure that the need for grid development and additional generation capacity is minimised. The use of blended charger technologies has the potential to reduce system peak demand by up to 1 GW in 2050, compared to all EVs charging with a simple profile.

Table 5.5: Electric vehicle charger framework – share of charger types

	Self-Sustaining			Offshore Opportunity			Constrained Growth			Gas Evolution		
	2035	2040	2050	2035	2040	2050	2035	2040	2050	2035	2040	2050
Passenger vehicles, motorcycles												
Simple	30%	25%	10%	30%	25%	10%	80%	70%	50%	60%	45%	15%
Smart	40%	40%	40%	40%	40%	40%	15%	22%	30%	25%	30%	45%
Smarter	30%	35%	50%	30%	35%	50%	5%	8%	20%	15%	25%	40%
Buses, road freight, goods vehicles												
Simple	80%	70%	50%	80%	70%	50%	95%	90%	80%	90%	80%	65%
Smart	20%	30%	50%	20%	30%	50%	5%	10%	20%	10%	20%	35%

5.2.6 Industrial demand

Electricity demand from industrial sources in Ireland comes from end uses such as food and tobacco; chemicals and petrochemicals; machinery; non-ferrous metal; mining and quarrying; non-metallic minerals, e.g. glass and building materials; agriculture, forestry and fisheries; wood and wood products; paper, pulp and print; transport equipment; textile and leather; and construction, among others.

Approximately 27% of the final energy demand from these industrial customers was supplied by electricity in 2019[24]. The current trends in electrical industrial demand remain steady with no significant increase. However, due to the increasing climate ambitions of the Irish government[25], the percentage of electricity that supplies industrial demand is set to rise as more industrial processes are decarbonised and electrified.

By comparison to what we see in 2023, all of the TES scenarios have high levels of industrial electrification. Offshore Opportunity and Self-Sustaining have the highest levels of industrial demand as it is anticipated that the large amount of renewable energy available in Ireland will draw new industries to the country.

Data centres and NTLs

Data centres and NTLs have become a significant growth area in Ireland. There are many NTL projects in the connection process and many more that have made material enquiries for connections. As per the GCS, we have examined the status of these proposed projects and have made assumptions concerning the demand from these NTLs in the future. On the basis of scenario storylines and increasing demand for data service provision, we have projected the possible development of NTL demand out to 2050. It is assumed that the more renewable energy there is on the system, the more likely new NTLs may be drawn to connect to the system.

24 Eurostat, Energy Balances
25 Climate Action Plan 2023 has 3.5 TWh of industrial heating processes to be electrified by 2030.

5.3 Demand forecast Northern Ireland

Electricity demand is forecasted to significantly increase by 2050, ranging from 21 to 26 TWh. This results in more than a doubling of demand from current levels.

Increasing demand is driven by a number of factors:

- Northern Ireland's projected population;
- Growth of data centres and New Tech Loads (NTLs);
- Electrification of heating and transport;
- Projected growth of industrial demand; and
- Electrification of industrial demand processes.

This section outlines the breakdown of electricity demand per final energy use sectors, namely residential, tertiary (also known as commercial), transport, and industry. The growth assumptions used for the different demand input sectors are shown in Table 5.6. Growth rates take account of economic factors and personal consumption rates and have been informed by assumptions considered previously for the GCS[26].

These rates were then adjusted to fit each scenario storyline narrative. Please note, the growth rates in the below table do not include efficiency savings (see Section 5.2.3 Demand flexibility).

The forecasted population growth used in TES 2023 for Northern Ireland is based on the 2021 Census from the Northern Ireland Statistics and Research Agency[27]. These projections were used to forecast a slight overall rise in population from 1.90 million in 2021 to 1.93 million by 2050.

26 Generation Capacity Statement 2022–2031
27 2021 Census

Table 5.6: Per annum growth assumptions (NI)			
Scenario	**Sector**	**2031–2040**	**2041–2050**
Self-Sustaining	Industrial	1.3%	1.0%
	Residential	1.1%	0.7%
	Tertiary	1.9%	1.5%
Offshore Opportunity	Industrial	1.3%	1.0%
	Residential	1.1%	0.7%
	Tertiary	1.9%	1.5%
Constrained Growth	Industrial	0.4%	0.1%
	Residential	0.2%	0.0%
	Tertiary	0.7%	0.3%
Gas Evolution	Industrial	0.7%	0.4%
	Residential	0.4%	0.0%
	Tertiary	1.1%	0.7%

5.3.1 Total Electricity Requirement

Total Electricity Requirement (TER) is the sum of the annual electricity demand for the residential, tertiary, transport, and industrial sectors. TER also includes power system losses, which are again calculated to be approximately 8% of final use demand. For TES 2023 analysis, TER does not include self-consumption (demand met by on-site generation). Micro generation is an output of the TES 2023 model.

Figure 5.5 below illustrates how the TER for Northern Ireland's demand is built up from the various components in keystone years over the study horizon. Demand growth to 2035 is primarily driven by increases in the residential, tertiary, and transport sectors, due to the electrification of heat, transport, and industrial processes. The red line on the graph indicates the TER for Northern Ireland in 2022.

It is important to note that while there is electrolyser demand in Figure 5.5, this demand has not been included in our model. The electrolyser demand shown below is potential extra load that could be required for generating indigenous green hydrogen through electrolysers, however this load could be supplied by non-grid connected generators and therefore is not considered as part of the electricity load (TER and peaks) highlighted elsewhere in this report. Indicative renewable capacities that are required to supply this electrolysis load are outlined in Section 6 of this report.

Electrolyser demand was assessed and informed by applying a ratio to the Irish hydrogen demand forecasts, outlining the potential hydrogen demand levels there could be by 2050 in Northern Ireland.

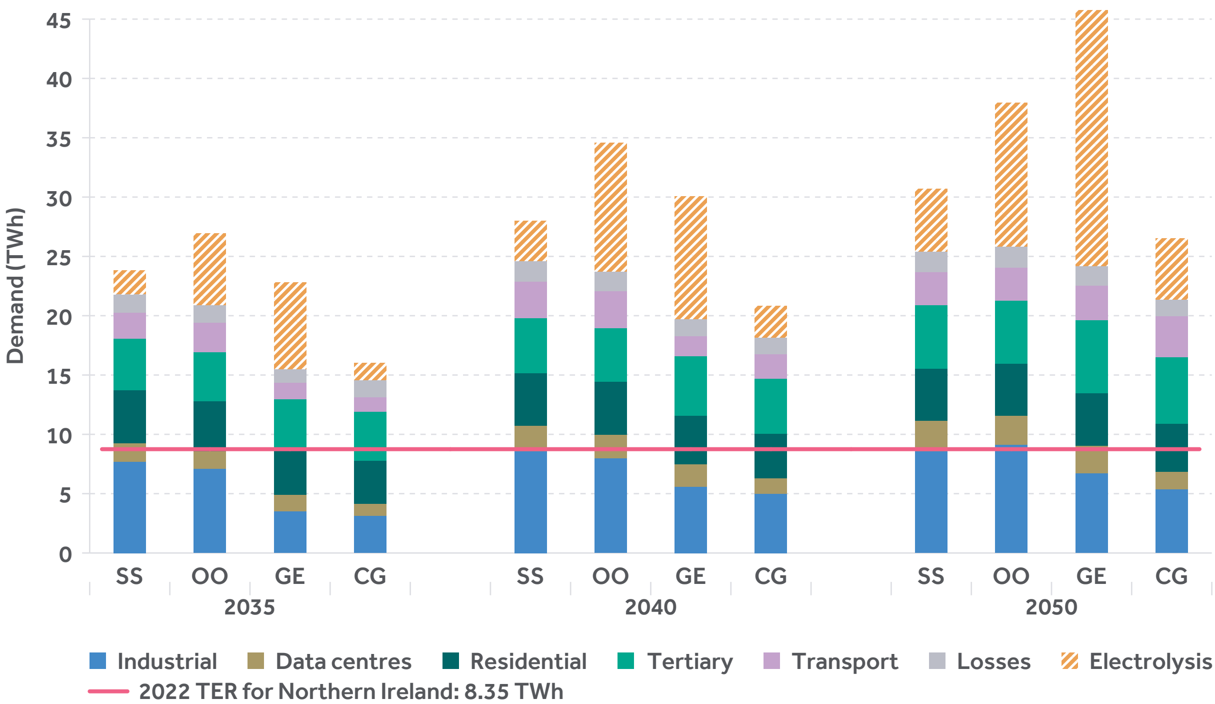

Figure 5.5: Annual Total Electricity Requirement (NI)

5.3.2 Peak electricity demand

As with Ireland in the previous section, Northern Ireland's peak demand for electricity generally occurs on a weeknight in winter at approximately 6:00pm. As peak demand varies with temperature and weather conditions, the peak demand forecasting methodology accounts for an average ambient temperature by selecting 2009 as the average historical climate year, for consistency with the climate year used across the model. This climate year is deemed an average climate year for Europe in general. The peak demand projections for each scenario are shown in Figure5.6.

Figure 5.6 below shows how peak electricity demand is forecast to change for each scenario. The timing and sectoral composition of peak demand varies across scenarios driven by adoption of new technologies such as smart meters and electric vehicles. The greatest increase in peak demand is seen in Offshore Opportunity and is driven by greater demand from electrified industrial processes and high uptake of EVs and heat pumps. Constrained Growth shows a slower peak demand growth for electricity as this scenario takes longer to transition away from fossil fuels. Gas Evolution sees a transition to renewable gases such as green hydrogen, which tends to reduce demand growth on the electricity system. The increase to peak is most pronounced in Offshore Opportunity, as outlined below. The red line on the graph indicates the 2022 peak demand in Northern Ireland.

Figure 5.6 shows the peak demand after smart EV charging is applied (see Section 5.3.5 for more details on the blended charging profiles for EVs). Self-Sustaining and Offshore Opportunity see increased flexibility and efficiency improvements while the majority of demand has already been electrified by 2040. The flexibility technologies that can potentially be developed for short duration peak mitigations are outlined in Section 5.3.3.

In Northern Ireland, increases to peak demand are primarily driven by the electrification of consumer demand areas such as heat, transportation, and industrial processes, as well as increasing population until around 2045 leading to increased household numbers (as indicated by the 2021 NISRA census). These increases raise peak demand to 2050 in each scenario, outweighing increases in energy efficiency across the various sectors. The increase is particularly evident in the Offshore Opportunity scenario.

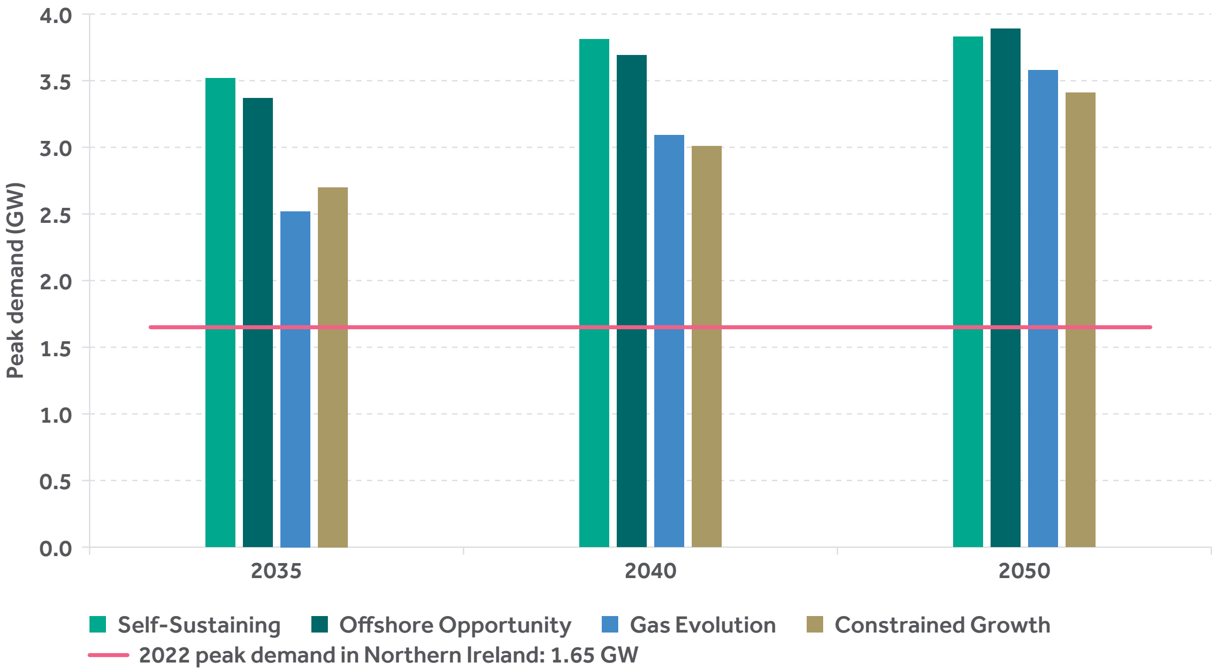

Figure 5.6: Forecasted peak demand (the red line on the graph indicates the 2022 peak demand in Northern Ireland)

5.3.3 Demand Flexibility and Energy Efficiency

Demand Flexibility

Demand Flexibility will be key to allowing overall electricity demand to increase while maintaining system security. Managing peak demand on the system alleviates pressure on the power grid overall and may minimise the level of system reinforcements that are required, ultimately saving expenditure on new infrastructure. Shifting peak demand to times of high RES should allow for cheaper end-use electricity for the consumer. For TES 2023, we have included demand flexibility in all of the scenarios – the highest levels being in Self-Sustaining and Offshore Opportunity.

Flexibility measures included in TES modelling are as follows:

- As heat pumps are rolled out and electricity demand grows in that area, it is assumed that this will be flat across the day as Building Energy Ratings (BERs) from new builds and retrofits will allow efficient running of heat pumps across the day due to efficiency savings.
- Smart devices are expected to assist consumers to reduce their electricity demand at peak times when electricity prices are highest. This shifting of demand is incentivised by time-of-use tariffs and enabled by smart meter data. The ability to shift demand largely depends on the potential flexibility of new electricity demand.

- A share of traditional baseload demand ranging from 5% to 9% is assumed to be flexible by 2050. This is designed in the model in such a way that at times of high renewable availability, load will shift to this period when prices are low. This reduces curtailment of renewable electricity and enables the consumer to access cheaper electricity.
- There is significant potential to shift electric vehicle demand away from peak times depending on the location and sophistication of charging infrastructure and the price signals offered to consumers through time-of-use tariffs. All scenarios assume high electric vehicle adoption rates by 2050, but the level of smart charging vehicles that limit the peak demand differs between scenarios. The potential impacts of higher system peaks and the assumed charging profiles for electric vehicles are discussed in Section 5.3.5.
- Extensive rollout of vehicle-to-grid is assumed by 2050. This allows EVs to act as batteries and give electricity back to the grid at times of high demand and low renewable generation.
- Energy efficiency improvements are expected to reduce demand in all sectors as technology and homes become more efficient over time.

Demand that is not considered to offer flexibility is modelled as flat (i.e. it does not vary at different times in the day). This includes data centre and NTL demand. On average, approximately 8% of power produced is lost as it passes through the electricity transmission and distribution systems to homes and businesses, this is reflected as a percentage of additional demand in the demand profiles.

Potential additional demand flexibility impacts can be seen in the table below:

	2050 hourly demand shift potential (MW)			
	Self-Sustaining	**Offshore Opportunity**	**Gas Evolution**	**Constrained Growth**
Traditional baseload demand to provide flexible demand in some form	410	335	200	185
DSU	380	380	380	380
V2G	1,180	1,180	950	430
Total	**1,970**	**1,895**	**1,530**	**995**

Energy efficiency

Energy efficiency refers to the implementation of energy saving measures, for example improvements in insulation, window glazing, lighting, and heating.

Such measures can have other benefits such as improved thermal comfort, long-term energy cost savings, as well as reduced CO_2 emissions and energy imports.

Table 5.7 shows the range of year-on-year energy efficiency gains assumed for various demand sectors in NI. In Offshore Opportunity and Self-Sustaining, more energy efficiency measures are adopted and embedded in each area of electricity demand. For Constrained Growth and Gas Evolution, lower levels of implementation of energy efficiency uptake are seen. Note that for energy efficiency gains to be effective they will need to be enabled by appropriate policy incentives.

Table 5.7: Year-on-year energy efficiency gains

	Self – Sustaining	Offshore Opportunity	Gas Evolution	Constrained Growth
Residential	-1.5%	-1.5%	-1.0%	-0.8%
Tertiary	-1.5%	-1.5%	-1.0%	-0.8%
Transport – passenger EVs	-0.9%	-0.9%	-0.9%	-0.5%
Transport – all other EVs	-0.5%	-0.5%	-0.5%	-0.5%
Data centre and NTLs (%)	-0.3%	-0.3%	-0.3%	-0.3%
Industrial processes (%)	-1.0%	-1.0%	-0.8%	-0.5%

Smart meters

The model for the rollout of smart meters in NI is, at time of writing, yet to be agreed between the relevant stakeholders. However, the NI DfE intend to develop a plan for the rollout of electricity smart meters and systems, following a cost benefit analysis conducted in late 2022.[28]

Assuming that the rollout of smart meters begins before the end of 2030, consumers will begin to realise the energy savings benefits during the period studied by TES 2023. Smart meters are represented in the form of the percentage traditional baseload demand mentioned in the Demand Flexibility section above.

28 economy-ni.gov.uk/articles/smart-meters-update

5.3.4 Residential and tertiary

Residential and tertiary electricity demand can be broken down into two key components:

1. Lighting and power.
2. Electrified heating and cooling.

The main technologies we focus on are electric direct heaters, air source heat pumps, ground source heat pumps, and hybrid heat pumps as these dominate growth in electrical demand in the residential and tertiary sectors.

It is also anticipated there will be growth in heating technologies using biomass as a source of fuel, but the majority of existing heating systems shift to electrical sources. While this does add significant load to the power system, the efficiency of electrical heat pumps will lead to reductions in overall energy demand in this sector.

Heat pumps

Electricity demand from heat pumps was calculated from consideration of overall heating demand per year and the projected percentage of residential and tertiary properties with heat pumps installed in each scenario.

This demand increases over time based on increasing population and number of households, economic growth, and continued heat pump installations, and decreases based on improvements in heat pump operational efficiency and building heating efficiency ratings.

The energy demand from a given heat pump is a function of the average heat demand from a dwelling and the efficiency of a heat pump. Heat pump efficiency can be described in terms of Coefficient of Performance (COP), which measures the ratio of useful heat output to the energy required. The COPs of heat pumps in dwellings, which are fixed across scenarios but improve across the study horizon, are given in Table 5.8. These COP assumptions were based on the SEAI National Heat Study Low Carbon Heating and Cooling Technologies Report[29], with rates of technological improvement assumed to be consistent across IE and NI. Note that these improvements occur primarily between 2022 and 2030. Note that the COP for heat pumps has been assumed to be the same throughout the year, it is not based on seasonal temperature shifts.

Table 5.8: Air- and ground-source heat pump COP

Heat pump	COP
Air-source heat pump	2.6
Ground-source heat pump	2.94

29 National Heat Study, Low Carbon Heating and Cooling Technologies

To assess the level of electricity demand from heat pumps we took the following approach:

1. We reviewed existing demand by individual subsectors of heating, cooling, lighting and power. This was then further broken down into the individual fuel and technology sources for each subsector.
2. Demand was then forecasted for each sub-sector based on the increase in number of residences and the technology shift driven by decarbonisation goals.
3. Within our demand profiles, we have assumed that heat pumps output at a steady fixed rate over the day[30]. This provided a forecast of electrical heat pump demand in TWh.

Figure 5.7 below shows the development of electrical heating demand as a result of heat pumps. The variations seen across the scenarios reflect the increasing volume of heat being electrified and the adoption of efficiency improvements that ultimately act to slow and reduce the total electrical demand from heat pumps in Self-Sustaining and Offshore Opportunity in 2050.

Included in the demand figures in Figure 5.7 are heat pumps committed to district heating systems. We have assumed that a portion of electrical heating demand will be from district heating schemes. We have assumed a relatively low proportion of homes in district heating schemes due to local population densities in Northern Ireland, with a maximum of 7% of residences assumed to be in these schemes by 2050.

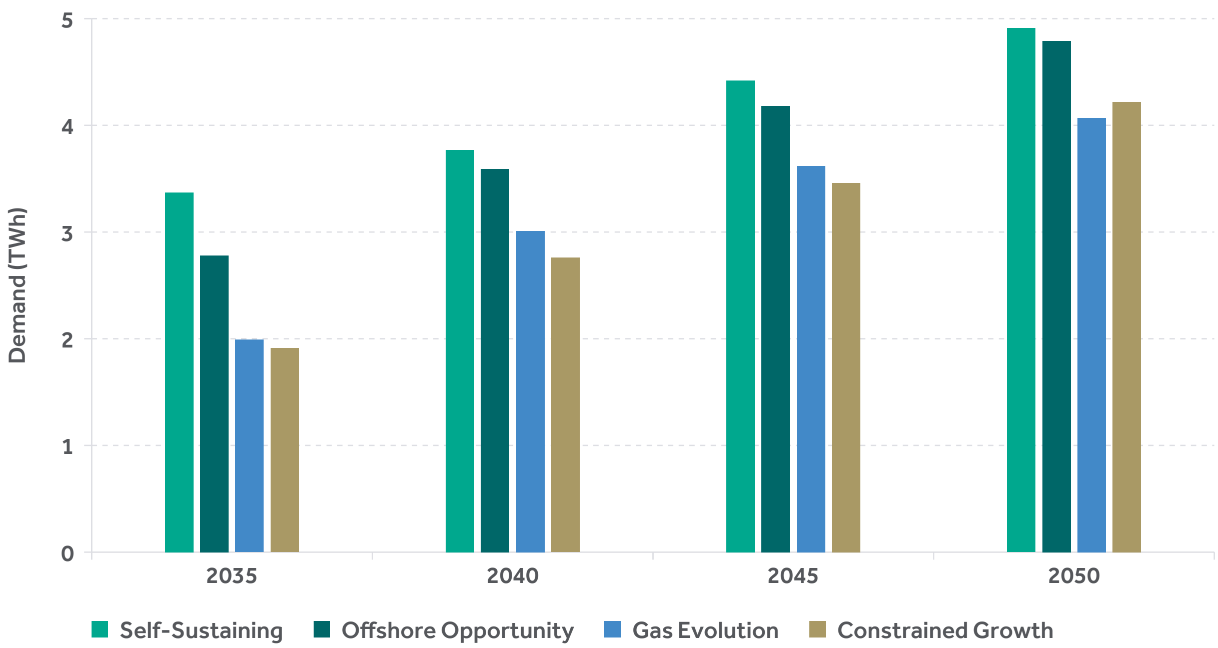

Figure 5.7: Residential and tertiary heat pump electrical demand (NI)

30 [How will heat pumps alter national half-hourly heat demands? Empirical modelling based on GB field trials]

5.3.5 Transport

Electric vehicles

Electricity demand from transport is a function of the proportion of each type of transport that are electrified (cars, motorcycles, vans, buses, freight, and rail), the distance and type of travel by citizens, and the efficiency of each the vehicle technology.

Within the scenarios, a range of possible EV adoption rates is assumed in line with the degree of electrification in each scenario. Self-Sustaining and Offshore Opportunity share the same degree of electrification, showing a significant increase in the adoption of EVs. This increase may be promoted by falling EV costs, stronger economic growth, higher consumer appetite for decarbonisation, or a ban on the sale of new non-zero emissions vehicles post-2030.

Gas Evolution and Constrained Growth show a slightly more sluggish transition to EVs as is expected in these scenarios. Gas Evolution also includes for some transport demand to be met by alternative renewable fuels, such as green hydrogen.

As more electric vehicles enter general use, they will have an increasing impact on the operation of the electricity grid. The exact extent of this impact will depend on a wide range of factors such as the types of electric vehicles in use, vehicle usage trends, types and locations of vehicle chargers, and the charging patterns of vehicle owners. Electric vehicle adoption numbers are shown in Figure 5.8.

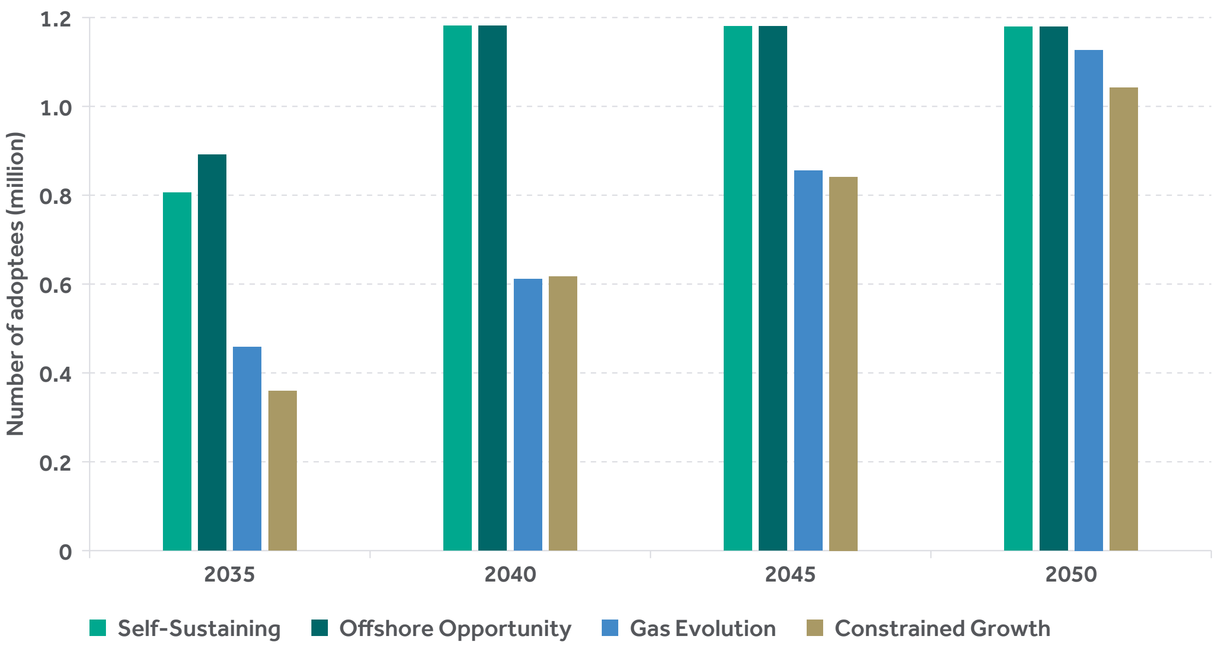

Figure 5.8: Projected number of EVs (NI)

The efficiency of EVs is assumed to improve over time, leading to a higher distance travelled per unit of electricity input, known as specific consumption. Table 5.9 shows our assumptions for electric passenger vehicles (including plug-in hybrid electric vehicles) and electric delivery vans.

As the number of electric vehicles grows, they will have an increasing impact on the electricity grid and on electricity markets. The scale of this impact will depend on a wide range of factors such as the quantity and types of electric vehicles in use, vehicle usage, types and locations of vehicle chargers and the charging patterns of vehicle owners. Vehicle charger technology has the potential to minimise the potential impact of electric vehicle demand on the electricity system, and on electricity markets.

Table 5.9: Specific consumption rates (kWh/100 km), electric passenger vehicles and delivery vans

	2035	2040	2050
Self-Sustaining	16.19	15.48	14.14
Offshore Opportunity	16.19	15.48	14.14
Gas Evolution	16.86	16.12	14.72
Constrained Growth	17.41	16.98	16.15

It is assumed that charger technology will evolve over time from simple chargers and patterns that are readily available today, to smart chargers with features such as programmable charge start times to smarter charging technology that optimise vehicle charging in line with dynamic electricity price signals.

The TES 2023 framework for electric vehicle chargers is shown in Table 5.10. It shows the different blended configurations of simple, smart, and smarter profiles that EVs can operate at.

The ratio of simple to smart to smarter differs depending on the scenario and the year, indicating a behavioural change in vehicle charging and the development of policy to incentivise smart charging and vehicle-to-grid charging.

In scenarios with high uptake of electric vehicles, optimisation of charging demand is required to ensure that the need for grid development and additional generation capacity is minimised. The use of blended charger technologies has the potential to reduce system peak demand by up to 200 MW in 2050, compared to all EVs charging with a simple profile.

Table 5.10: Electric vehicle charger framework showing the most numerous charger types by vehicle type, scenario and year

	Self-Sustaining			Offshore Opportunity			Constrained Growth			Gas Evolution		
	2035	2040	2050	2035	2040	2050	2035	2040	2050	2035	2040	2050
Passenger vehicles, motorcycles												
Simple	30%	25%	10%	30%	25%	10%	80%	70%	50%	60%	45%	15%
Smart	40%	40%	40%	40%	40%	40%	15%	22%	30%	25%	30%	45%
Smarter	30%	35%	50%	30%	35%	50%	5%	8%	20%	15%	25%	40%
Buses, road freight, goods vehicles												
Simple	80%	70%	50%	80%	70%	50%	95%	90%	80%	90%	80%	65%
Smart	20%	30%	50%	20%	30%	50%	5%	10%	20%	10%	20%	35%

5.3.6 Industrial demand

Electricity demand from industrial sources in Northern Ireland comes from end uses such as: agri-food production; quarrying and mining; manufacture of glass and building materials; agriculture; forestry and fisheries; wood and wood products; paper, pulp and print; transport equipment; textile and leather; and construction, among others.

Approximately 22% of the final energy demand from these industrial customers was supplied by electricity in 2015[31], which was extrapolated to be the starting percentage for this study. It is assumed that these users will decarbonise their demand over the study period, whether via electrification or the use of zero-carbon fuels such as hydrogen. In reflection of ambitious decarbonisation targets, this electrification increases steadily over the study horizon.

31 Tomorrow's Energy Scenarios Northern Ireland 2020, SONI

The electricity demand increases in each milestone year to 2050 in all scenarios other than Self-Sustaining. In this scenario, the decarbonisation of the industrial sector is completed by 2040, at which point demand plateaus as industrial growth is balanced by efficiency improvements. In Offshore Opportunity, industrial demand grows faster in the later years in response to the abundance of renewable energy supply, leading to this scenario having the highest demand by 2050. Gas Evolution and Constrained Growth both see significantly slower decarbonisation, coupled with slower economic growth. This is most pronounced in the Constrained Growth Scenario, leading to the lowest overall industrial electricity demand, while in Gas Evolution, more demand is decarbonised via hydrogen use, leading to lower electricity demand than in Self-Sustaining and Offshore Opportunity.

Data centres and NTLs

Currently, the vast majority of connected data centre demand is in located in Ireland, with far fewer centres contracted or under application in Northern Ireland. However, there remains scope for this to be a growth area in the north, and as such the scenarios here assume a certain level of demand growth for NTL connections, scaled down from the equivalent trajectories in Ireland. In general, it is assumed that the faster economic growth is and the more renewable energy there is on the system, the more likely new NTLs may be drawn to connect to the system.

6. Electricity generation

TES 2023 assesses the generation portfolio for both Ireland and Northern Ireland – the capacities of electricity generators, energy storage and interconnection, and how the portfolio may evolve from 2035 to 2050.

6.1 Introduction

Energy policy has changed significantly in the last few years to reflect a growing renewable ambition. In Ireland, renewable targets were increased in 2022. By 2030, 80% of electricity must be produced from renewable sources. Carbon budgets introduced in 2022 set out, in five-year blocks of time, a limit for the total amount of carbon emissions that Ireland can emit. The electricity sector is no longer solely aiming to achieve a 2030 target, but now must also do so without exceeding carbon emissions across five-year blocks.

Given these policy changes, the generation portfolio of the future is expected to be significantly different from that of the past. There will be a changing role for thermal generation and an increasingly important role for weather-dependent renewables.

Flexibility across both the demand and supply side will be needed to maximise the utilisation of renewable generation that is weather-dependent. Demand across all sectors will need to flex up in periods of high renewable generation and flex down in periods of low renewable generation. Energy storage can help smooth renewable supply, capturing surplus renewables for later discharge in low renewable periods. Similarly, electricity interconnection can help to use surplus renewable generation when it is plentiful by providing a connection to other markets and provide alternative sources of generation when domestic renewable generation is lower than demand.

In addition to renewable technologies, each of our scenarios also demonstrate the importance of other low or zero carbon technologies in the future such as hydrogen, bioenergy and CCUS (Carbon Capture, Usage and Storage). A key enabler of achieving a net zero power system is the introduction of these technologies at scale.

6.1.1 Modelling approach

In TES 2023, the period modelled is 2030 to 2050. In each scenario the thermal capacities assumed in SOEF v1.1 are used as a starting point while the renewables and storage portfolios from SOEF v1.1 are used in two scenarios, Self-Sustaining and Offshore Opportunity. In Gas Evolution and Constrained Growth lower renewable and storage capacities than those in SOEF v1.1 are used in 2030 in line with their storylines. Note that SOEF v1.1 derived its targets from CAP23.

The modelling proceeds in two stages. In the first stage, beyond 2030, capacities for generators, storage and interconnection are expanded using a least cost optimisation model.

Constraints are applied to the model to align with the scenario storylines. While optimising for cost the model must also comply with an emissions constraint designed to continuously reduce the carbon emissions in the power sector from 2030 until a net zero date which differs by scenario. The costs for each technology type are sourced from TYNDP 2022, a study carried out by ENTSO-E and ENTSO-G[32].

Table 6.1: IE 2022, 2030 and scenario installed generation capacities (all figures in MW)

Generation type	2022 Capacity	Assumed 2030 capacity[33]	SS 2030	OO 2030	CG 2030	GE 2030
Solar PV	167	8,000	8,000	8,000	4,000	4,000
Onshore wind	4,480	9,000	9,000	9,000	7,000	7,000
Offshore wind	25	5,000	5,000	5,000	2,000	5,000
Gas	4,636	5,750	5,750	5,750	5,750	5,750

Table 6.2: NI 2022, 2030 and scenario installed generation capacities (all figures in MW)

Generation type	2022 Capacity	Assumed 2030 capacity	SS 2030	OO 2030	CG 2030	GE 2030
Solar PV	285	600	600	600	400	400
Onshore wind	1,430	2,450	2,450	2,450	1,800	1,800
Offshore wind	0	500	500	500	500	500
Gas	1,013	2,050	2,050	2,050	2,050	2,050

32 TYNDP 2022 Scenario Report
33 Informed by Climate Action Plan 2023 (CAP23).

In the second stage, after capacity expansion, electricity supply and demand must be matched on an hourly basis using an unconstrained network. These hourly dispatch results allow us to examine in detail how demand will be met at any point in time.

6.1.2 Structure of this section

Section 6.2 summarises the installed capacity for Ireland in each scenario and Section 6.3 provides the same report for Northern Ireland.

Section 6.4 presents our findings for electricity interconnection between Ireland and Northern Ireland with Great Britain and Continental Europe.

Sections 6.5 and 6.6 explains how installed generation capacity, storage and interconnection combine in each scenario as a generation mix. We highlight electricity generation analysis when each scenario has reached a net zero power system – the overall share for each technology throughout the year and the results for two distinct weeks with high and low levels of renewable generation.

Section 6.7 summarises the results of our analysis in terms of carbon emissions reductions.

6.2 Generation technologies – Ireland

Decarbonisation of electricity supplies means that we will need more generation from low carbon and renewable sources.

TES 2023 has included a range of technology types:

- Renewables such as solar, onshore and offshore wind (Subsection 6.2.1–6.2.4).
- Energy Storage (Subsection 6.2.5).
- Flexible thermal generation technology such as natural gas, hydrogen and biomass (Subsection 6.2.6–6.2.9).
- Electricity Interconnection (Section 6.4).

It has been assumed that the following technologies will not be operating by 2035: coal, peat and oil fired generators.

6.2.1 Onshore wind

Since 2000, over 4.5 GW of onshore wind generation has been installed in Ireland[34]. Throughout that period onshore wind has been the lowest cost form of renewable energy on the island and was the main contributor to achieving 2020 RES-E targets.

CAP23 includes the connection of 9 GW of onshore wind generation by 2030. This level of capacity is included as the starting point for Self-Sustaining and Offshore Opportunity scenarios.

An important consideration regarding onshore wind is the potential number of available sites remaining for development in Ireland and an estimate of 12 GW was used.

Figure 6.1 below shows the changes in onshore wind capacity over time in each scenario. This new capacity could be delivered by both new windfarms and the repowering of already existing windfarms.

Self-Sustaining, Gas Evolution and Constrained Growth see continued expansion of onshore wind capacities beyond the CAP23 target of 9 GW, ultimately reaching the limit of 12 GW. Offshore Opportunity sees growth in onshore wind moderated by the much larger growth of offshore wind.

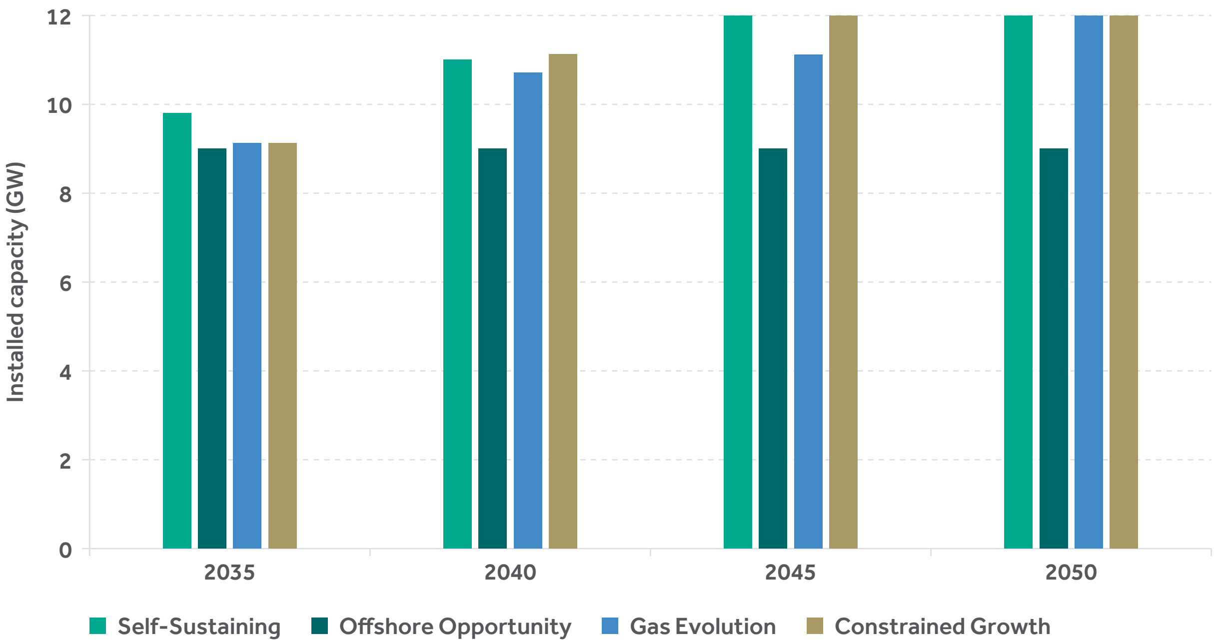

Figure 6.1: Installed onshore wind capacity (IE)

34 EirGrid and SONI Group, System and Renewable Data

6.2.2 Offshore wind

Historically there has been little in the way of offshore wind development in Ireland. As of 2023 the total installed capacity of offshore wind in Ireland is only 25 MW, compared to several GW in neighbouring regions such as Great Britain and Denmark. However, this is expected to change significantly in the coming years.

By comparison with other European countries, Ireland has a relatively large and unconstrained maritime area, significantly larger than its land area. Recognising this opportunity, CAP23 requires Ireland to develop 5 GW of offshore wind generation by 2030, and a further 2 GW of offshore wind generation specifically for the production of hydrogen (this generation will not be connected to the electricity grid). This will be primarily met through the development of fixed bottom offshore wind farms through auctions run under the Offshore Renewable Electricity Support Scheme (ORESS) – ORESS1 and ORESS2. This level of capacity is included as the starting point for the Self-Sustaining, Offshore Opportunity and Gas Evolution scenarios.

In June 2023, Ireland held its first offshore wind auction which awarded over 3 GW of capacity at a price of €86.05/MWh. This displayed the interest in offshore wind in Ireland. The government has set ambitions to increase offshore wind capacity in the coming years. Offshore wind has the potential to grow considerably both in the period until 2030 and beyond.

Looking out to 2050, with the NSEC, Ireland has agreed non-binding targets for further development of offshore renewable generation of up to 37 GW[35]. This includes development of floating offshore wind power in deeper waters in the Atlantic Ocean and Celtic Sea. Ireland has some of the highest capacity factors for offshore wind in the world, especially off the west coast in the Atlantic Ocean meaning that if technology costs reduce enough and there is sufficient demand in other markets then exporting offshore wind generation may represent a significant economic opportunity. This is discussed further in the interconnection section.

It is important to note that spare transmission capacity on the existing transmission system is very limited, and developments of large scale offshore wind on the South and West coasts could require an unprecedented upgrade to the transmission system, far beyond what has been set out in Shaping Our Electricity Future. This will be assessed further in the TES System Needs Assessment studies due to take place in 2024.

Offshore Opportunity foresees the largest offshore wind build with over 37 GW installed by 2050. The other scenarios include comparatively less but still significant builds apart from Gas Evolution which sees very little grid-connected offshore wind development as decarbonisation of the system happens more gradually with more reliance on hydrogen.

35 Joint Statement on the North Seas Energy Cooperation – 12 Sept 2022

All scenarios also contain offshore wind that is assumed not to be connected to the transmission system and instead used directly for electrolysis.

Gas Evolution shows the most significant build out of this non-grid connected offshore wind with up to 14 GW. This is discussed more in Section 6.2.7 on Hydrogen.

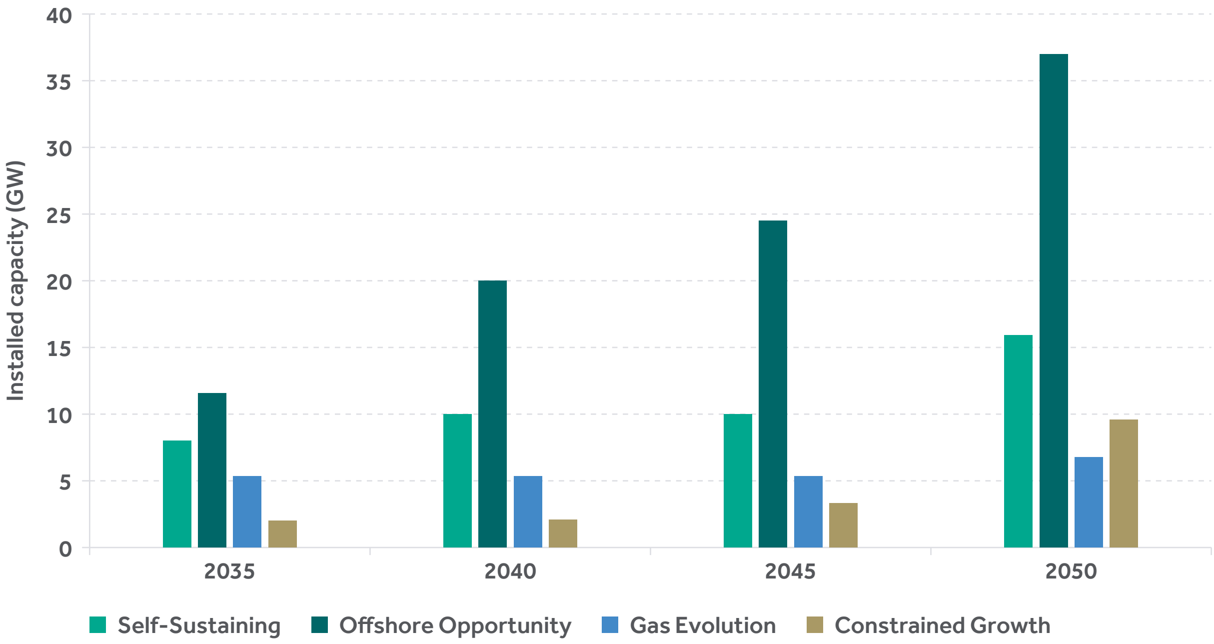

Figure 6.2: Installed offshore wind capacity (IE)

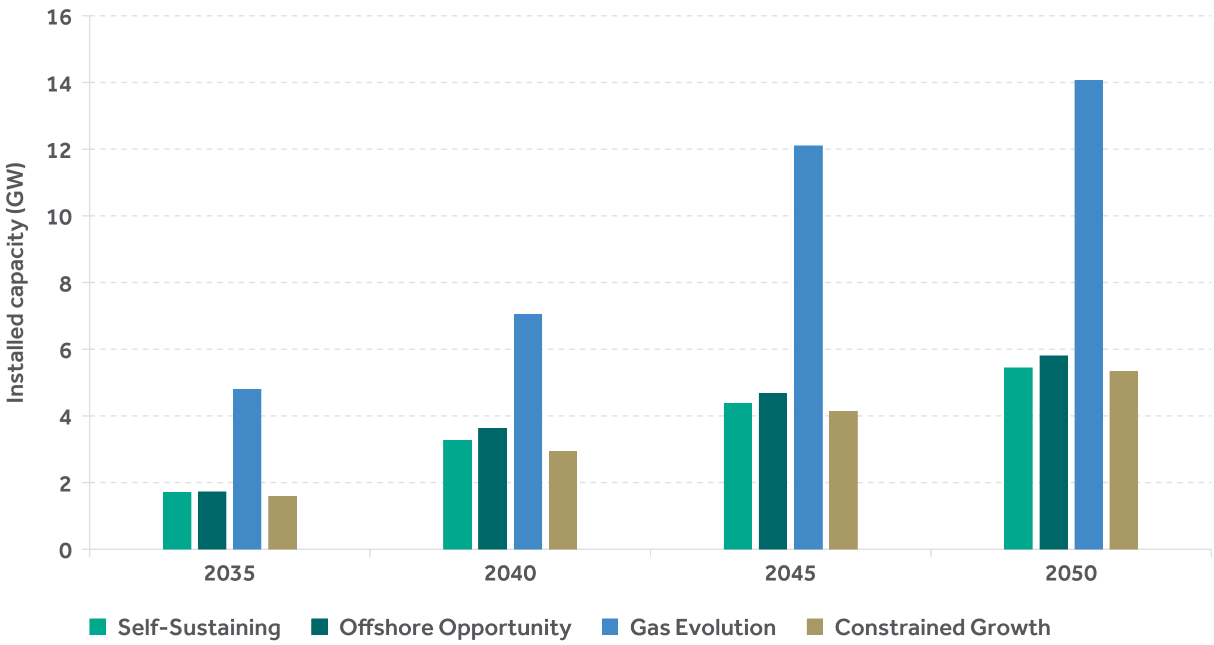

Figure 6.3: Non-grid connected offshore wind capacity for hydrogen production (IE)

6.2.3 Solar photovoltaics

There has been massive growth of Solar PV capacity across the world over the last decade, rising from about 70 GW in 2011 to nearly 900 GW in 2021[36]. While having a low capacity factor in Ireland compared to much sunnier regions, the cost of solar is so low that the technology is now becoming economically competitive with wind energy.

Furthermore, solar offers a valuable diversification benefit to a generation portfolio. High periods of solar generation in the summer months generally complement higher periods of wind generation in the winter months. Solar generation is also very predictable in terms of total energy production over a monthly or annual basis meaning that with appropriate levels of storage it's contribution towards meeting energy demand can be well forecasted. Similarly to the constraint on onshore wind development based on site suitability, a total installed capacity of utility scale PV has been assessed up to 12 GW. In spatial terms, this equates to up to circa 20,000 hectares[37].

As the amount of PV generation connected to transmission systems around the world has grown significantly over the last decade so too has small scale PV. As of 2023, it is estimated that there is currently in the region of 60,000 homes in Ireland with their own small scale PV systems[38]. This consists mostly of roof mounted PV on homes, businesses, and public buildings. An important factor in the growth of this sector will be the trend of retail electricity prices. Higher retail electricity prices will make 'behind the meter' systems like this more economically attractive to homeowners and business owners. We also expect that there will be a desire among certain individuals to take ownership over their own energy production and make their own contributions to decarbonisation.

36 Solar PV power capacity in the Net Zero Scenario
37 Frequently Asked Questions on Solar Photovoltaics
38 ISEA – Scale of Solar

Figure 6.4 below shows the growth of PV capacity in each scenario over time. In the case of this graph, the solid areas of each bar denote utility scale PV and the lighter areas denote small scale PV.

In each scenario except for Offshore Opportunity, the installed capacities of utility scale PV continue to grow from 2035 to 2050. In all scenarios the capacity of small scale PV grows during the same period.

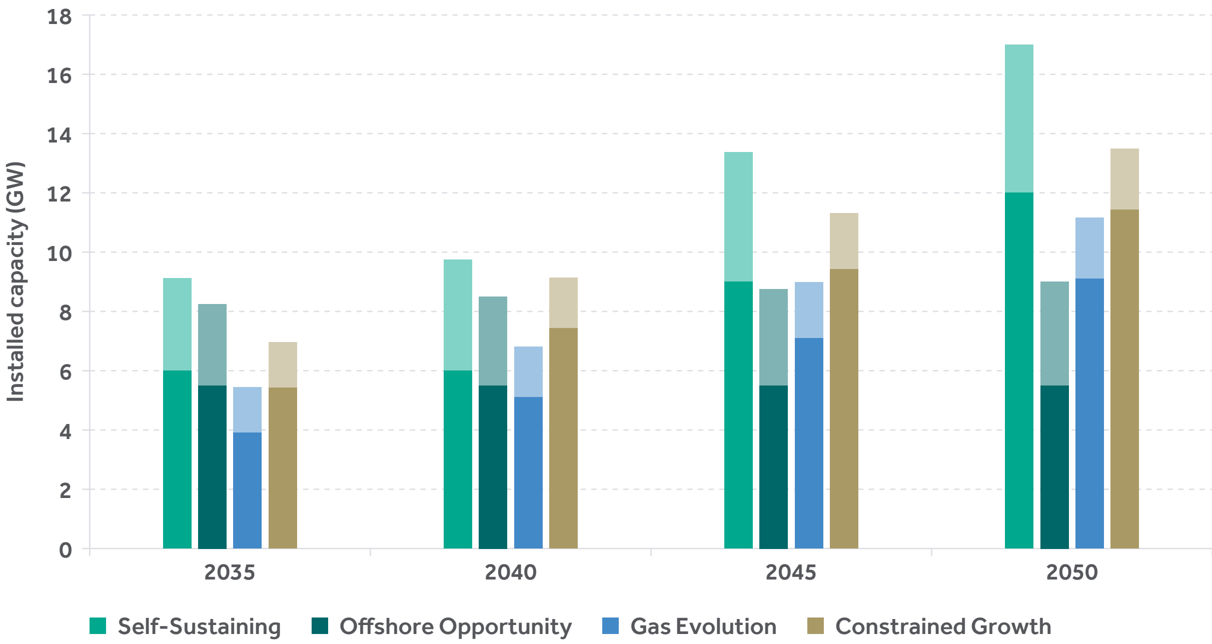

Figure 6.4: Installed solar PV capacity (IE) (lighter colour denotes non-utility scale solar PV)

6.2.4 Variable renewables summary

Clearly, each scenario foresees a central role for variable renewable sources, namely wind and solar, in the decarbonisation of the Irish power system. An important consideration when operating a system with such high levels of renewable generation is the dispatch-down of those renewables. There are typically three reasons why renewable generation is dispatched down.

1. **Constraints**
   Generators may need to be dispatched down due to transmission network limitations and to ensure that the thermal overload limits of transmission circuits and transformers are not breached. Changes in generator output for this reason are referred to as a 'constraint'. The constraining of generation is location specific.

2. **Curtailment**
   To ensure a safe and secure electricity system, the TSO must operate the system within certain operational limits. Curtailment is applied to reduce the output of renewable generators to ensure that operational limits are not breached, and the system can remain secure and stable. Curtailment is applied to all renewable generators across the island on a pro-rata basis. (see graph of percentage curtailment annually by scenario in Figure 6.5 below).

3. **Surplus renewable generation**
   The reduction of available renewable generation for oversupply reasons is necessary when the total available generation exceeds system demand plus interconnector export flows.

Of these three forms of dispatch-down, only surplus renewable generation is considered in our model, as network and operational constraints are not considered. Therefore, the level of dispatch-down shown below could be higher in reality if network and operational constraints were also considered.

With high levels of renewable generation on the system, it is likely that the available generation from these renewables will exceed demand in many hours of the year. However, there will still be periods during which renewable generation is not able to meet the entirety of demand.

Figure 6.6 below shows the number of hours in each year that the availability of renewables is not sufficient to meet demand. Clearly, this shows that adding higher levels of renewable capacity to the system can reduce the number of these hours but not eliminate them entirely.

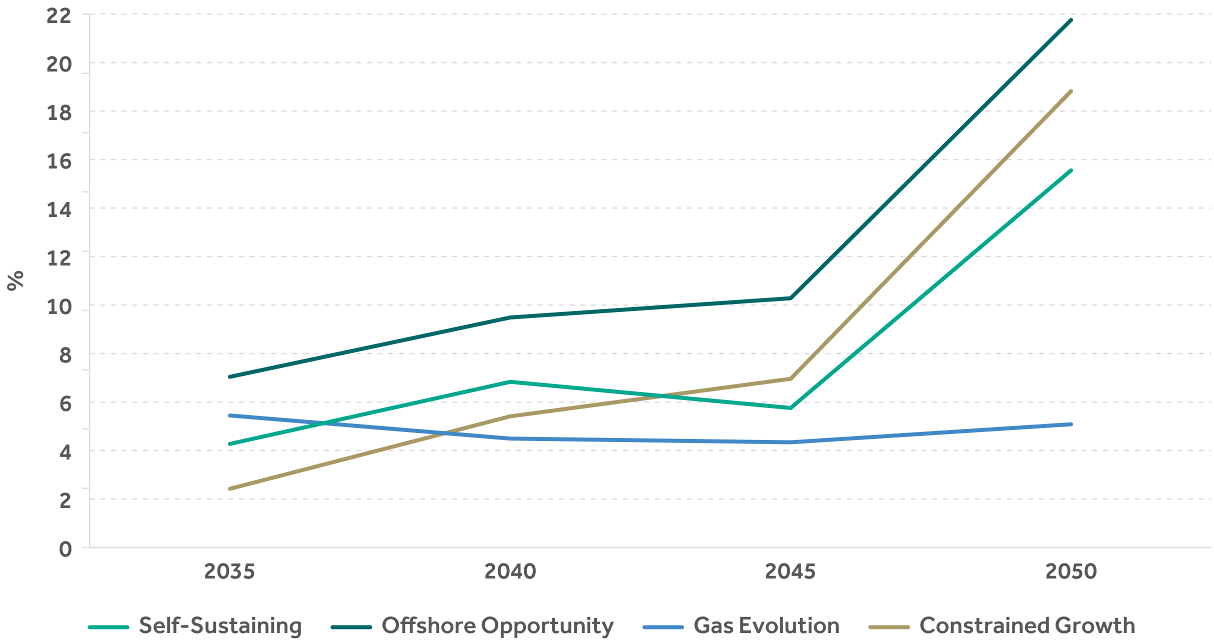

Figure 6.5: Dispatch down of renewable generation assumed to be done on an all-island basis. Constraints and curtailment not included

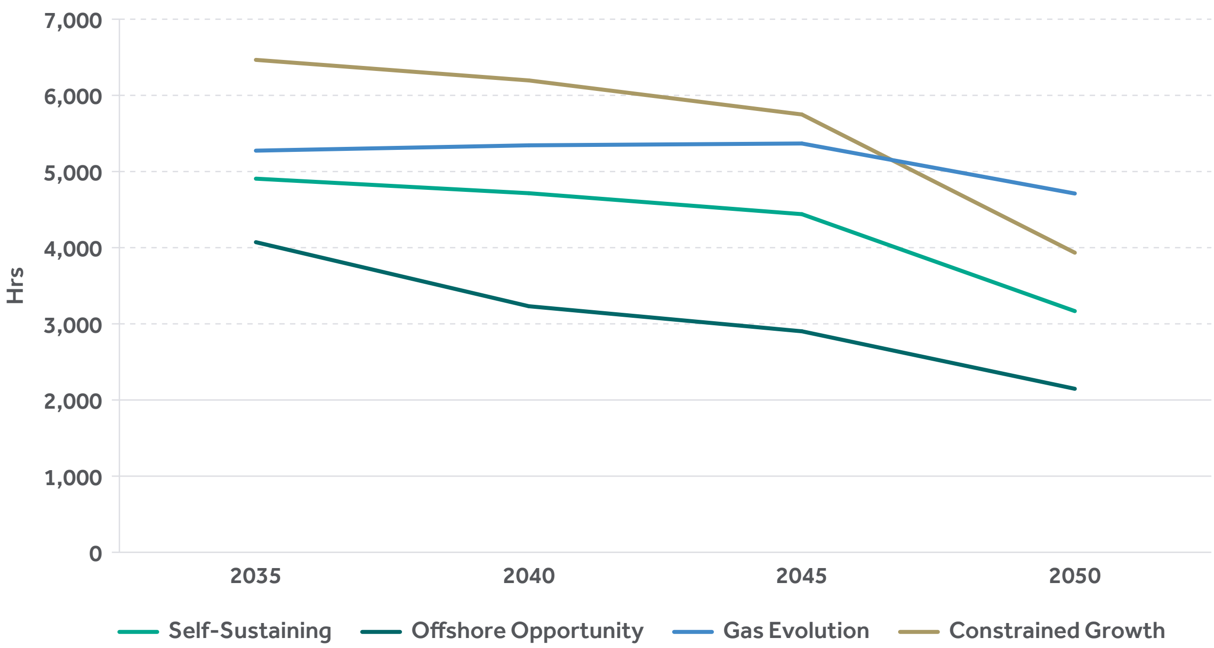

Figure 6.6: Hours of demand where wind and solar generation needs to be supplemented by other sources (i.e. energy storage, interconnection, thermal capacity) (IE)

The following sections explore some of the various technologies that can help to meet demand in these hours.

6.2.5 Storage

With increasing electrification around the world, the potential for energy storage technology is developing rapidly. Currently, pumped hydro systems provide over 90% of global electricity storage but with the potential for pumped-hydro geographically constrained other technologies are being developed. For power systems, energy storage is seen as increasingly important when we consider the growing role of variable renewable capacity and can also provide other system services for transmission networks. Energy storage has the potential to capture surplus renewable generation, reduce curtailment and provide flexibility when renewable generation is not sufficient to meet demand.

The capital cost of electricity storage and available revenue streams have meant that it has not always been attractive for development projects. It is anticipated that future arrangements for markets may change to encourage energy storage investments that support the power system, reduce the need for flexible dispatch capacity, and help reduce power sector carbon emissions. Technological innovations are anticipated that may both reduce the capital cost of storage infrastructure and also improve the round-trip efficiency. This is likely to apply to batteries designed to store for up to 8 hours (currently dominated by lithium-ion), long-duration or multi-day storage (circa 100 hours) and also seasonal storage (multi-week).

A range of different storage technologies may be available between 2035–2050 and currently these show varying levels of technology readiness. These include mechanical (pumped hydro, liquid air and compressed air), electrochemical (Li-ion and flow batteries) thermal storage and chemical storage (hydrogen and synthetic gases and fuels).

For TES 2023, the following forms of storage were modelled:

- **Pumped hydro** – the existing pumped hydro energy storage will continue to operate in Ireland until 2050 and the large scale Silvermines hydro project (ENTSOE TYNDP project 1025) has been deemed a PCI project by the European Union and has also been included in all scenarios from 2030 onwards.
- **Batteries** – all batteries are assumed to be lithium-ion units with the exception of 100-hour batteries in Self-Sustaining, which for modelling purposes are assumed to be iron-air type batteries.
- **Vehicle to Grid (V2G)** – additional energy storage can be discharged to meet demand from through vehicle to grid solutions. It is noted that participation in V2G will depend on both suitable vehicle and grid technologies and consumer acceptance.

The total installed capacity of battery storage in each scenario is shown below in Figure 6.7. The includes a blend of up to 8-hour batteries, Vehicle to Grid and Pumped Hydro Energy Storage. The Vehicle to Grid capacity can offer significant short-term flexibility to the system.

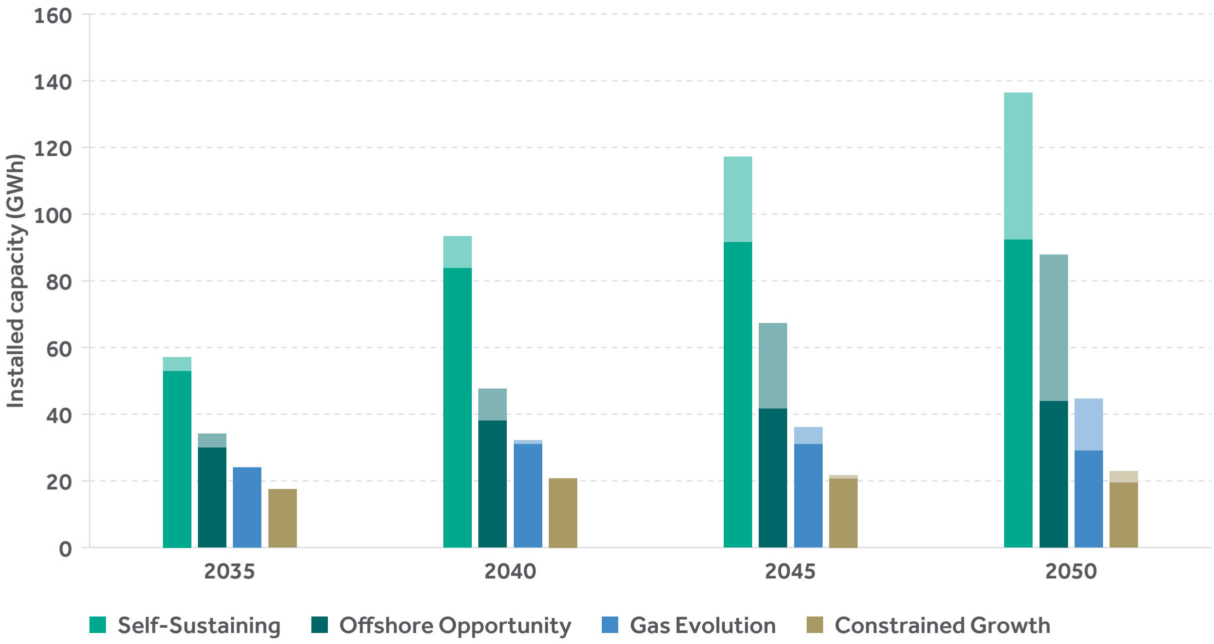

Figure 6.7: Installed storage capacity (IE) (lighter colour denotes Vehicle to Grid)

6.2.6 Natural gas

Currently, the majority of Ireland's electricity mix that does not come from renewable sources comes from natural gas fired generation.

Based on the findings in SOEF v1.1, which are based on an assessment of a balanced portfolio needed to meet demand in 2030, the natural gas capacity in Ireland is expected to increase to 5750 MW by 2030.

As the decarbonisation of the power system proceeds, the capacity factor of gas generators will decline to much lower levels – there will be increasing periods in which demand can be almost or entirely met by renewables, storage and interconnection. However, the importance of this gas fired generation is anticipated to remain – it is crucial to providing security of electricity supply and ensuring Ireland's generation adequacy standards can be met in prolonged periods when renewable generation may not be available. In Self-Sustaining, Offshore Opportunity and Constrained Growth there are no assumed retirements of gas units included in the scenarios. In Gas Evolution, it is assumed that gas units are converted to, or replaced by, hydrogen units. Figure 6.8 below shows the natural gas fired generation capacity in each scenario. Any new additions to gas capacity in the study period are assumed to be equipped with Carbon Capture and Storage (CCS) capability.

CCS is the process of capturing, transporting, and storing carbon dioxide – it has been estimated that 90–99% of emissions released from burning fossil fuels in generation can be captured from the flue[39].

39 Towards Zero Emissions CCS in Power Plants Using Higher Capture Rates or Biomass

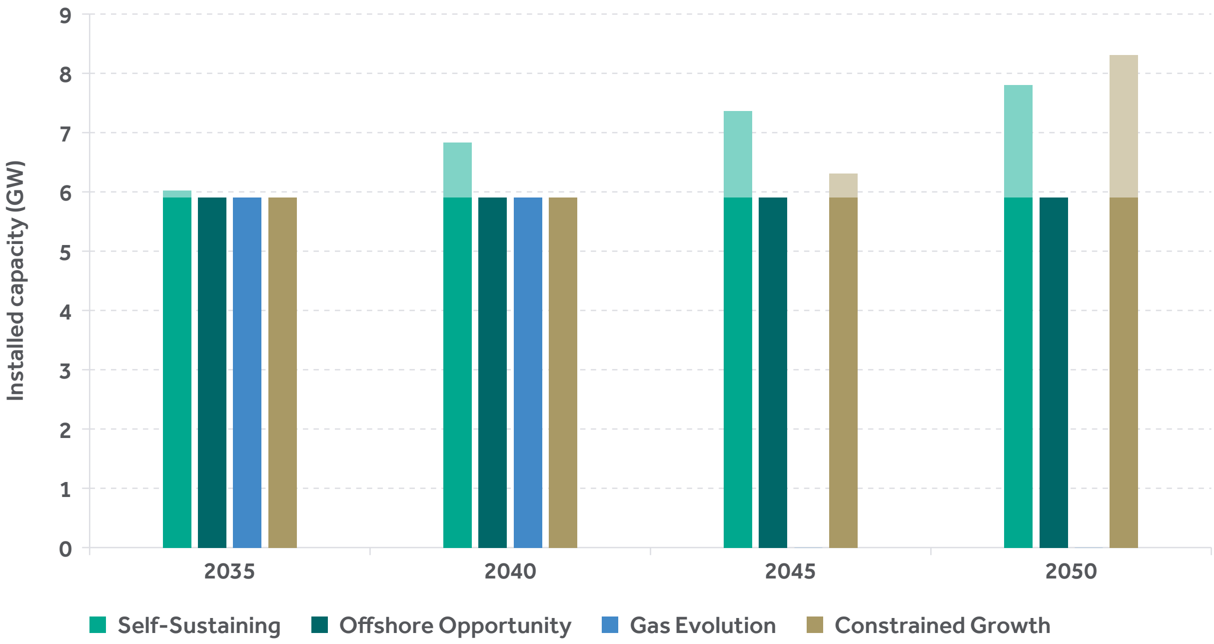

Figure 6.8: Installed gas thermal generation capacities (IE) (lighter colour denotes gas thermal generation equipped with CCS)

Carbon transportation is typically done via pipeline or ship, with geological formations, such as depleted oil and gas fields, acting as storage sites. Previous studies[40] have indicated the potential suitability of storage sites for carbon dioxide in Ireland and Northern Ireland.

Globally, the IEA reports 40 commercial facilities are in operation applying CCS processes with a further 500 projects in development[41]. Measures are being taken in the US, UK and European Union to encourage investment in CCS projects, however, for Ireland it is currently considered not a commercially viable technology and the speed of its development in the future is uncertain.

The following are the years we assume gas fired generators with CCS can be connected to the transmission system.

In the Gas Evolution scenario, the speed and scale of the development of hydrogen technologies means CCS does not ever become as commercially viable.

Self-Sustaining:	2033
Offshore Opportunity:	2036
Constrained Growth:	2045
Gas Evolution:	Not available

It is also expected that biomethane will play a role in decarbonising the gas mix in Ireland and Northern Ireland. However, indigenous biomethane supply is expected to be limited and may be prioritised for other harder to abate sectors in the economy than electricity. It should be noted that biomethane can also be blended with regular natural gas and burned in existing gas generators.

40 Assessment of the Potential for Geological Storage of CO_2 for the Island of Ireland
41 Carbon Capture, Utilisation and Storage

6.2.7 Hydrogen

Green hydrogen produced from renewable electricity is a zero emissions gas that could play an important role in helping to decarbonise the Irish power system. The use of hydrogen for power generation will likely require either a very significant retrofit of existing gas turbines or new purpose-built hydrogen turbines.

In our modelling we have assumed that any hydrogen used for power generation will be burned in purpose-built hydrogen turbines and not blended with natural gas in existing turbines.

In Gas Evolution, it is assumed that the gas network changes to carry large volumes of hydrogen to demand centres around Ireland and this creates an environment in which building out larger volumes of hydrogen generators is more economical. Whereas in Constrained Growth, there is zero hydrogen capacity added to the system as it is assumed the technology does not develop to the point of becoming economically feasible. The rollout of hydrogen generation in Offshore Opportunity and Self-Sustaining is a function of the larger and faster demand growth in those scenarios leading to an increased requirement for firm generation capacity.

The installed capacities of hydrogen fuelled generators in each scenario are shown in Figure 6.9 below. Similar to other thermal plant on the system, the hydrogen fuelled generators experience quite a low utilisation as they have a higher marginal cost than most other generator types.

However, they play a crucial role in providing reliability to the system by ensuring that there are sufficient generation resources in Ireland to meet demand in times of low renewable generation and low availability of interconnector imports.

A distinct advantage of hydrogen as a form of long duration energy storage is the scale at which it can be stored. With suitable storage sites, hydrogen can be stored at the TWh scale which is much more difficult to achieve with other technologies. However, the overall efficiency of this process from electrolysis to storage to combustion in a turbine is quite inefficient at around 30%[42]

In TES 2023, it is assumed that all hydrogen used in Ireland is produced from purpose built offshore wind farms. In practice there are many ways that green hydrogen could be sourced. This includes the possibility of hydrogen being imported into Ireland through repurposed gas interconnectors. Future hydrogen interconnectors may also offer a route to market for exports of Irish green hydrogen and could therefore lead to higher levels of hydrogen production than we have forecast in these scenarios with hydrogen exports potentially becoming an economically advantageous energy export opportunity for Ireland. If the international market for green hydrogen develops this will have important interactions with international markets for electricity, potentially reducing the quantity of electricity exports forecast in this study. To understand this relationship will require a more detailed review of future interactions between the electricity and gas systems in Ireland, Northern Ireland, Great Britain and Europe.

42 Hydrogen or batteries for grid storage? A net energy analysis

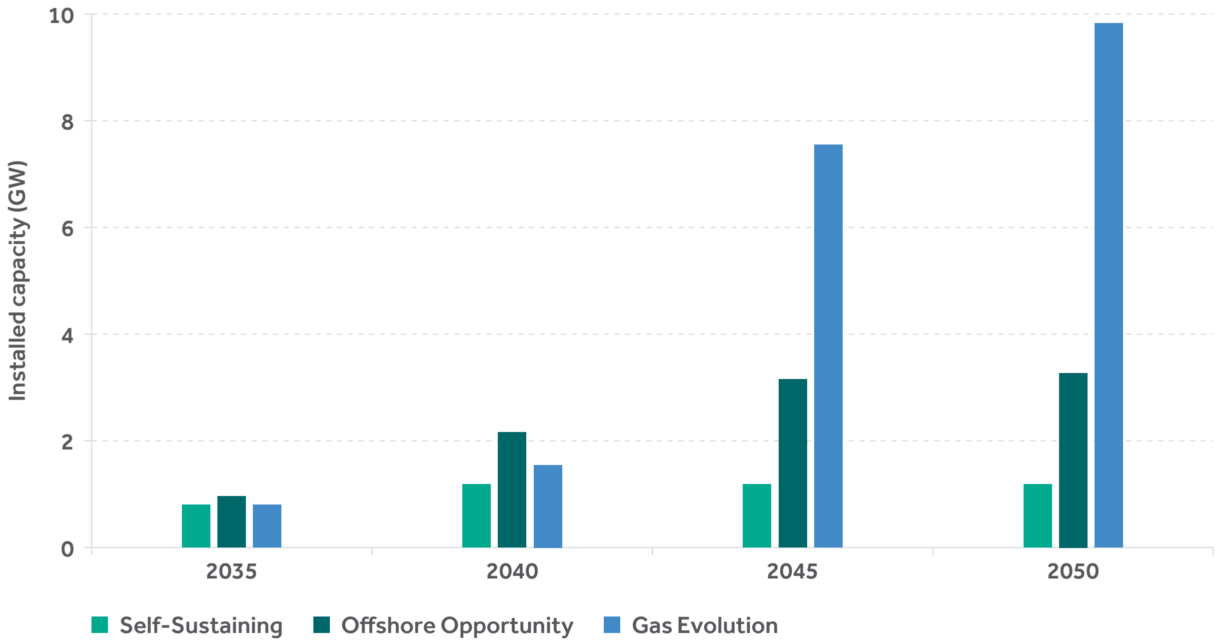

Figure 6.9: Installed hydrogen capacity (IE)

6.2.8 Biomass

Currently there is 118 MW of biomass fired generation on the Irish transmission system. We have assumed that this 118 MW biomass plant in Ireland is closed in 2031 as that is when planning permission for the unit expires. TES modelling includes the option to expand the capacity for both biomass and biomass with CCS up to certain limits. Our modelling shows a preference for biomass plants with the ability to capture and store carbon (BECCS) despite their much higher capital cost.

As Figure 6.10 below shows, BECCS is a net negative emissions form of electricity generation. Due to the negative emissions associated with this generation type it tends to run at very high load factors. Our assumptions on when biomass with CCS will become available in each scenario aligns with our assumption on natural gas with CCS which is the following:

Self-Sustaining:	2033
Offshore Opportunity:	2036
Constrained Growth:	2045
Gas Evolution:	Not available

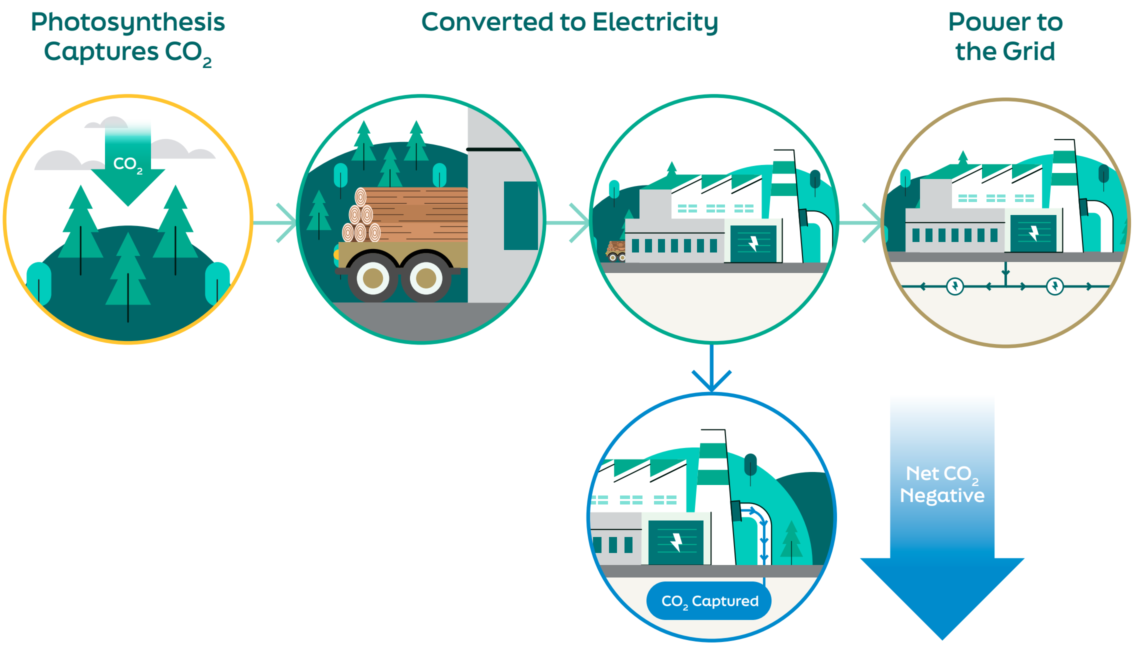

Figure 6.10: Negative emissions technology – biomass with carbon capture and storage

The effect of negative emissions in the model is significant. By removing carbon from the system it allows a certain level of unabated gas generation to be used when required while still allowing the system to stay at zero or negative emissions overall. The volume of BECCS installed determines the quantity of emissions removed. The installed volumes by scenario are shown in Figure 6.11 below.

Other forms of negative emissions technologies may exist at utility scale in the future such as Direct Air Carbon Capture (DACC) but the only form of negative emissions considered in this modelling was biomass fired power plants equipped with CCS.

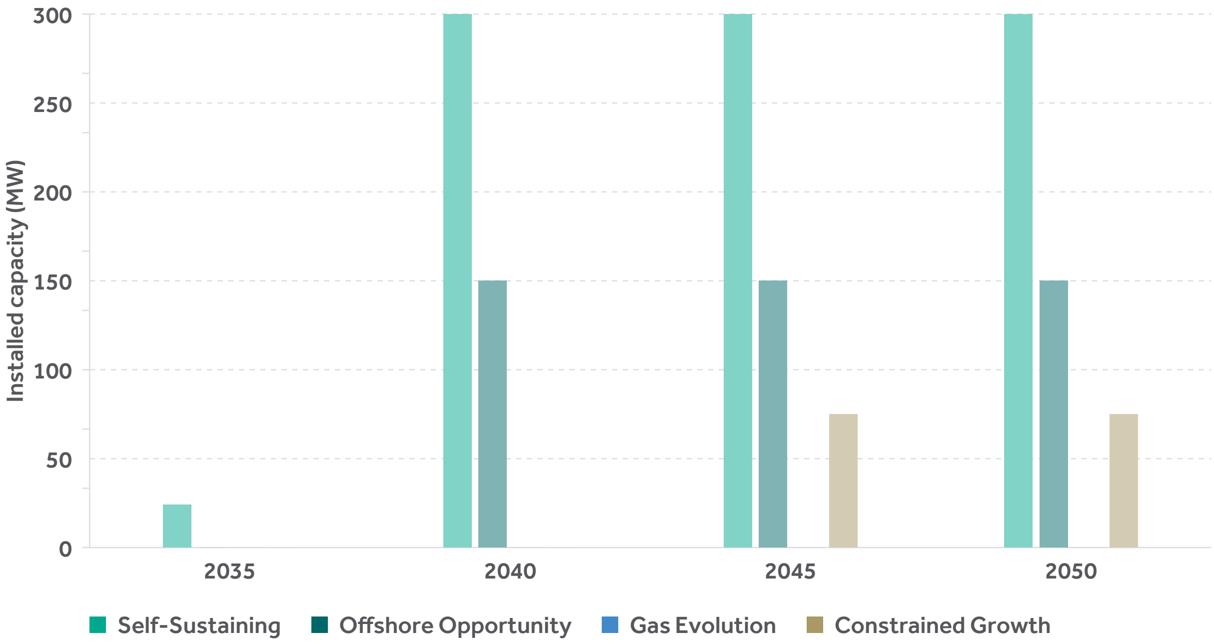

Figure 6.11: Biomass and BECCS capacity (IE) (lighter colour denotes BECCS)

6.2.9 Waste

All four scenarios see a continuation of the existing waste generation capacities in Ireland of 79 MW. Waste to Energy is considered partially renewable, and as these plants use traditional steam turbines to create electricity, they also provide valuable mechanical inertia to the power system.

6.3 Generation technologies – Northern Ireland

Decarbonisation of electricity supplies means that we will need less generation that use traditional hydrocarbon fuels and more supply technologies from low carbon and renewable sources. TES 2023 has included a range of technology types:

- Renewables such as solar, onshore and offshore wind (Section 6.3.1–6.3.4).
- Energy storage (Section 6.3.5).
- Flexible thermal generation technology such as natural gas, hydrogen and biomass (Section 6.3.6–6.3.9).
- Electricity interconnection (Section 6.4).

It has been assumed that the following technologies will not be operating by 2035: coal, peat and oil fired generators.

6.3.1 Onshore wind

As of 2023, Northern Ireland currently has over 1.8 GW installed onshore wind generation. However, looking forward to 2050, an important consideration regarding onshore wind is the potential number of available sites remaining for development in Northern Ireland. In order to realistically limit land use, an estimated upper limit of 3.4 GW onshore wind was used in each scenario. Figure 6.12 below shows the changes in onshore wind capacity over time in each scenario. This new capacity could be delivered by both new windfarms and the repowering of already existing windfarms.

The Self Sustaining scenario sees the most significant growth of onshore wind, reaching the capacity limit by 2040. The other scenarios do not see this growth in onshore wind and instead rely on a larger growth of offshore wind to decarbonise the system. Gas Evolution and Constrained Growth see more restrained growth of onshore wind, both reaching around 2.8 GW by 2050. Offshore Opportunity sees no growth in capacity beyond the 2030 targets, with buildout in the scenario concentrated in offshore wind as discussed in the following section.

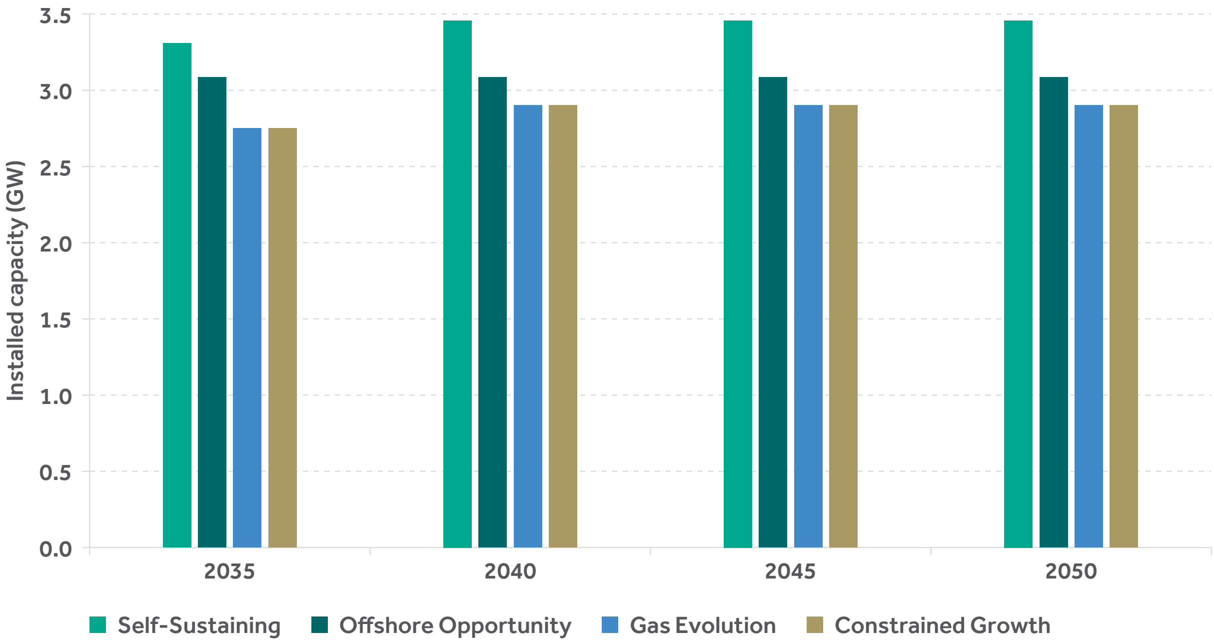

Figure 6.12: Installed onshore wind capacity (NI)

6.3.2 Offshore wind

Northern Ireland currently has no offshore wind capacity, and as of 2023 the total installed capacity of offshore wind in the island of Ireland is only 25 MW compared to several GW in neighbouring regions such as Great Britain and Denmark. However, this is expected to change significantly in the coming years. Already in 2023, the Northern Ireland Energy Strategy has a target of at least 1 GW of offshore wind from 2030 with The Crown Estate, who manage the UK coastline. For the modelling performed here, the 500 MW target for 2030 included in SOEF v1.1 is used as the starting point for the scenarios. Currently, it is unclear how much renewable capacity can be installed off the coat of Northern Ireland. For the purpose of this analysis, an upper limit of 4 GW transmission connected capacity has been applied.

Figure 6.13 below shows the buildout over time of offshore wind capacity in each scenario. It is important to note that spare transmission capacity on the existing transmission system is limited, and significant development of offshore wind could require a large-scale upgrade to the transmission system, beyond what has been set out in the most recent SOEF v1.1. This will be assessed further in the TES System Needs Assessment studies, due to take place in 2024.

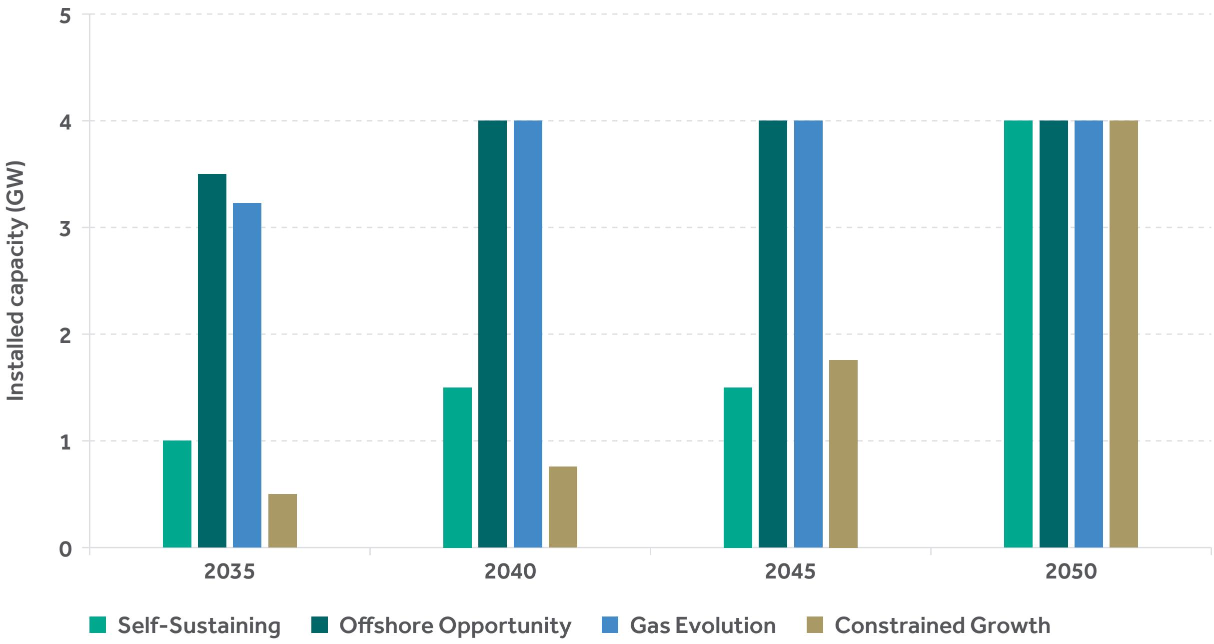

Figure 6.13: Installed offshore wind capacity (NI)

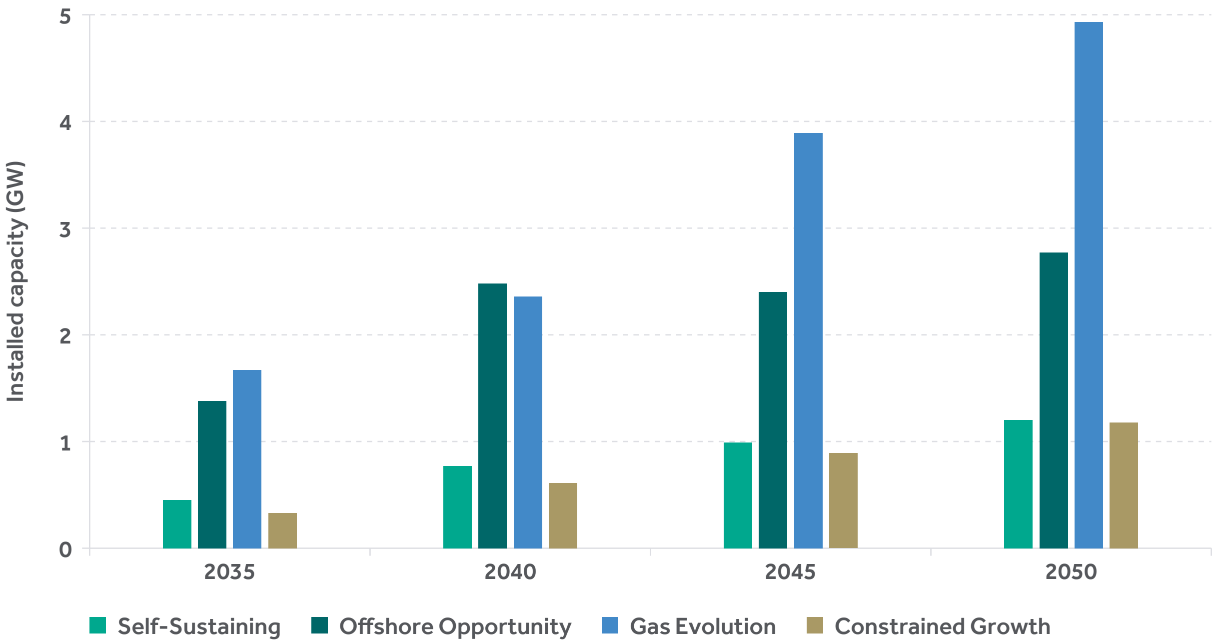

Figure 6.14: Indicative, non-grid connected wind capacity for hydrogen production (NI)

Offshore Opportunity and Gas Evolution see the fastest initial offshore wind build, reaching the 4 GW limit by 2040. Following this, Self-Sustaining and Constrained Growth scenarios build out 4 GW by 2050.

For the purpose of this analysis, an indicative allowance of up to 5GW of offshore wind dedicated to hydrogen production (in addition to the 4 GW for electricity generation).

We note that this may exceed NI's spatial limits for offshore wind and other renewable sources of generation may be required.

6.3.3 Solar photovoltaics

There has been massive growth of Solar PV capacity across the world over the last decade, rising from about 70 GW in 2011 to nearly 900 GW in 2021[43]. While PV generation in Northern Ireland has a relatively low capacity factor compared to warmer regions, the costs of solar PV systems are low enough that the technology is becoming economically competitive with wind energy.

Furthermore, solar power offers a valuable diversification benefit to a generation portfolio. High periods of solar generation in the summer months generally complement higher periods of wind generation in the winter months. Solar generation is also very predictable in terms of total energy production over a monthly or annual basis meaning that with appropriate levels of storage its contribution towards meeting energy demand can be well forecast.

As the amount of PV generation connected to transmission systems around the world has grown massively over the last decade, so too has small scale PV. It is estimated that, as of 2023, there are currently over 27,000 homes in Northern Ireland with their own small-scale PV systems according to data from the Microgeneration Certification Scheme. This consists mostly of roof mounted PV on homes, businesses, and public buildings. An important factor in the growth of this sector will be the trend in retail electricity prices; higher retail electricity prices will make 'behind the meter' systems like this more economically attractive to homeowners and business owners. There will likely also be a desire among certain individuals to take more ownership over their energy production and carbon footprint.

Figure 6.15 below shows the growth of PV capacity in each scenario over time. In the case of this graph, the solid areas of each bar denote utility scale PV and the lighter shaded areas denote small scale PV.

All four scenarios see continuous growth in PV capacity over the study period, with the Self Sustaining scenario leading the way and Constrained Growth and Gas Evolution lagging somewhat behind. It is also notable that in all scenarios, small-scale PV capacity rises in tandem with utility-scale.

43 Solar PV power capacity in the Net Zero Scenario

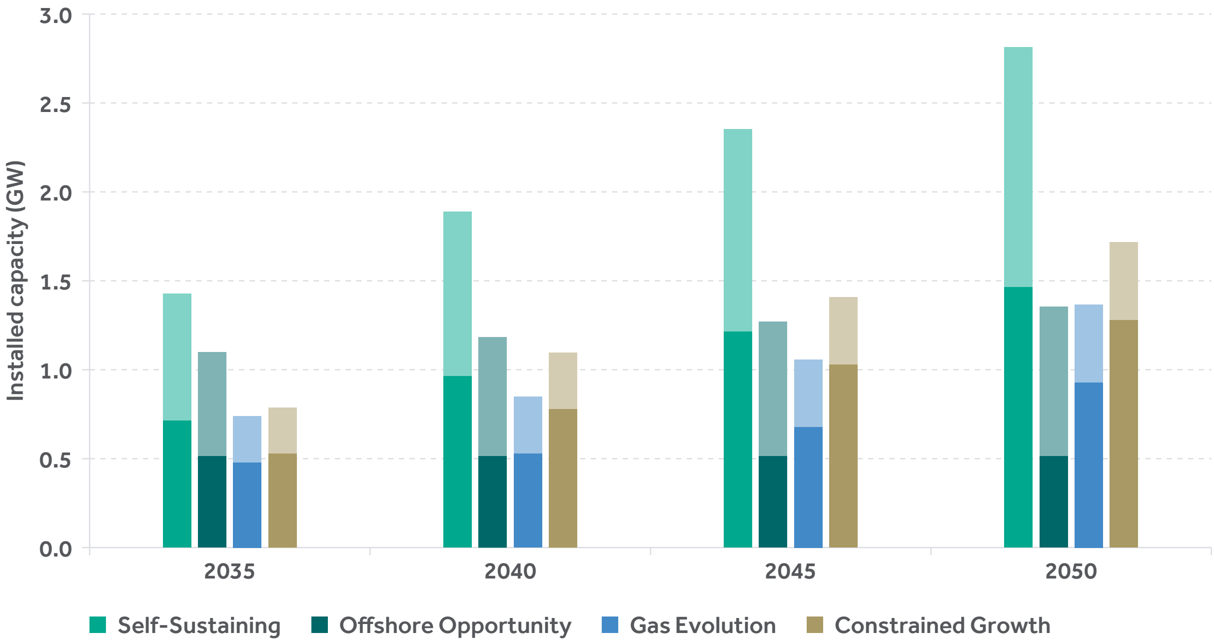

Figure 6.15: Installed solar PV capacity (NI) (lighter colour denotes non-utility scale solar PV)

6.3.4 Variable renewables summary

Clearly, each scenario foresees a central role for variable renewable sources, namely wind and solar, in the decarbonisation of the Northern Irish power system. An important consideration when operating a system with such high levels of renewable generation is the dispatch-down of those renewables.

There are typically three reasons why renewable generation is dispatched down.

1. **Constraints**
   Generators may need to be dispatched down due to transmission network limitations and to ensure that the thermal overload limits of transmission circuits and transformers are not breached. Changes in generator output for this reason are referred to as a 'constraint'. The constraining of generation is location specific.

2. **Curtailment**
   To ensure a safe and secure electricity system, the TSO must operate the system within certain operational limits. Curtailment is applied to reduce the output of renewable generators to ensure that operational limits are not breached, and the system can remain secure and stable. Curtailment is applied to all renewable generators across the island on a pro-rata basis (see graph of percentage curtailment annually by scenario in Figure 6.16 below).

3. **Surplus renewable generation**
   The reduction of available renewable generation for oversupply reasons is necessary when the total available generation exceeds system demand plus interconnector export flows.

Of these three forms of dispatch-down, only surplus renewable generation is considered in our model, as network and operational constraints are not considered. Therefore, the level of dispatch-down shown below could be higher in reality if network and operational constraints were also considered.

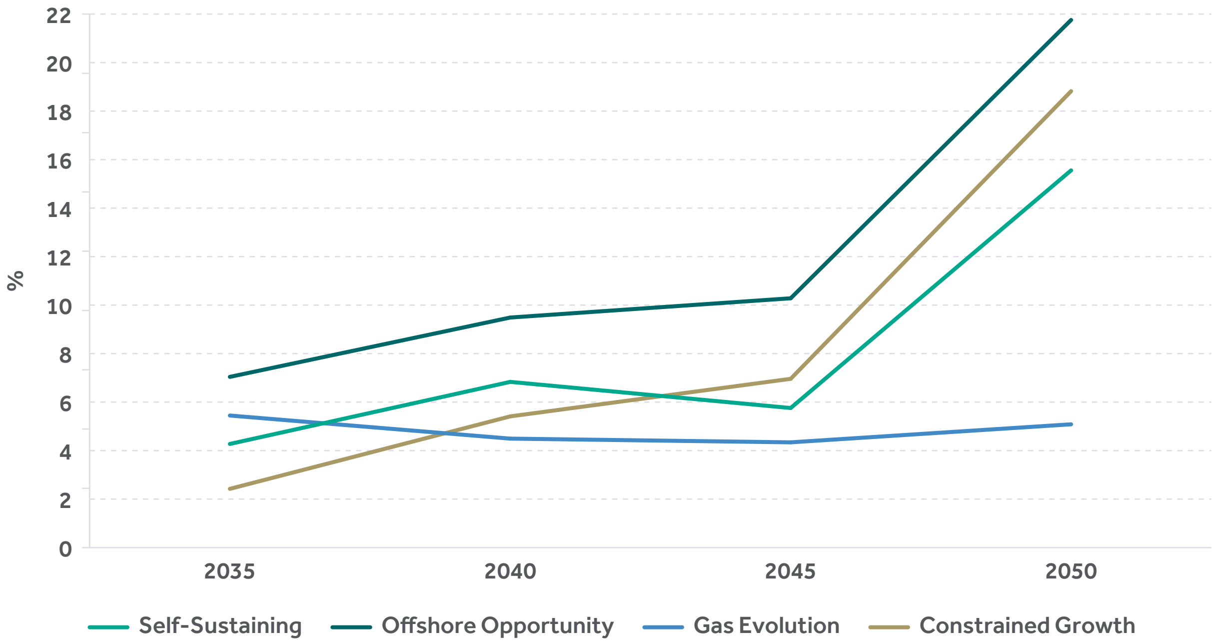

Figure 6.16: Dispatch down of renewable generation assumed to be done on an all-island basis. Constraints and curtailment not included

With high levels of renewable generation on the system, it is likely that the available generation from these renewables will exceed demand most hours of the year. However, there will likely be some periods during which renewable generation is not sufficient to meet the entirety of demand. Figure 6.17 below shows the number of hours in each year that the availability of renewables is not sufficient to meet demand.

This demonstrates that adding higher levels of renewable capacity to the system can reduce the number of these hours but not eliminate them entirely. The following sections explore some of the various technologies that can help to meet demand in these hours.

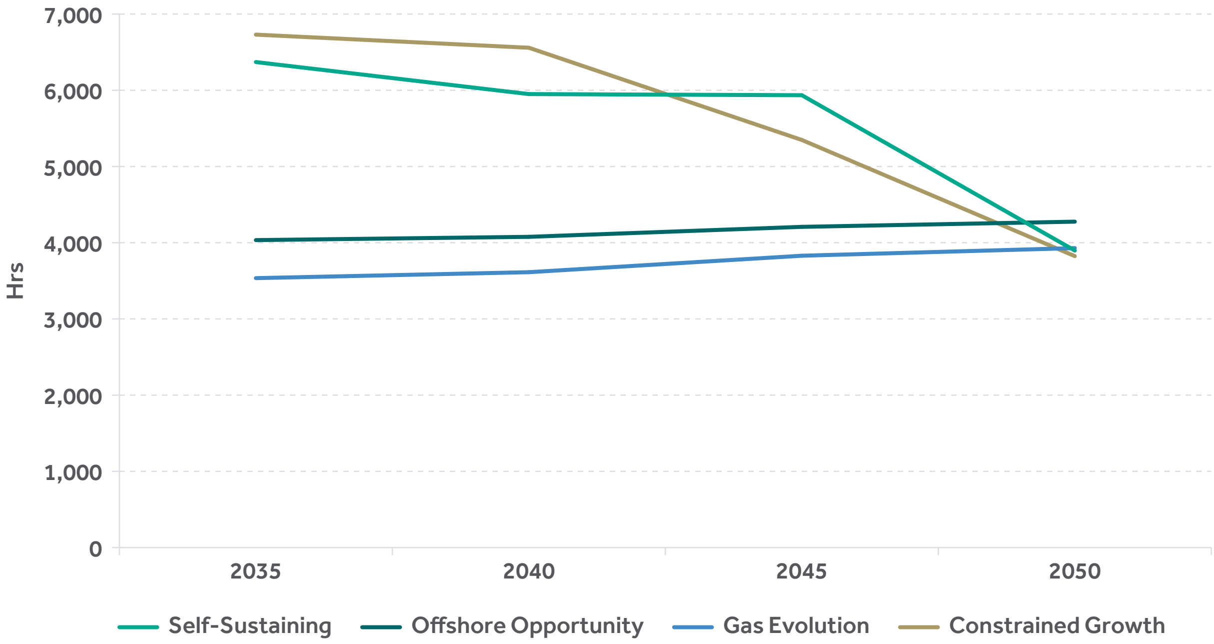

Figure 6.17: Hours of demand where wind and solar generation needs to be supplemented by other sources (i.e. energy storage, interconnection, thermal capacity) (NI)

6.3.5 Storage

With increasing electrification around the world, the potential for energy storage technology is developing rapidly. For power systems, energy storage is seen as increasingly important when considering the growing role of variable renewable capacity and they can also provide other system services for transmission networks. Energy storage has the potential to capture surplus renewable generation, reduce curtailment, and provide flexibility when renewable generation is not sufficient to meet demand.

The capital cost of electricity storage and available revenue streams have meant that it has not always been attractive for development projects. It is anticipated that future arrangements for markets may change to encourage energy storage investments that support the power system, reduce the need for flexible dispatch capacity, and help reduce power sector carbon emissions.

Technological innovations are anticipated that may both reduce the capital cost of storage infrastructure and also improve the round-trip efficiency. This is likely to apply to batteries designed to store energy for up to 8 hours (currently dominated by lithium-ion), long-duration or multi-day storage (circa 100 hours) and also seasonal storage (multi-week).

A range of different storage technologies may be available between 2035-2050 and currently these show varying levels of technology readiness. These include mechanical (pumped hydro, liquid air and compressed air), electrochemical (Li-ion and flow batteries), thermal storage, and chemical storage (hydrogen and synthetic gases and fuels).

For TES 2023 in Northern Ireland, the following forms of storage were modelled:

- **Batteries** - all batteries are assumed to be lithium-ion units with the exception of 100-hour batteries in Self-Sustaining, which for modelling purposes are assumed to be iron-air type batteries.
- **Vehicle to Grid (V2G)** - additional energy storage can be discharged to meet demand from through vehicle to grid solutions. It is noted that participation in V2G will depend on both suitable vehicle and grid technologies and consumer acceptance.

The total installed capacity of battery storage in each scenario is shown below in Figure 6.18. The includes a blend of up to 8-hour batteries and Vehicle to Grid. The Vehicle to Grid capacity can offer significant short-term flexibility to the system.

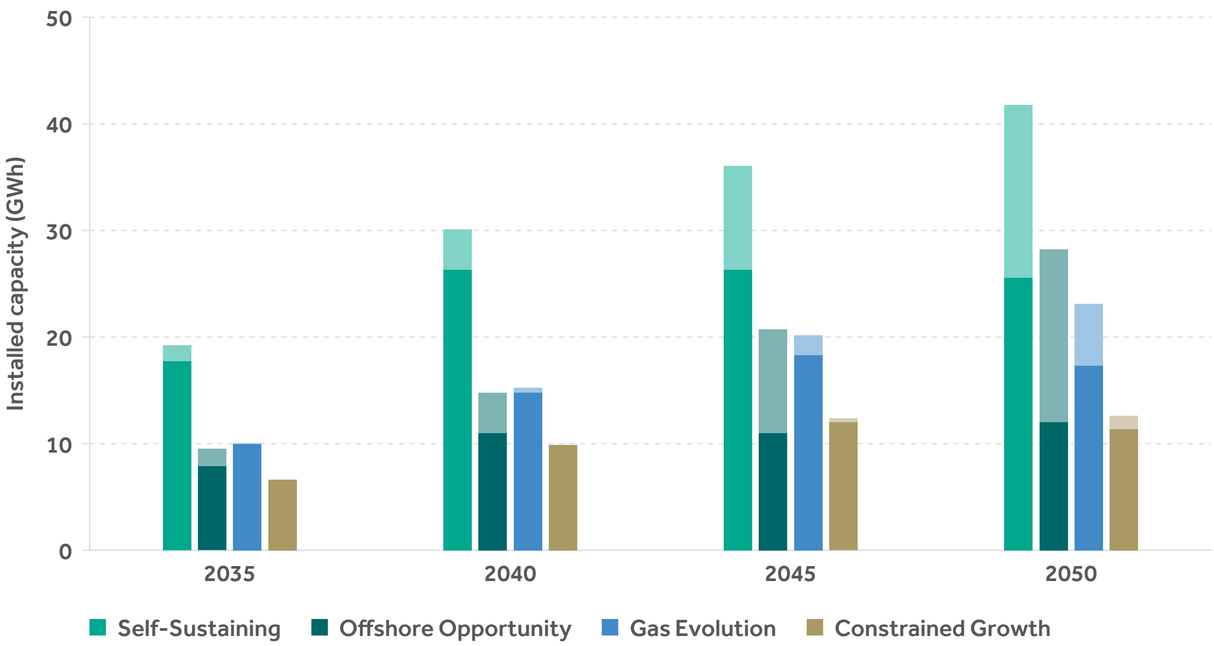

Figure 6.18: Installed storage capacity (NI) (lighter colour denotes Vehicle to Grid)

6.3.6 Natural gas

As of 2023, the majority of Northern Ireland's electricity that is not generated from renewable sources comes from natural gas fired generation. Based on the findings in SOEF v1.1, which are based on an assessment of a balanced portfolio needed to meet demand in 2030, natural gas capacity in Northern Ireland is expected to increase to over 2.05 GW by 2030.

As the decarbonisation of the power system proceeds, the capacity factor of gas generators will decline to much lower levels as there will be increasing periods in which demand can be almost or entirely met by renewables, storage and interconnection. However, the importance of this gas fired generation is anticipated to remain – it is crucial to providing security of electricity supply and ensuring Northern Ireland's generation adequacy standards can be met. We have assumed there are no retirements of existing gas capacity in the scenarios – if plant does reach end of life, it is assumed this will be replaced with an equivalent gas generator. Any new additions to gas capacity beyond 2030 are assumed to be equipped with Carbon Capture and Storage (CCS) capability.

CCS is the process of capturing, transporting, and storing carbon dioxide – it has been estimated that 90–99% of emissions released from burning fossil fuels in generation can be captured from the flue[44]. Carbon typically transported via pipeline or ship, with geological formations, such as depleted oil and gas fields, acting as storage sites.

Previous studies have indicated the potential suitability of storage sites for carbon dioxide in Ireland and Northern Ireland[45].

Globally, the IEA reports 40 commercial facilities are in operation applying CCS processes with a further 500 projects in development[46]. Measures are being taken in the US, UK and European Union to encourage investment in CCS projects, however, for Northern Ireland it is currently considered not a commercially viable technology and the speed of its development in the future is uncertain. The following are the years we assume gas fired generators with CCS can be connected to the transmission system. In the Gas Evolution scenario, the speed and scale of the development of hydrogen technologies means CCS does not ever become as commercially viable.

Self-Sustaining:	2033
Offshore Opportunity:	2036
Constrained Growth:	2045
Gas Evolution:	Not available

Figure 6.19 below shows the natural gas fired generation capacity in each scenario.

In each scenario, installed capacity without CCS is stable at 2.2 GW across the study horizon. Following the dates of availability of CCS, the Self-Sustaining and Constrained Growth scenarios install increasing amounts of gas with CCS. Offshore Opportunity installs only a small amount by 2035 and then no more, while the Gas Evolution relies on hydrogen-powered generation.

44 Towards Zero Emissions CCS in Power Plants Using Higher Capture Rates or Biomass
45 Assessment of the Potential for Geological Storage of CO_2 for the Island of Ireland
46 Carbon Capture, Utilisation and Storage

It is also expected that biomethane will play a role in decarbonising the gas mix in Ireland and Northern Ireland. However, indigenous biomethane supply is expected to be limited and may be prioritised for other harder to abate sectors in the economy.

Biomethane can be blended with regular natural gas and burned in existing gas generators.

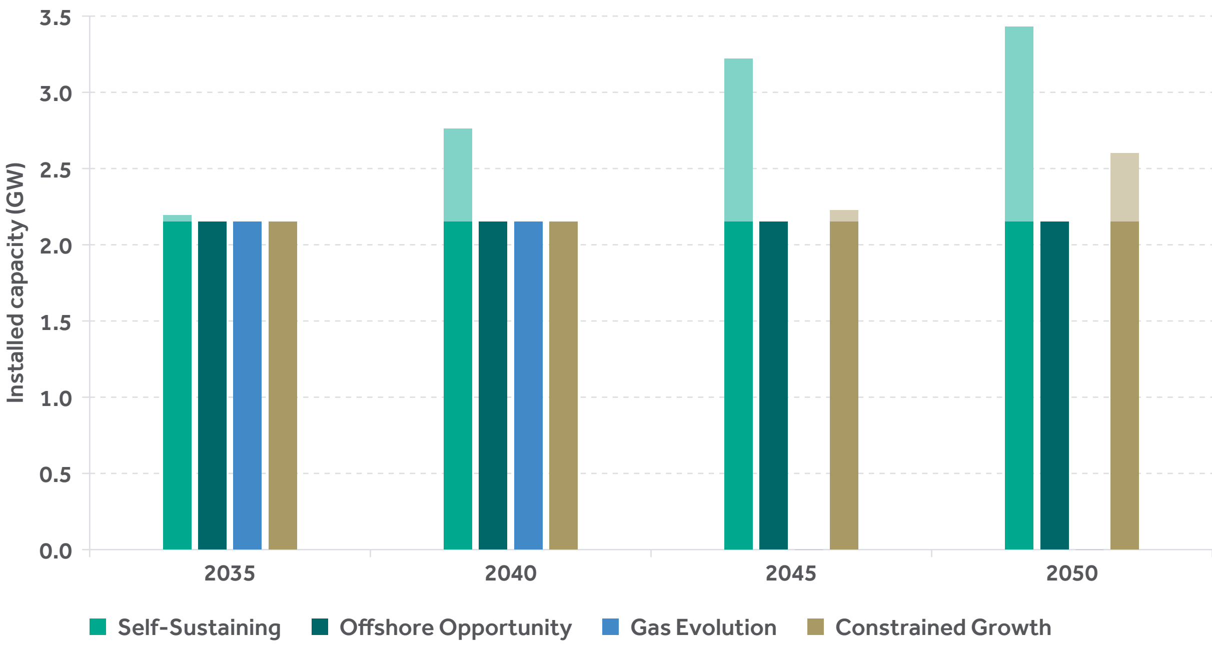

Figure 6.19: Installed gas thermal generation capacities (NI) (lighter colour denotes gas thermal generation equipped with CCS)

6.3.7 Hydrogen

Green hydrogen produced from renewable electricity is a zero emissions gas that could play an important role in helping to decarbonise the power system. The use of hydrogen for power generation will likely require either a very significant retrofit of existing gas turbines or new purpose-built hydrogen turbines. In our modelling, we have assumed that any hydrogen used for power generation will be burned in purpose-built hydrogen turbines and not blended with natural gas in existing turbines.

In Gas Evolution, it is assumed that the gas network adapts to carry large volumes of hydrogen to demand centres around Northern Ireland and this creates an environment in which developing out larger volumes of hydrogen fuelled generators is more economical. Whereas in Constrained Growth, no hydrogen capacity added to the system as it is assumed the technology does not become economically feasible. The more rapid rollout of hydrogen generation in Offshore Opportunity and Self-Sustaining is a function of the larger and faster demand growth in those scenarios, leading to an increased requirement for firm generation capacity.

The installed capacities of hydrogen fuelled generators in each scenario are shown below. Similar to other thermal plants on the system, hydrogen fuelled generators will experience a relatively low utilisation as they have a higher marginal cost than most other generator types. However, they play a crucial role in providing reliability to the system by ensuring that there are sufficient generation resources in Northern Ireland to meet demand in times of low renewable generation and low availability of interconnector imports. The installed capacities of hydrogen generation over the study period are shown in Figure 6.20 below.

A distinct advantage of hydrogen as a form of long duration energy storage is the scale at which it can be stored. With suitable storage sites hydrogen can be stored at the TWh scale which is much more difficult to achieve with other technologies. However, the overall efficiency of this process from electrolysis to storage to combustion in a turbine is relatively low at around 30%[47].

In TES 2023, it is assumed that all hydrogen used in Northern Ireland is produced from purpose built renewable generation. In practice, there are many ways that green hydrogen could be sourced. This includes the possibility of hydrogen being imported into Northern Ireland through repurposed gas interconnectors. Future hydrogen interconnectors may also offer a route to market for exports of green hydrogen and could therefore lead to higher levels of hydrogen production than we have forecast in these scenarios with hydrogen exports potentially becoming an economically advantageous energy export opportunity. If the international market for green hydrogen develops this will have important interactions with international markets for electricity, potentially reducing the quantity of electricity exports forecast in this study. Understanding this relationship will require a more detailed review of future interactions between the electricity and gas systems in Ireland, Northern Ireland, Great Britain and Europe.

47 Hydrogen or batteries for grid storage? A net energy analysis

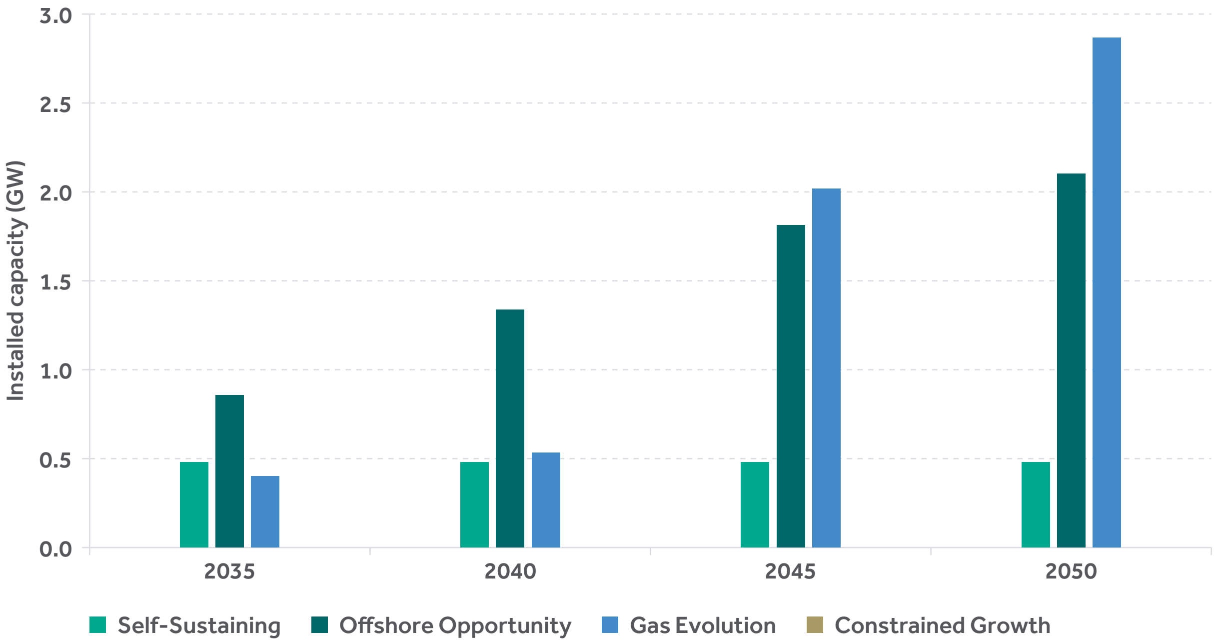

Figure 6.20: Installed hydrogen capacity (NI)

6.3.8 Biomass

We have assumed that Northern Ireland has 18 MW of biomass generation capacity by 2031. In the scenarios, there is the option within the model to expand the capacity for both biomass and biomass with CCS up to certain limits. In most cases our modelling shows a preference for biomass plants with the ability to capture and store carbon despite their much higher capital cost. TES modelling includes the option to expand the capacity for both biomass and biomass with CCS up to certain limits. Generally, our modelling shows a preference for biomass plants with the ability to capture and store carbon (BECCS) despite their much higher capital cost.

As Figure 6.21 below shows, BECCS is a net negative emissions form of electricity generation. Due to the negative emissions associated with this generation type it tends to run at very high load factors.
Our assumptions on when biomass with CCS will become available in each scenario align with our assumption on natural gas with CCS which are the following:

Self-Sustaining:	2033
Offshore Opportunity:	2036
Constrained Growth:	2045
Gas Evolution:	Not available

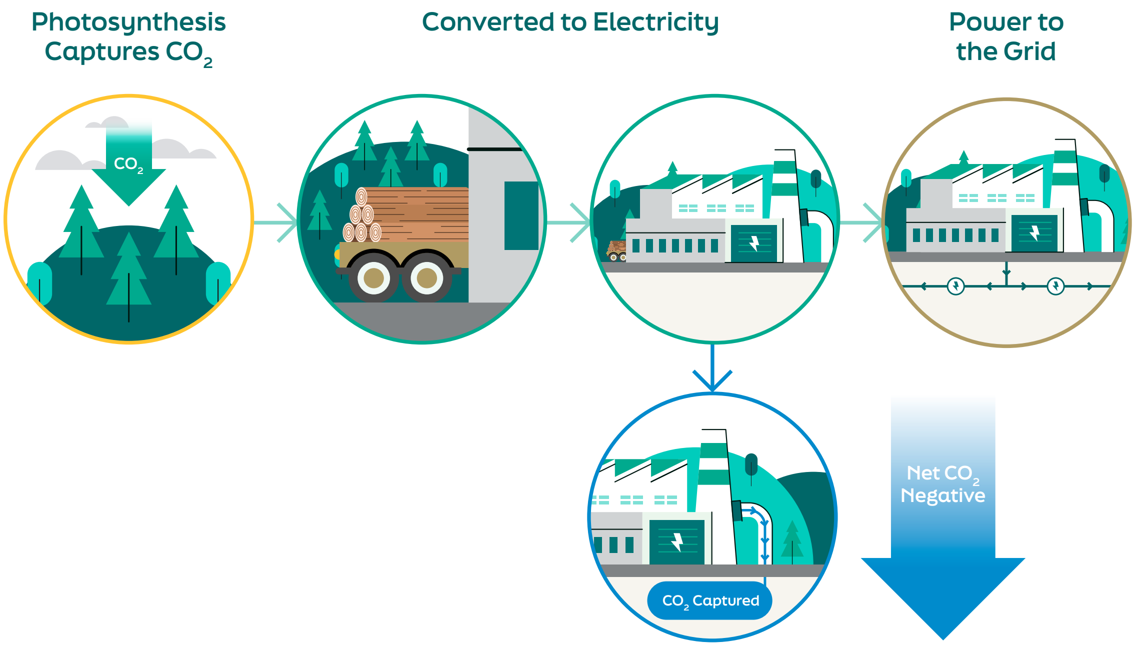

Figure 6.21: Negative emissions technology – biomass with carbon capture and storage

The effect of negative emissions in the model is significant. By removing carbon from the system it allows a certain level of unabated gas generation to be used when required while still allowing the system to stay at zero or negative emissions overall. The volume of BECCS installed determines the quantity of emissions removed. The installed volumes by scenario are shown in Figure 6.22 below.

Other forms of negative emissions technologies may exist at utility scale in the future such as Direct Air Carbon Capture (DACC) but the only form of negative emissions considered in this modelling was biomass fired power plants equipped with CCS.

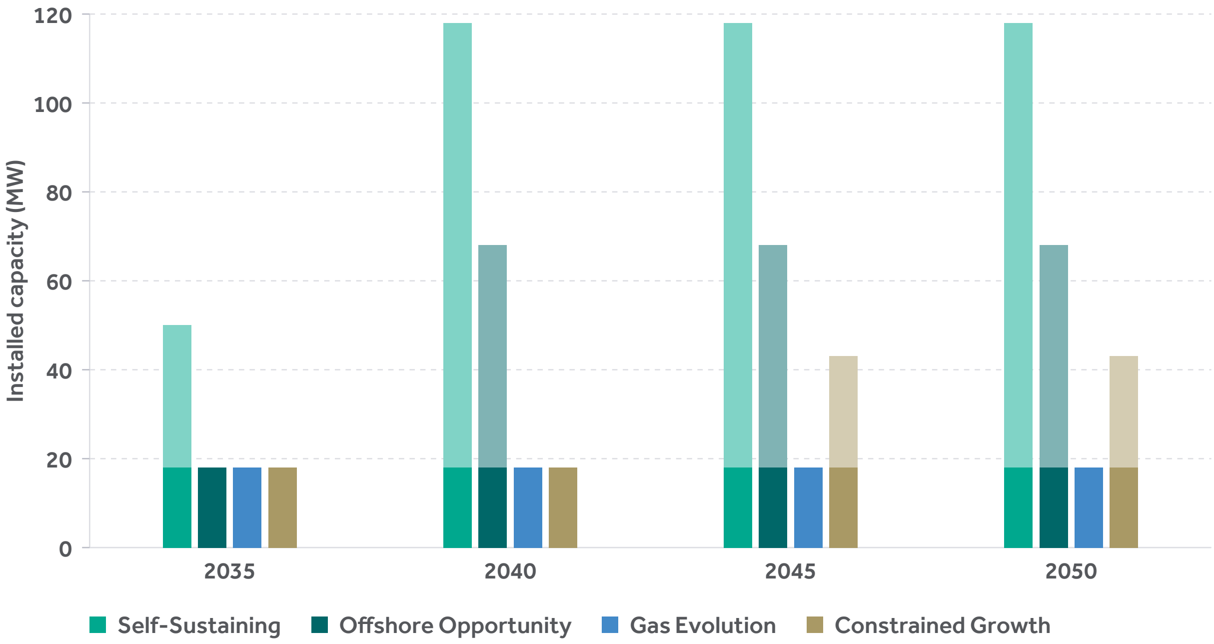

Figure 6.22: Biomass and BECCS capacity (NI) (lighter colour denotes BECCS)

6.3.9 Waste

The starting point for this study includes 30 MW of waste generation in 2030 as considered by SOEF v1.1, and all four scenarios see this maintained. Waste to Energy is considered to be partially renewable, and as these plants use traditional steam turbines to create electricity, the also provide valuable mechanical inertia to the power system.

6.4 Interconnection

6.4.1 Interconnection to SEM

Interconnection facilitates the transport of electricity between two transmission systems. It can provide multiple benefits, such as greater levels of renewable integration (curtailment reduction), wholesale electricity price reduction, capacity adequacy improvement, as well as facilitating the sharing of reserve.

Ireland's current high voltage direct current (HVDC) interconnection is with Great Britain via the East-West interconnector (EWIC). The Celtic interconnector between Ireland and France is due to be completed in 2026 and will be Ireland's first electrical connection to continental Europe. Northern Ireland's current high voltage direct current interconnection is with Great Britain via the Moyle interconnector.

The assumed capacities of interconnection in the first modelled year of 2030 are shown in Table 6.3 below. This accounts for interconnectors currently under development as well as a second interconnector from Ireland to France that was identified as a system need in SOEF. The assumptions are not endorsements of interconnection projects at any stage of development. EirGrid and SONI will continue to monitor development of interconnection projects and are/will be cognisant of emerging policy around interconnection. Note that in the tables below CE refers to Continental Europe.

Additional interconnection is a feature of all scenarios and the exact capacities in each year are given in Table 6.3.

Table 6.3: Interconnection capacities (MW)

	Self-Sustaining			Offshore Opportunity			Constrained Growth			Gas Evolution		
	2035	2040	2050	2035	2040	2050	2035	2040	2050	2035	2040	2050
IE-NI	700	700	700	700	700	700	700	700	700	700	700	700
IE-GB	1,850	2,750	3,750	2,750	5,250	5,750	1,750	2,450	2,450	2,250	2,250	3,750
IE-CE	2,050	2,050	3,900	2,900	4,400	7,400	700	1,000	1,400	2,350	2,850	3,400
NI-GB	1,200	1,200	2,200	2,550	3,200	3,200	1,200	1,800	1,900	2,200	2,200	2,200

There is a slight preference shown in the expansion modelling for new interconnection capacity to be built to Continental Europe over Great Britain. There are a few potential reasons for this, namely:

- A larger variation in weather patterns and therefore renewable generation patterns as you connect to locations further away.
- There is a lot of similarity between the assumed GB generation portfolio and that in Ireland and Northern Ireland. This includes high levels of offshore wind in both regions as opposed to the European portfolio which has a higher level of solar and also non-weather dependent low carbon generation such as nuclear. These differences in generation technologies create more opportunities for trade.

It should be noted that these interconnection capacities are only indicative and more detailed studies are needed to determine the optimum levels of interconnection to both Great Britain and Continental Europe in the future.

6.4.2 IE-NI flows

There are existing interconnector ties between Ireland and Northern Ireland that use high voltage alternating current (HVAC). The North South Interconnector, planned for 2027, would significantly increase the total transfer capacity between Ireland and Northern Ireland. The interconnection capacity between Ireland and Northern Ireland that was modelled in all scenarios was 700 MW. This was chosen to ensure that the model treated both Ireland and Northern Ireland as distinct nodes.

6.5 Generation mix snapshots – Ireland

TES 2023 has analysed the way that the installed capacities are dispatched to generate electricity in each scenario. This assesses how electricity generation, storage and interconnection respond hour by hour from 2030 to 2050 to meet forecast electricity demands.

Sections 6.5.1–6.5.4 below explain the combined annual generation mix for each scenario in as they become a net zero power system. Weekly timeseries are presented to show how generation technologies combine in two contrasting weeks:

- A high renewable generation week in late summer.
- A low renewable generation week in winter.

An example of a weekly timeseries generation graph is shown below in Figure 6.23.

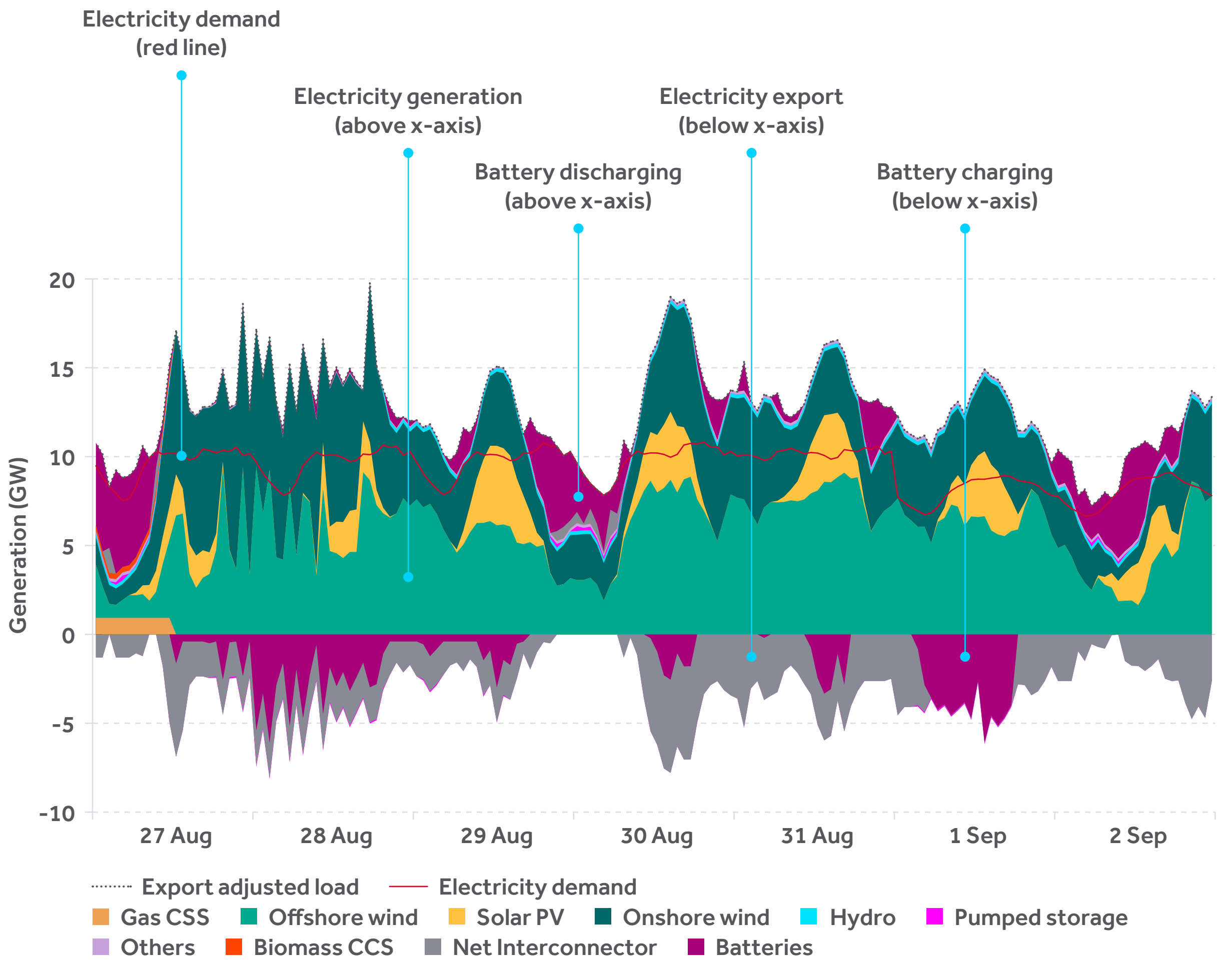

Figure 6.23: Example weekly timeseries showing how overall electricity generation above the x-axis and electricity exports and battery charging below the x-axis

In this chart, generation above the x-axis shows electricity dispatched to meet domestic demand. It also includes electricity imports and discharge from batteries and energy storage. Conversely, below the x-axis, shading indicates electricity exports and charging of energy stores. The red line represents the electricity demand on the transmission system. The dotted line at the top of the chart is the 'export adjusted load'. This is the sum of the generation required to meet demand, exported electricity, and electricity used to charge batteries and energy storage.

6.5.1 Self-Sustaining 2040

From 2040, the Self-Sustaining scenario achieves a Net Zero Power system. Figure 6.24 shows the annual generation mix. This includes:

- Over 75% of electricity coming directly from variable renewable generation, split between onshore and offshore wind and solar PV;
- Electricity imports; and
- Natural gas and other technologies providing flexible dispatch.

Please note that the annual generation mix does not show electricity exports from Ireland to other countries or the contribution from batteries and energy storage.

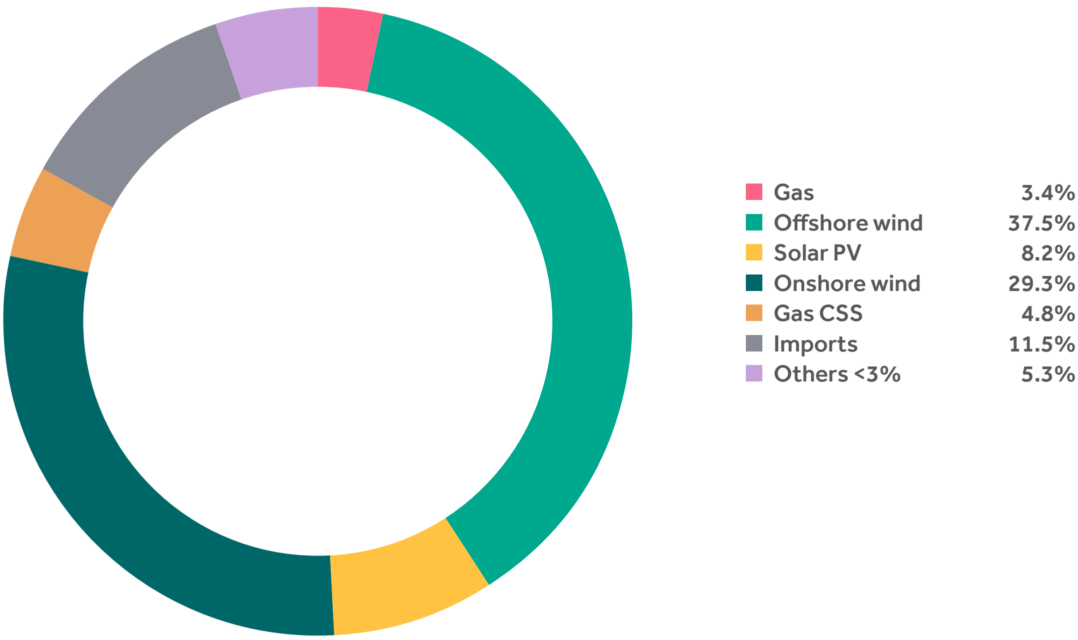

Figure 6.24: Self-Sustaining, annual generation mix in 2040 (net zero power system) (IE)

A week in summer with high wind

The balance of supply and demand across a weekly period is shown in Figure 6.25. In this chart, the charging and discharging of batteries can be observed as well as export flows across interconnectors. The areas below the x-axis show charging of batteries and export through interconnectors.

The timeseries selected is from a windy week in late summer. In this week, almost all demand is met by variable renewables and batteries.

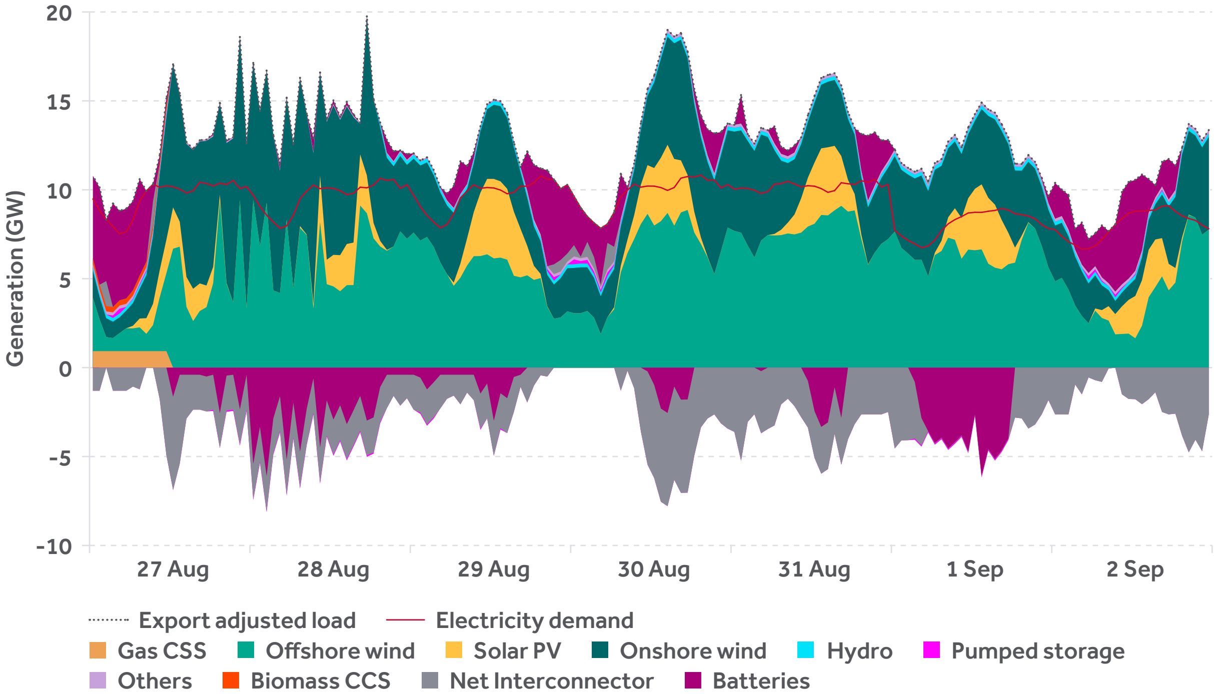

Figure 6.25: Self-Sustaining, weekly timeseries in 2040 – high wind in summer (IE)

A week in winter with low renewable generation

Figure 6.26 below shows how the same installed capacity mix responds during a period of high electricity demand, while renewable generation is low.

The timeseries shows that in this week, reductions in renewable generation are compensated by dispatchable generators, batteries and large interconnector imports.

In the Self-Sustaining scenario, flexible dispatchable power is largely provided by natural gas to secure electricity supplies for periods when renewable generation is not sufficient. To compensate for CO_2 emissions arising from gas generators, Self-Sustaining sees Bioenergy with Carbon Capture and Storage (BECCS) operating.

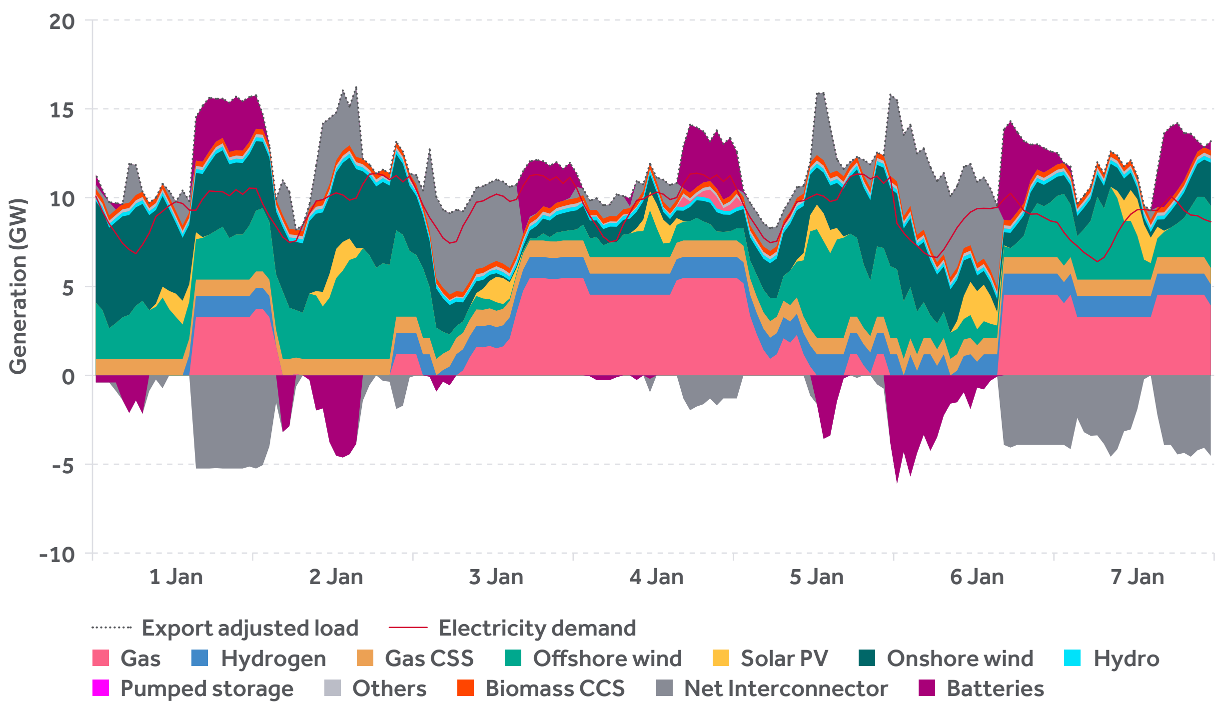

Figure 6.26: Self-Sustaining, weekly timeseries in 2040 – low renewables in winter (IE)

6.5.2 Offshore Opportunity 2040

From 2040, the Offshore Opportunity scenario achieves a Net Zero Power system. Figure 6.27 shows the annual generation capacity.
This includes:

- Over 84% of electricity coming directly from variable renewable generation, split between onshore and offshore wind and solar PV;
- Electricity imports; and
- Natural gas and other technologies providing flexible dispatch.

Please note that the annual generation mix does not show electricity exports from Ireland to other countries or the contribution from batteries and energy storage.

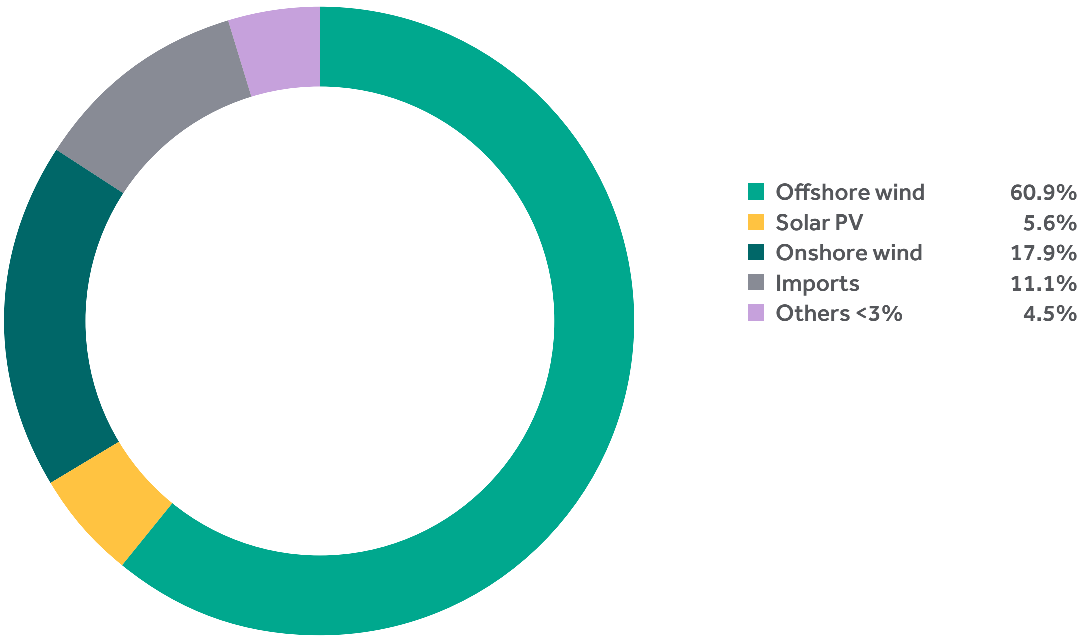

Figure 6.27: Offshore Opportunity, annual generation mix in 2040 (net zero power system) (IE)

A week in summer with high wind

The balance of supply and demand across a weekly period is shown in Figure 6.28. The timeseries selected is from a windy week in late summer. In this week, almost all demand is met by variable renewables and batteries.

Due to the high offshore wind rollout in this scenario, it is the dominant source of supply on a windy week, with the batteries on the system charging during these high wind periods and discharging when the wind levels dip. Another noteworthy feature of the system during this period is the very significant electricity exports.

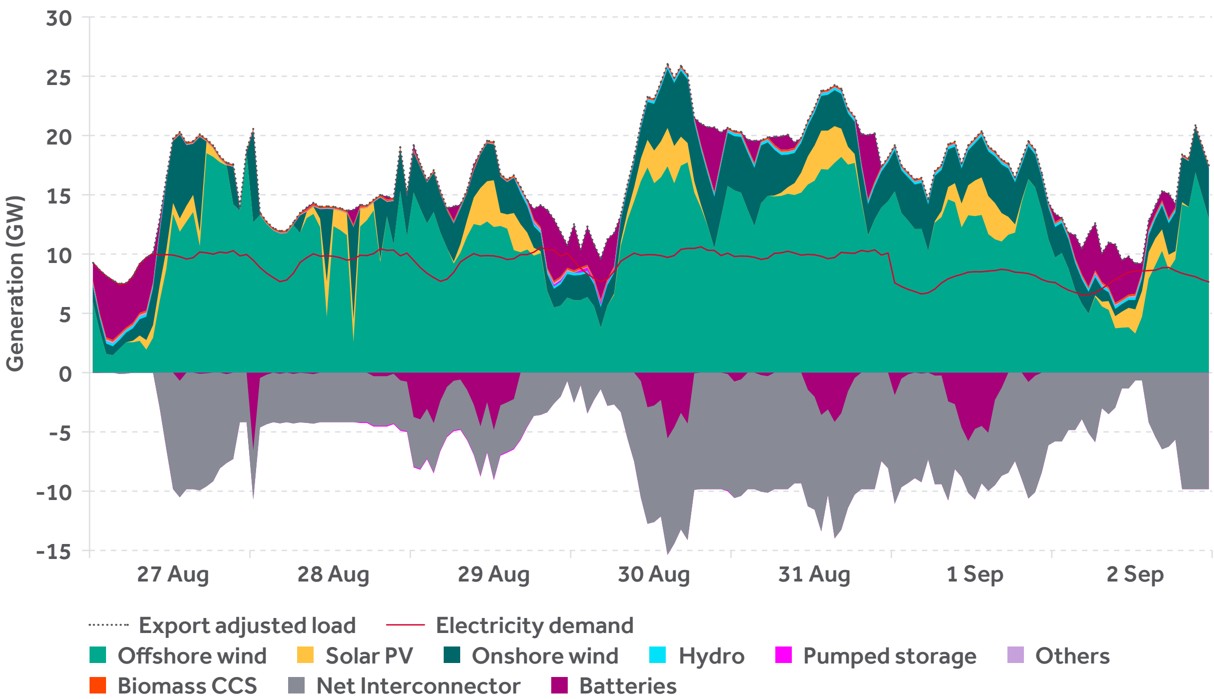

Figure 6.28: Offshore Opportunity, weekly timeseries in 2040 – high wind in summer (IE)

A week in winter with low renewable generation

Figure 6.29 below shows how the same installed capacity mix responds during a period of high electricity demand, while renewable generation is low.

The timeseries shows that in this week, reductions in renewable generation are compensated by dispatchable generators, batteries and large interconnector imports.

In the Offshore Opportunity scenario, flexible dispatchable power is largely provided by natural gas and hydrogen to secure electricity supplies for periods when renewable generation is not sufficient. The high interconnector capacity in Offshore Opportunity enables electricity imports to meet a significant portion of demand during these periods.

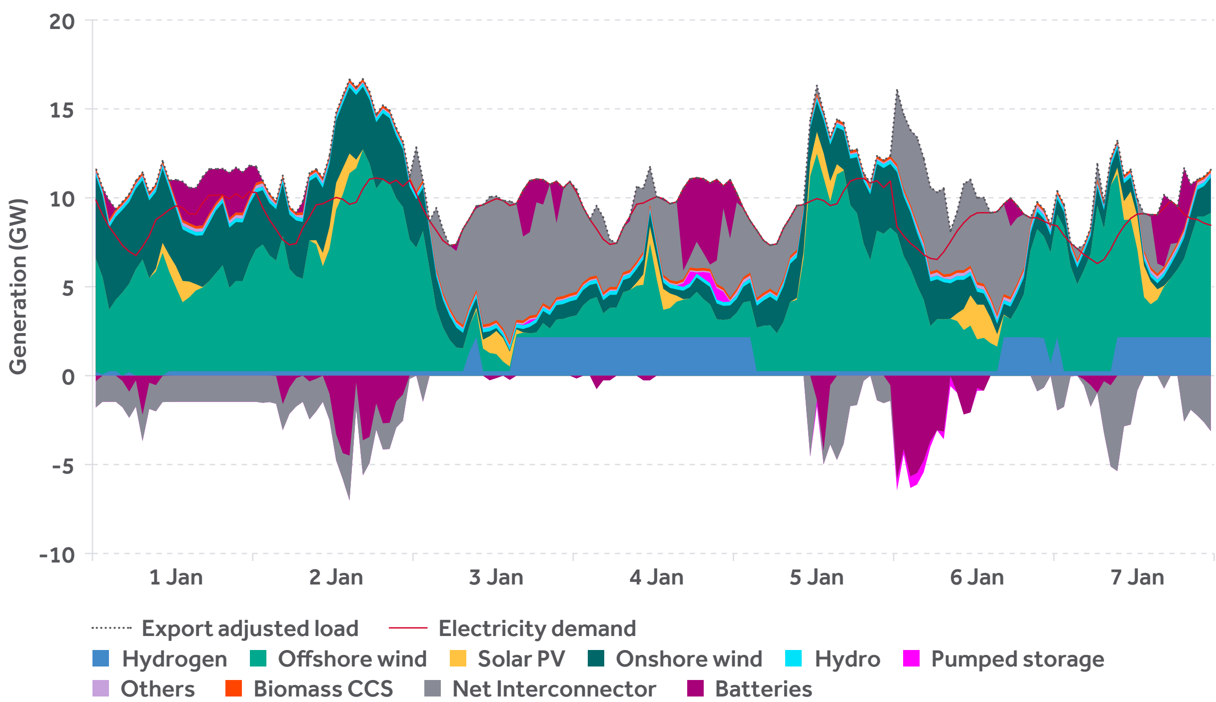

Figure 6.29: Offshore Opportunity, weekly timeseries in 2040 – low renewables in winter (IE)

6.5.3 Constrained Growth 2050

From 2050, the Constrained Growth scenario achieves a Net Zero Power system. Figure 6.30 shows the annual generation mix. This includes:

- Over 77% of electricity coming directly from variable renewable generation, split between onshore and offshore wind and solar PV;
- Electricity imports; and
- Natural gas and other technologies providing flexible dispatch.

Please note that the annual generation mix does not show electricity exports from Ireland to other countries or the contribution from batteries and energy storage.

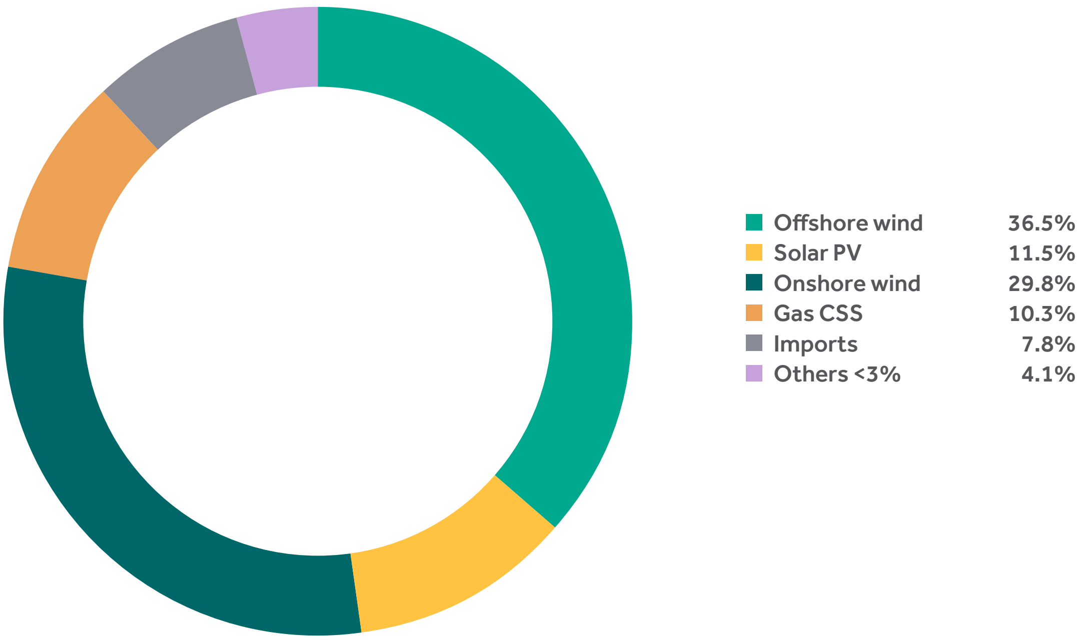

Figure 6.30: Constrained Growth, annual generation mix in 2050 (net zero power system) (IE)

A week in summer with high wind

The balance of supply and demand across a weekly period is shown in Figure 6.31. The timeseries selected is from a windy week in late summer. In this week, offshore wind is the leading source of supply while the solar and onshore wind capacities provide the majority of the remainder of supply.

Batteries play a smaller role in providing flexible electricity than in Self-Sustaining and Offshore Opportunity. Interconnector capacities are also lower than other scenarios leading to less electricity exports.

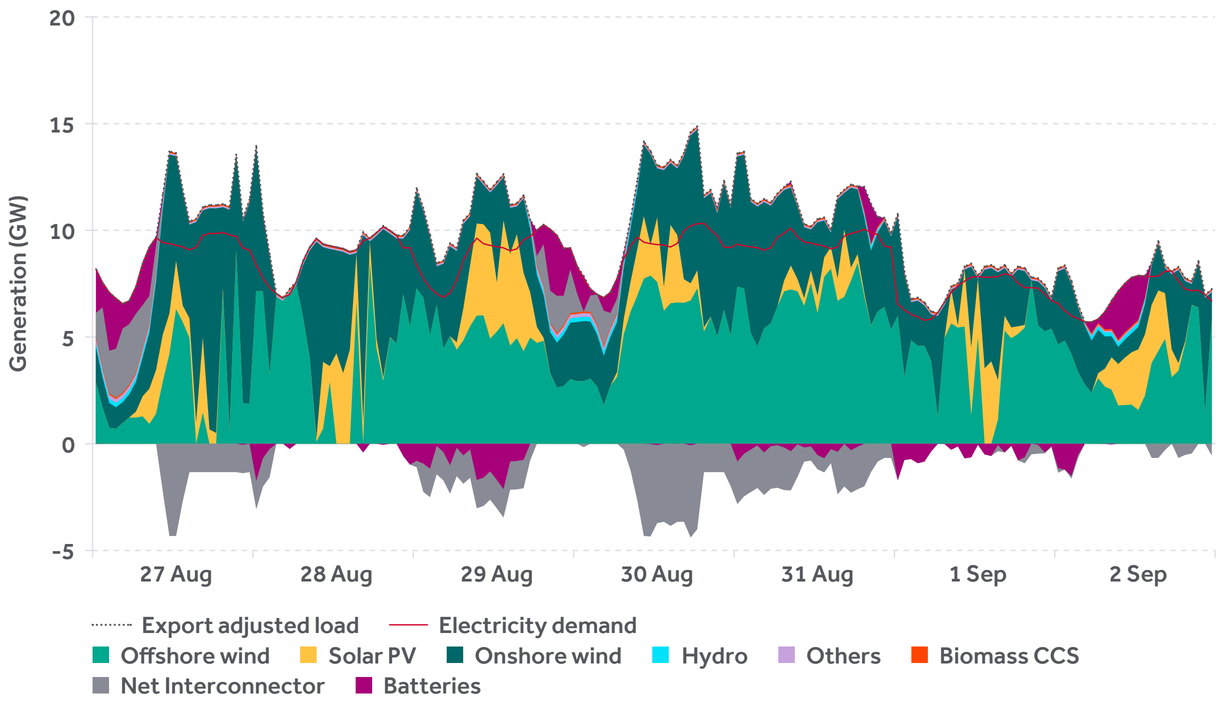

Figure 6.31: Constrained Growth, weekly timeseries in 2050 – high wind in summer (IE)

A week in winter with low renewable generation

Figure 6.32 below shows how the same installed capacity mix responds during a period of high electricity demand, while renewable generation is low.

The timeseries shows that in this week, reductions in renewable electricity generation are compensated by dispatchable generators, batteries and interconnector imports.

In the Constrained Growth scenario, flexible dispatchable power is largely provided by natural gas plants equipped with CCS to secure electricity supplies for periods when renewable generation is not available. With the lower capacity of renewable generation and interconnection compared to Self-Sustaining and Offshore Opportunity, these gas with CCS plants run quite frequently throughout the year.

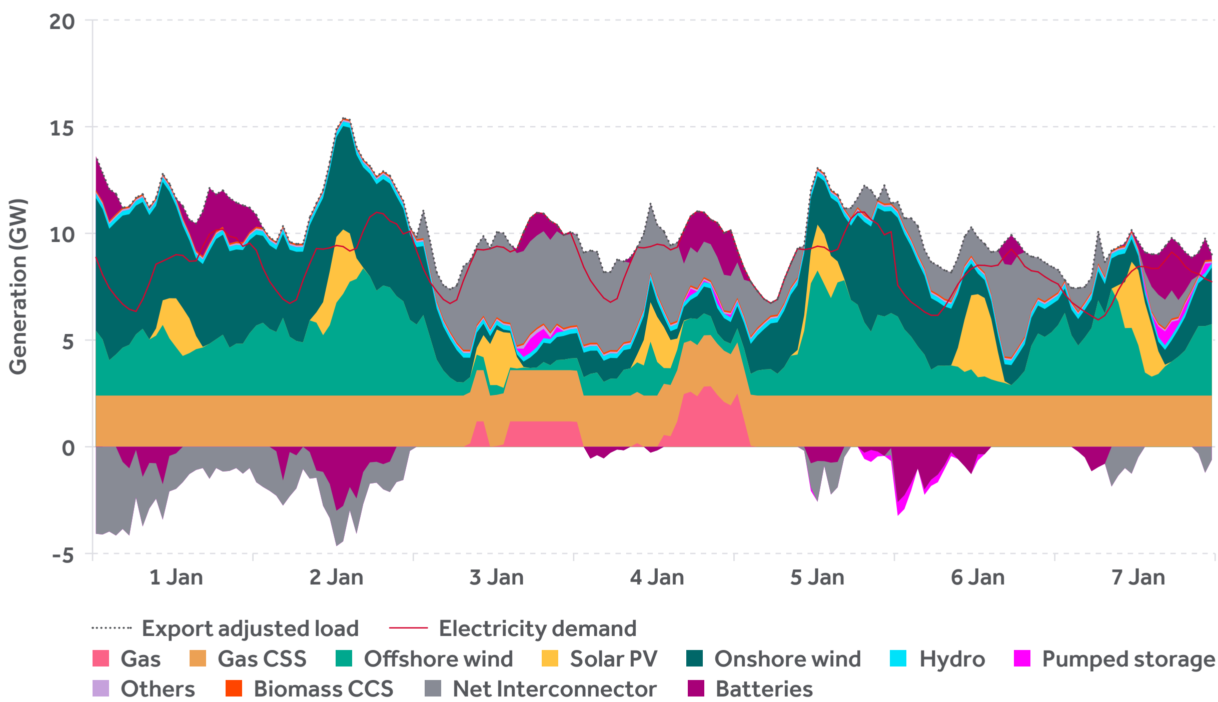

Figure 6.32: Constrained Growth, weekly timeseries in 2050 – low renewables in winter (IE)

6.5.4 Gas Evolution 2045

From 2045, the Gas Evolution scenario achieves a Net Zero Power system. Figure 6.33 shows the annual generation mix. This includes:

- Over 68% of electricity coming directly from variable renewable generation, split between onshore and offshore wind and solar PV;
- Electricity imports; and
- Hydrogen and other technologies providing flexible dispatch.

Please note that the annual generation mix does not show electricity exports from Ireland to other countries or the contribution from batteries and energy storage.

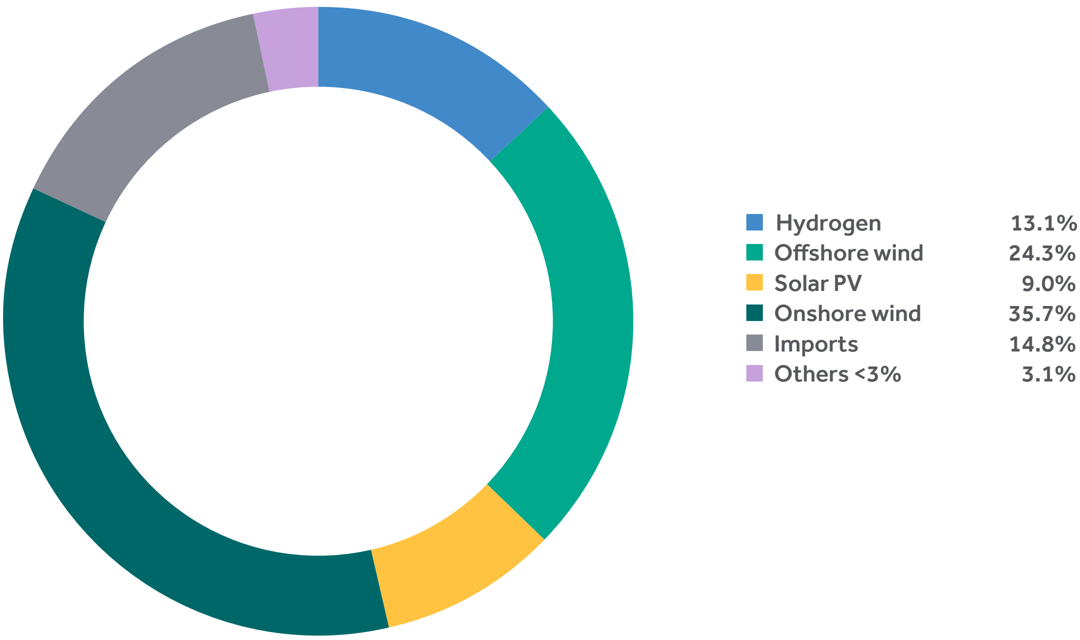

Figure 6.33: Gas Evolution, annual generation mix in 2045 (net zero power system) (IE)

A week in summer with high wind

The balance of supply and demand across a weekly period is shown in Figure 6.34. The timeseries selected is from windy week in late summer. In this week, almost all demand is met by variable renewables and batteries.

High amounts of offshore and onshore wind are the primary sources of power for the transmission system. There is a small baseload demand met by hydrogen that remains stable throughout the week.

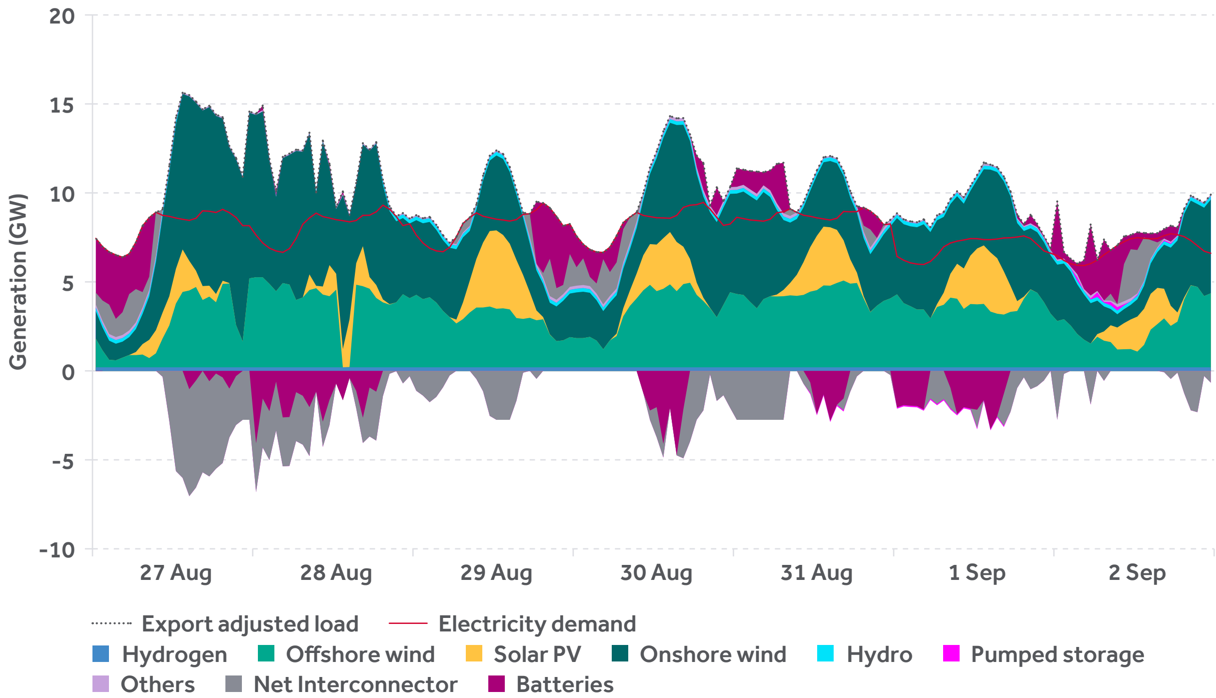

Figure 6.34: Gas Evolution, weekly timeseries in 2045 – high wind in summer (IE)

A week in winter with low renewable generation

Figure 6.35 below shows how the same installed capacity mix responds during a period of high electricity demand, while renewable generation is low.

The timeseries shows that in this week, reductions in renewable electricity are compensated by dispatchable generators, batteries and large interconnector imports.

In the Gas Evolution scenario, hydrogen provides a substantial amount of generation in weeks with low renewable generation. These hydrogen fuelled generators along with the significant rollout of interconnection help to ensure all electricity demand can be met.

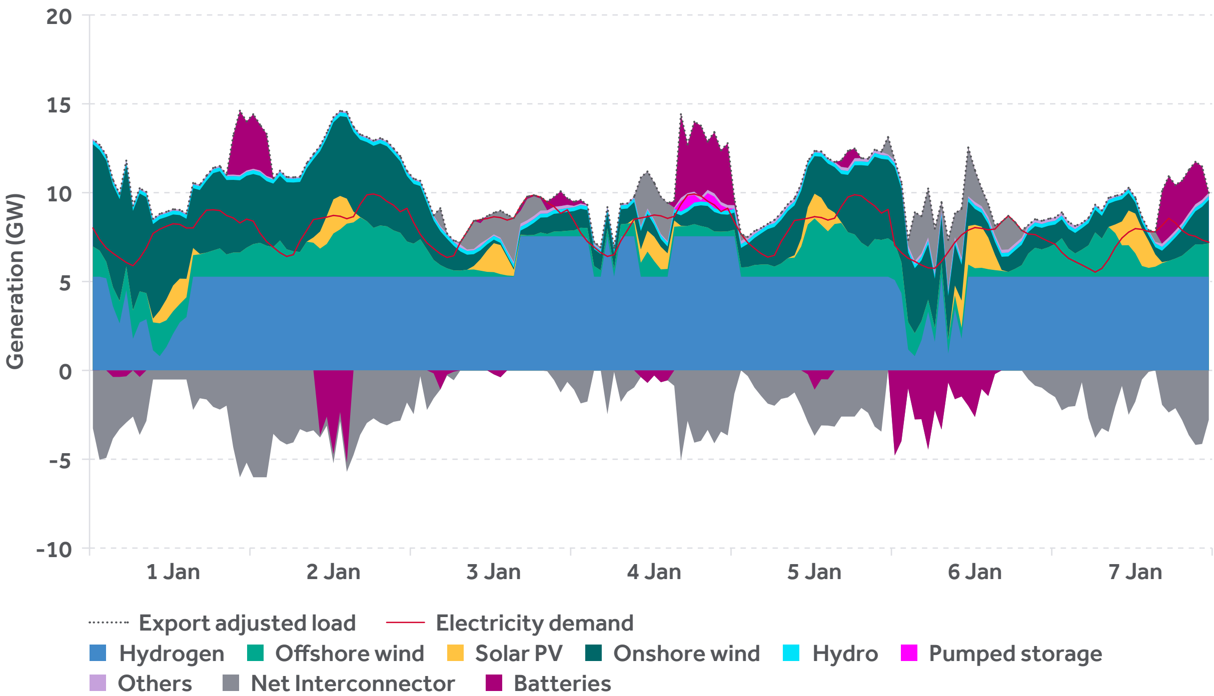

Figure 6.35: Gas Evolution, sample weekly timeseries in 2045 – low renewables in winter (IE)

6.6 Generation mix snapshots – Northern Ireland

TES 2023 has analysed the way that the installed capacities are dispatched to generate electricity in each scenario. This assesses how electricity generation, storage and interconnection respond hour by hour from 2030 to 2050 to meet forecast electricity demands.

Sections 6.6.1–6.6.4 below explain the combined annual generation mix for each scenario in as they become a net zero power system. Weekly timeseries are presented to show how generation technologies combine in two contrasting weeks:

- A high renewable generation week in late summer.
- A low renewable generation week in winter.

An example of a weekly timeseries generation graph is shown below in Figure 6.36.

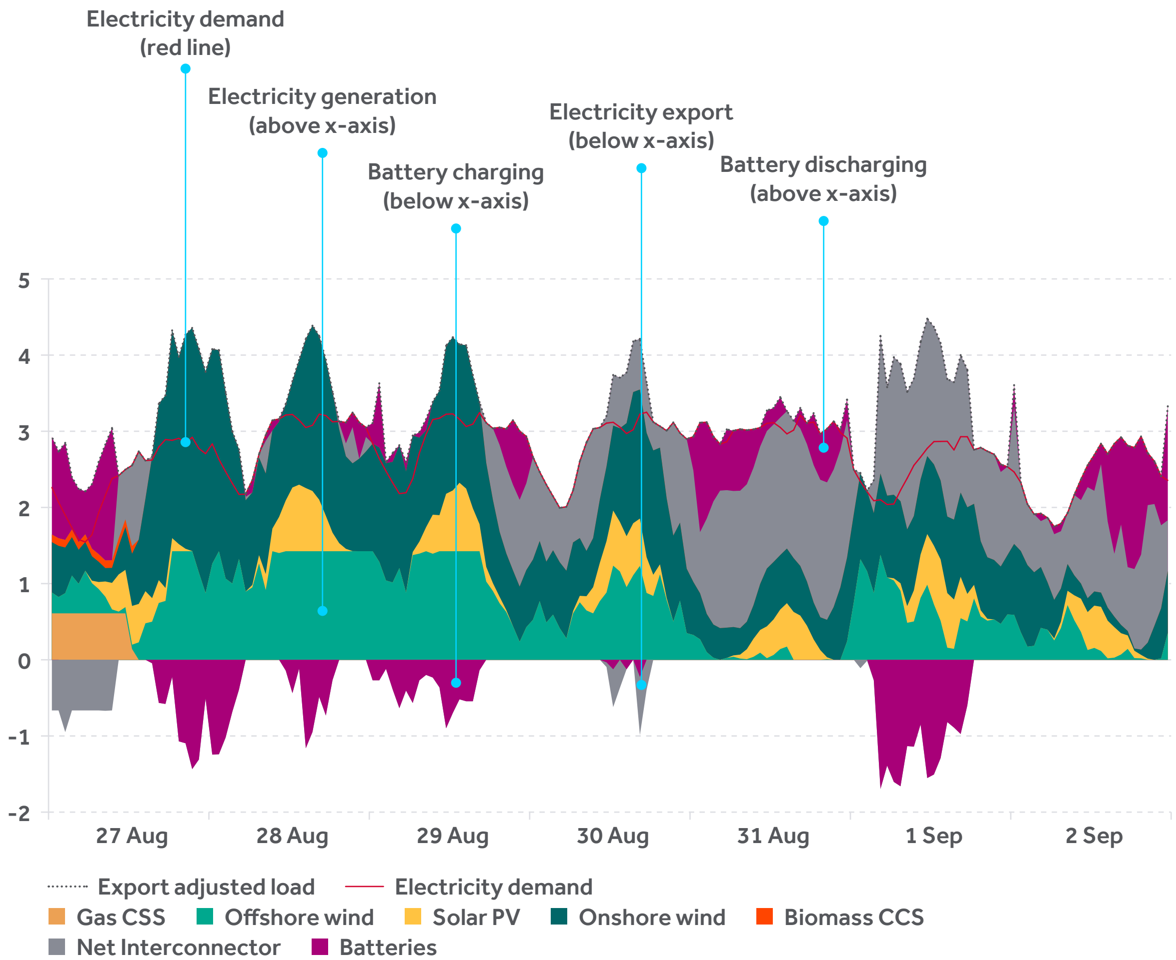

Figure 6.36: Example weekly timeseries showing how overall electricity generation above the x-axis and electricity exports and battery charging below the x-axis (NI)

In this chart, generation above the x-axis shows electricity dispatched to meet domestic demand. It also includes electricity imports and discharge from batteries and energy storage. Conversely, below the x-axis, shading indicates electricity exports and charging of energy stores. The red line represents the electricity demand on the transmission system. The dotted line at the top of the chart is the 'export adjusted load'. This is the sum of the generation required to meet demand, exported electricity, and electricity used to charge batteries and energy storage.

6.6.1 Self-Sustaining 2040

From 2040, the Self-Sustaining scenario achieves a Net Zero Power system. Figure 6.37 shows the annual generation mix. This includes:

- Over 62% of electricity coming directly from variable renewable generation, split between onshore and offshore wind and solar PV;
- Electricity imports via interconnectors; and
- Natural gas and other technologies providing flexible dispatch.

Note that the annual generation mix does not show electricity exports to other countries or the contribution from batteries and energy storage.

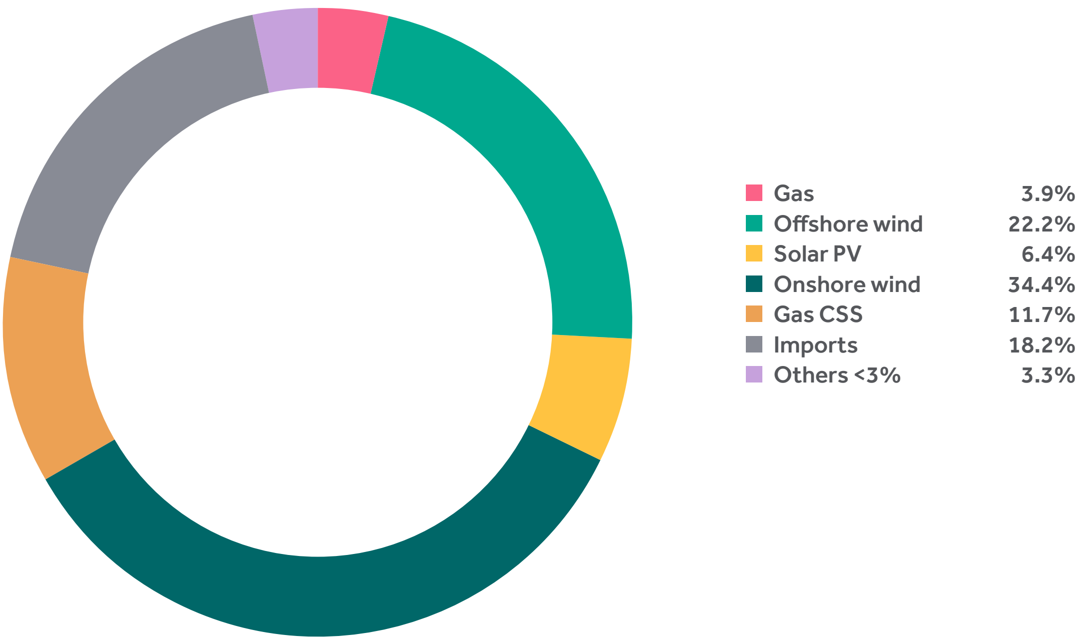

Figure 6.37: Self-Sustaining, annual generation mix in 2040 (NI)

A week in summer with high wind

The balance of supply and demand across a weekly period is shown in Figure 6.38. In this chart, the charging and discharging of batteries can be observed as well as import and export flows across interconnectors. The areas below the x-axis show charging of batteries and export through interconnectors.

The timeseries selected is from windy week in late summer. In this week, demand is met by variable renewables and batteries, as well as imports via interconnectors.

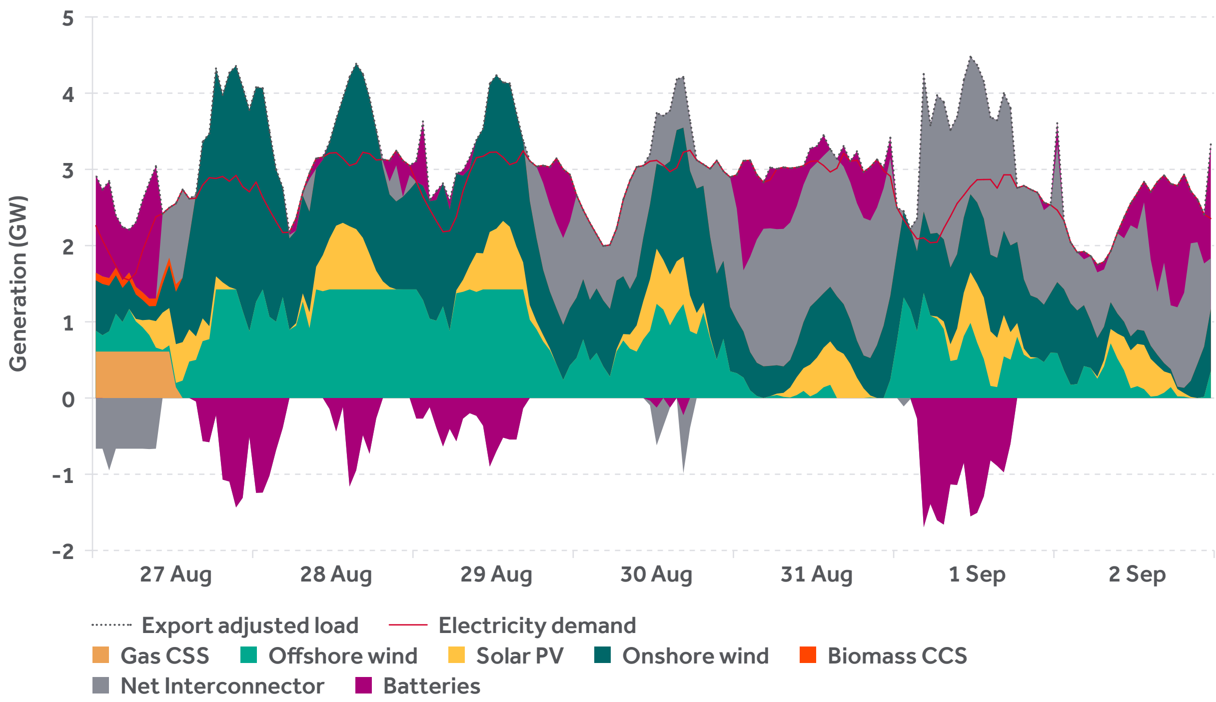

Figure 6.38: Self-Sustaining, weekly timeseries in 2040 – high wind in summer (NI)

A week in winter with low renewable generation

Figure 6.39 below shows how the same installed capacity mix responds during a period of high electricity demand, while renewable generation is low.

The timeseries shows that in this week, reductions in renewable generation are compensated by dispatchable generators, batteries and large interconnector imports.

In the Self-Sustaining scenario, flexible dispatchable power is largely provided by natural gas to secure electricity supplies for periods when renewable generation is not available. To compensate for CO_2 emissions arising from gas generators, Self-Sustaining sees Bioenergy with Carbon Capture and Storage (BECCS) operating.

Other zero carbon dispatchable sources such as hydrogen, gas with CCS play more minor roles in meeting demand.

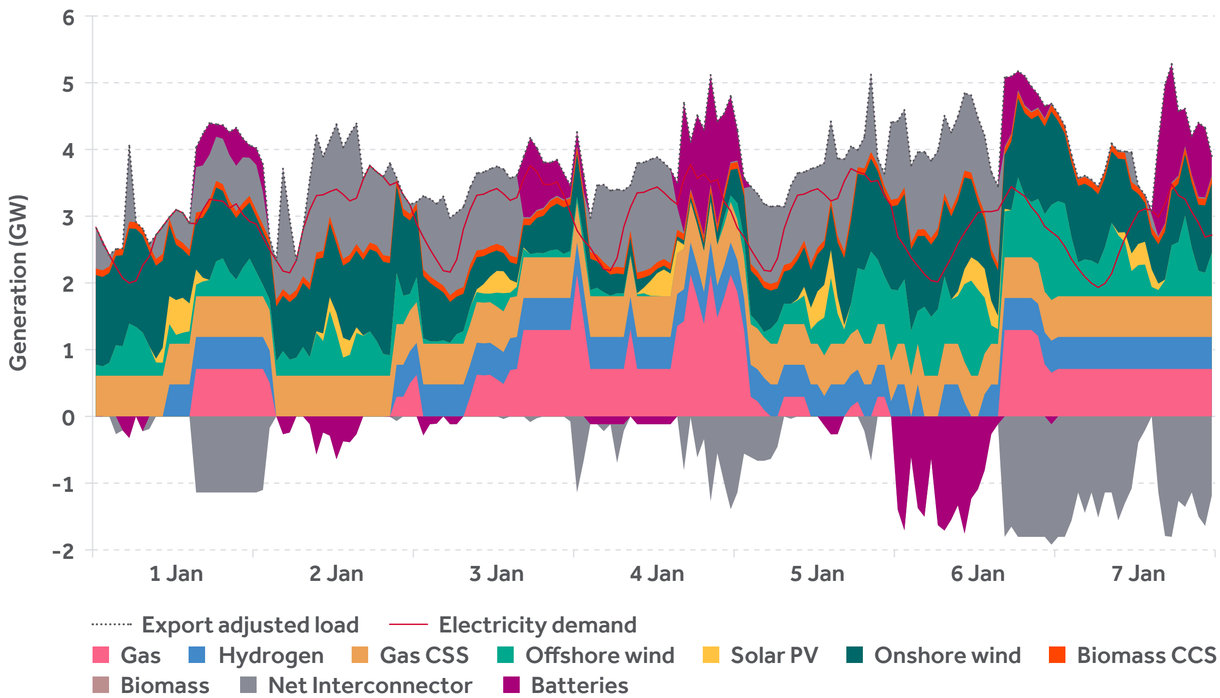

Figure 6.39: Self-Sustaining, weekly timeseries in 2040 – low renewables in winter (NI)

6.6.2 Offshore Opportunity 2040

From 2040, the Offshore Opportunity scenario achieves a Net Zero Power system. Figure 6.40 shows the annual generation mix. This includes:

- Over 75% of electricity coming directly from variable renewable generation, split between onshore and offshore wind and solar PV;
- Electricity imports via interconnectors; and
- Natural gas, hydrogen and other technologies providing flexible dispatch.

Note again that the annual generation mix does not show electricity exports to other countries or the contribution from batteries and energy storage.

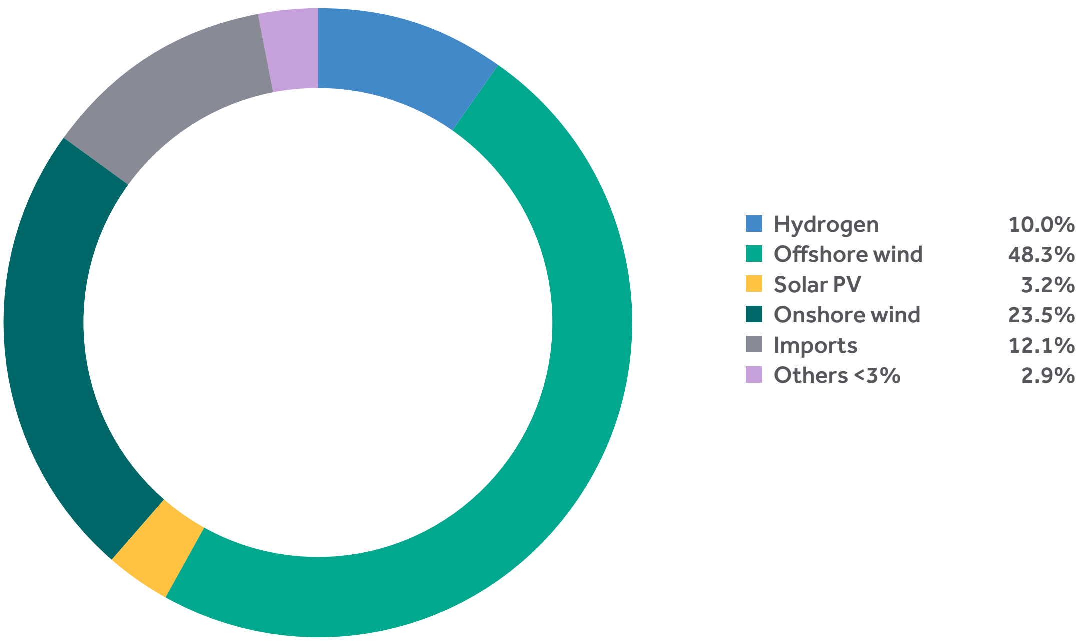

Figure 6.40: Offshore Opportunity, annual generation mix in 2040 (NI)

A week in summer with high wind

The balance of supply and demand across a weekly period is shown in Figure 6.41. In this chart, the charging and discharging of batteries can be observed as well as import and export flows across interconnectors. The areas below the x-axis show charging of batteries and export through interconnectors.

The timeseries selected is from a windy week in late summer. In this week, demand is met by renewable generators, batteries and imports.

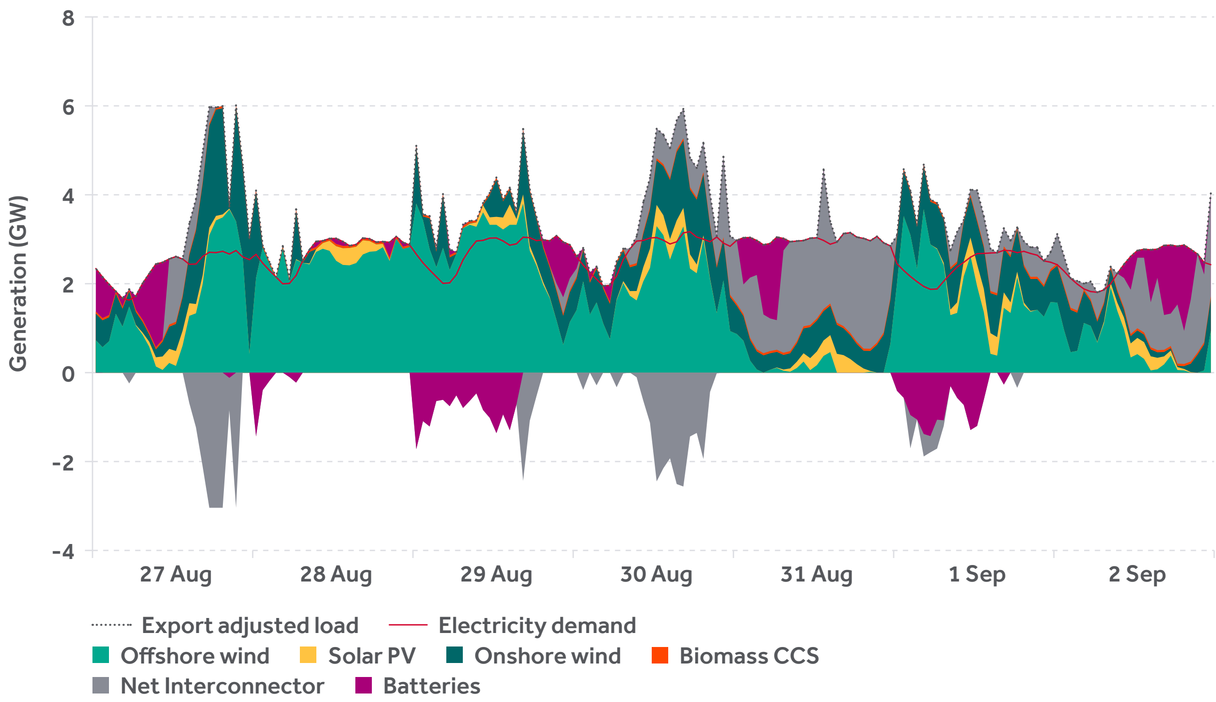

Figure 6.41: Offshore Opportunity, weekly timeseries in 2040 – high wind in summer (NI)

A week in winter with low renewable generation

Figure 6.42 below shows how the same installed capacity mix responds during a period of high electricity demand, while renewable generation is low.

The timeseries shows that in this week, reductions in renewable generation are compensated by dispatchable generators, batteries and large interconnector imports.

In the Offshore Opportunity scenario, flexible dispatchable power is provided primarily by hydrogen fuelled generators to secure electricity supplies for periods when renewable generation is not available. This scenario features the operation of BECCS.

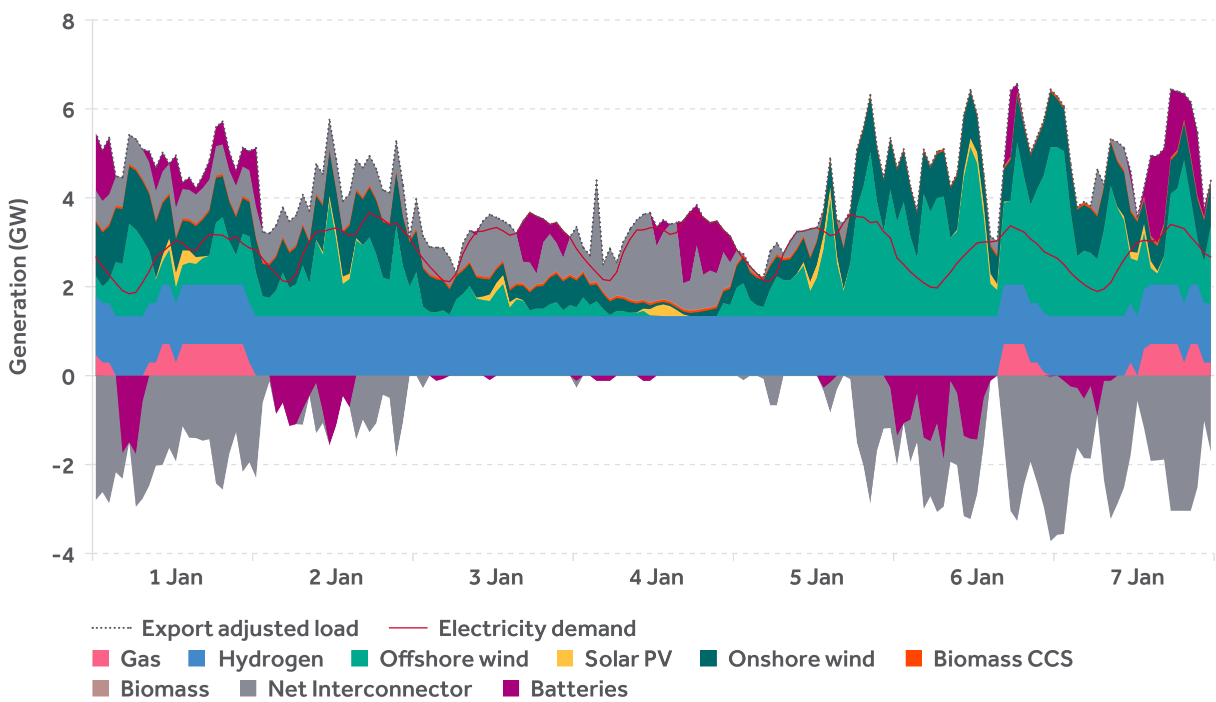

Figure 6.42: Offshore Opportunity, weekly timeseries in 2040 – low renewables in winter (NI)

6.6.3 Constrained Growth 2050

From 2050, the Constrained Growth scenario achieves a Net Zero Power system. Figure 6.43 shows the annual generation mix. This includes:

- Over 78% of electricity coming directly from variable renewable generation, split between onshore and offshore wind and solar PV;
- Electricity imports via interconnectors; and
- Natural gas and other technologies providing flexible dispatch.

Note again that the annual generation mix does not show electricity exports to other countries or the contribution from batteries and energy storage.

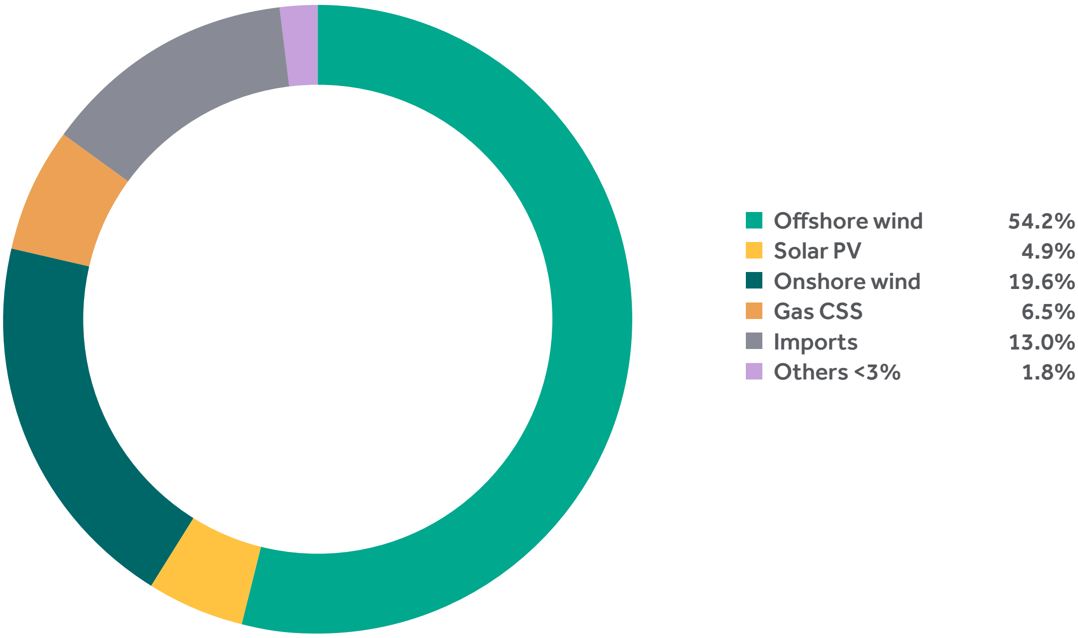

Figure 6.43: Constrained Growth, annual generation mix in 2050 (NI)

A week in summer with high wind

The balance of supply and demand across a weekly period is shown in Figure 6.44. The timeseries selected is from a windy week in late summer. In this week, almost all demand is met by renewable generators, imports and batteries.

In this chart, the charging and discharging of batteries can be observed as well as import and export flows across interconnectors.

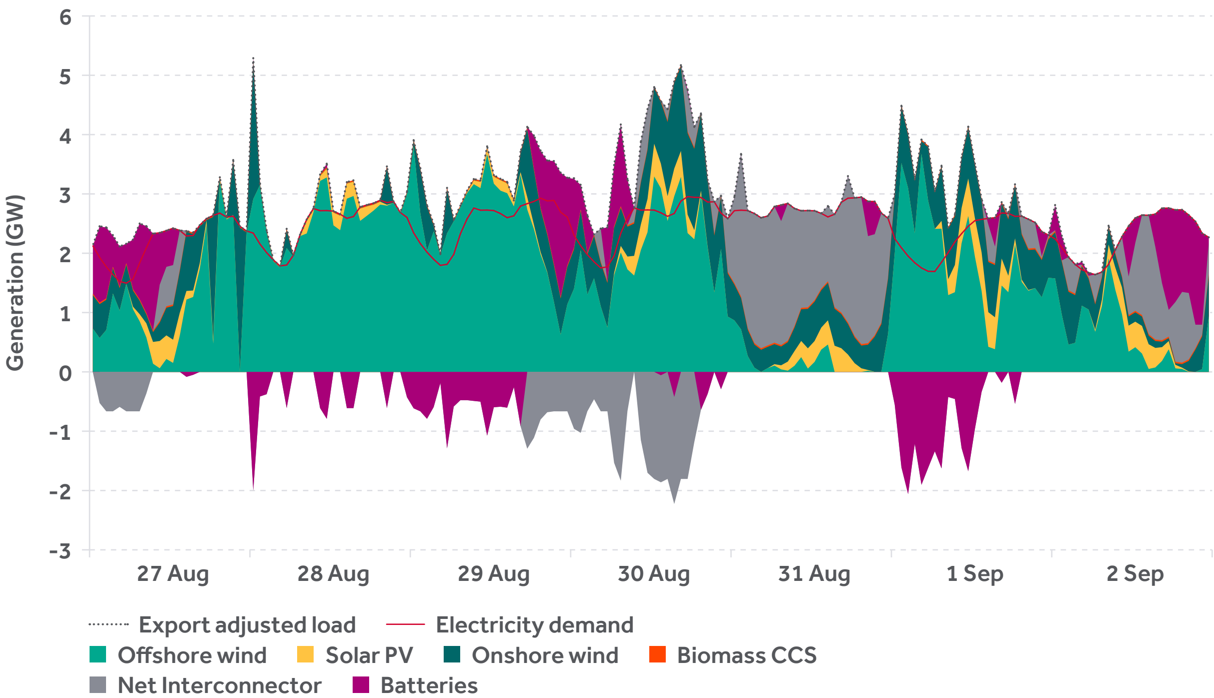

Figure 6.44: Constrained Growth, weekly timeseries in 2050 – high wind in summer (NI)

A week in winter with low renewable generation

Figure 6.45 below shows how the same installed capacity mix responds during a period of high electricity demand, while renewable generation is low.

The timeseries shows that in this week, reductions in renewable generation are compensated by dispatchable generators, batteries and large interconnector imports.

In the Constrained Growth scenario, flexible dispatchable power is again provided by natural gas with CCS to secure electricity supplies for periods when renewable generation is not available.

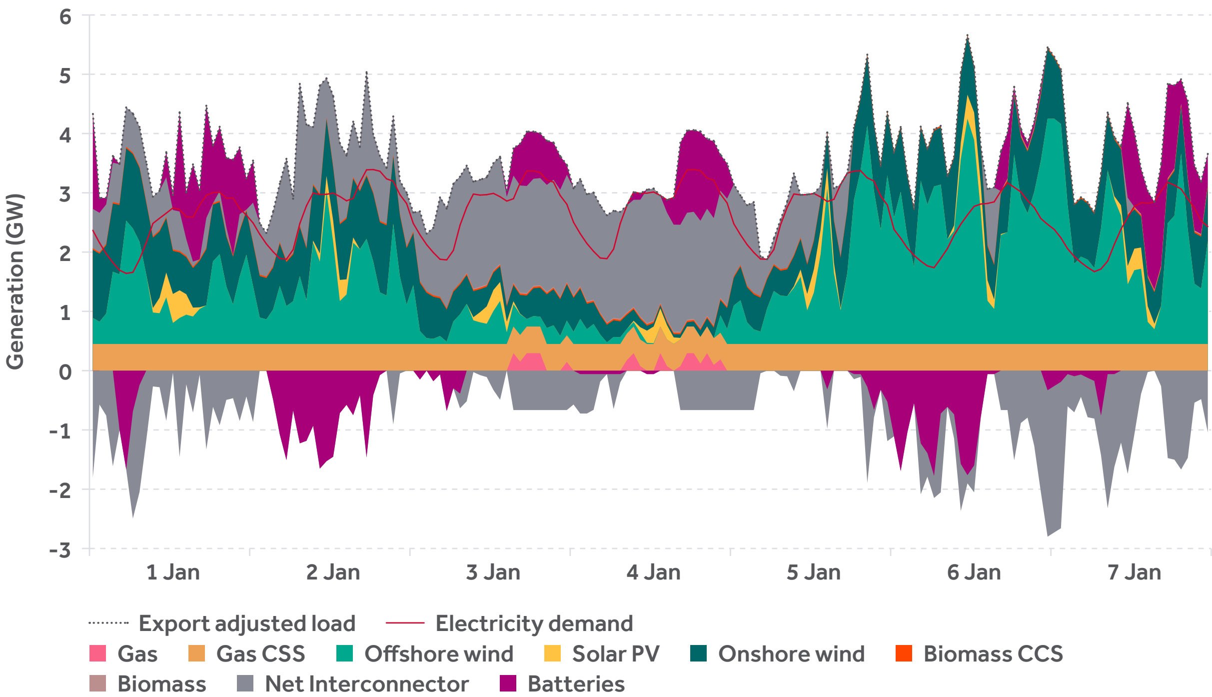

Figure 6.45: Constrained Growth, weekly timeseries in 2050 – low renewables in winter (NI)

6.6.4 Gas Evolution 2045

From 2045, the Gas Evolution scenario achieves a Net Zero Power system. Figure 6.46 shows the annual generation mix. This includes:

- Over 79% renewable electricity coming directly from variable renewable generation, split between onshore and offshore wind and solar PV;
- Electricity imports via interconnectors; and
- Hydrogen and other technologies providing flexible dispatch.

Note again that the annual generation mix does not show electricity exports to other countries or the contribution from batteries and energy storage.

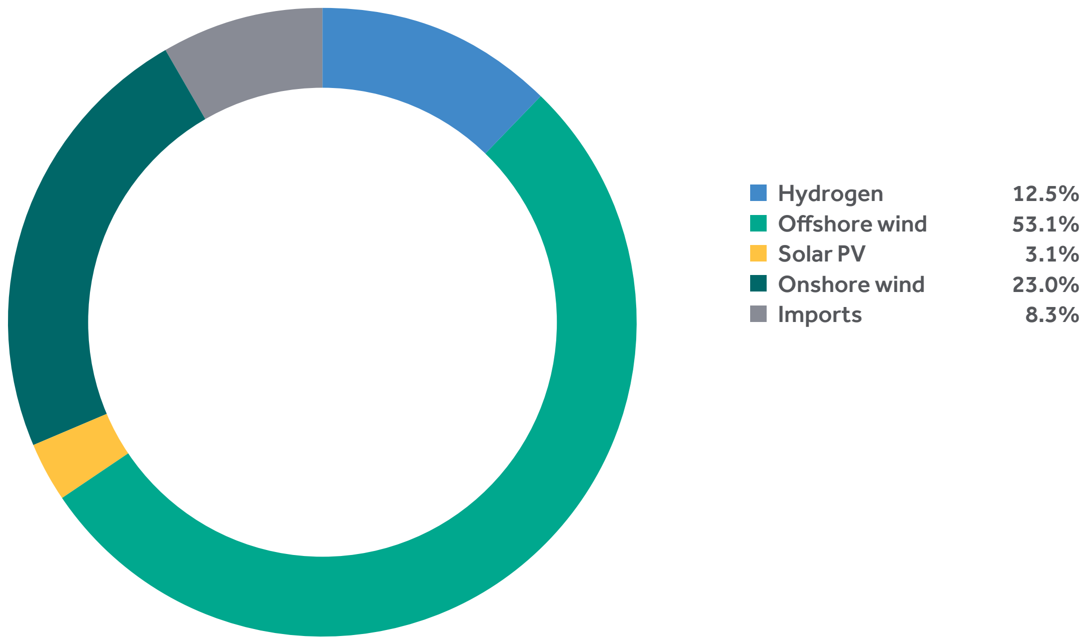

Figure 6.46: Gas Evolution, weekly timeseries in 2045– low renewables in winter (NI)

A week in summer with high wind

The balance of supply and demand across a weekly period is shown in Figure 6.47. The timeseries selected is from a windy week in late summer. In this week, almost all demand is met by renewable generators, imports and batteries.

In this chart, the charging and discharging of batteries can be observed as well as import and export flows across interconnectors.

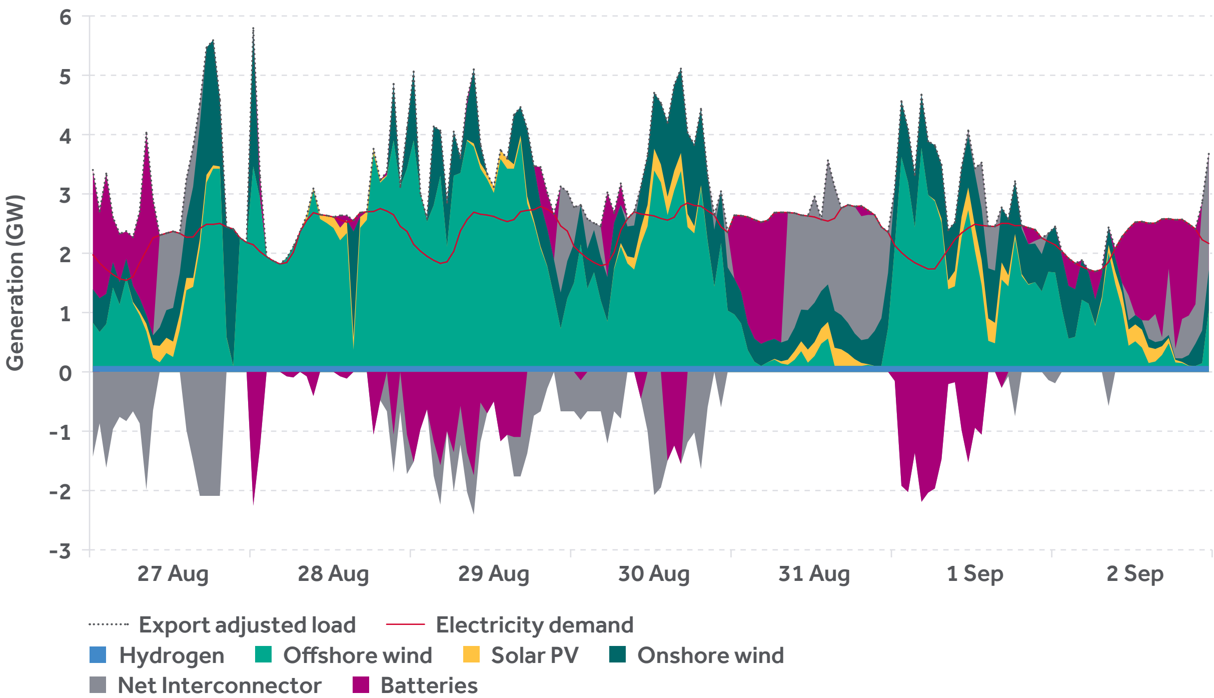

Figure 6.47: Gas Evolution, weekly timeseries in 2045 – high wind in summer (NI)

A week in winter with low renewable generation

Figure 6.48 below shows how the same installed capacity mix responds during a period of high electricity demand, while renewable generation is low.

The timeseries shows that in this week, reductions in renewable generation are compensated by dispatchable generators, batteries and large interconnector imports.

In the Gas Evolution scenario, flexible dispatchable power is primarily provided by hydrogen fuelled generators during periods when renewable generation is not available.

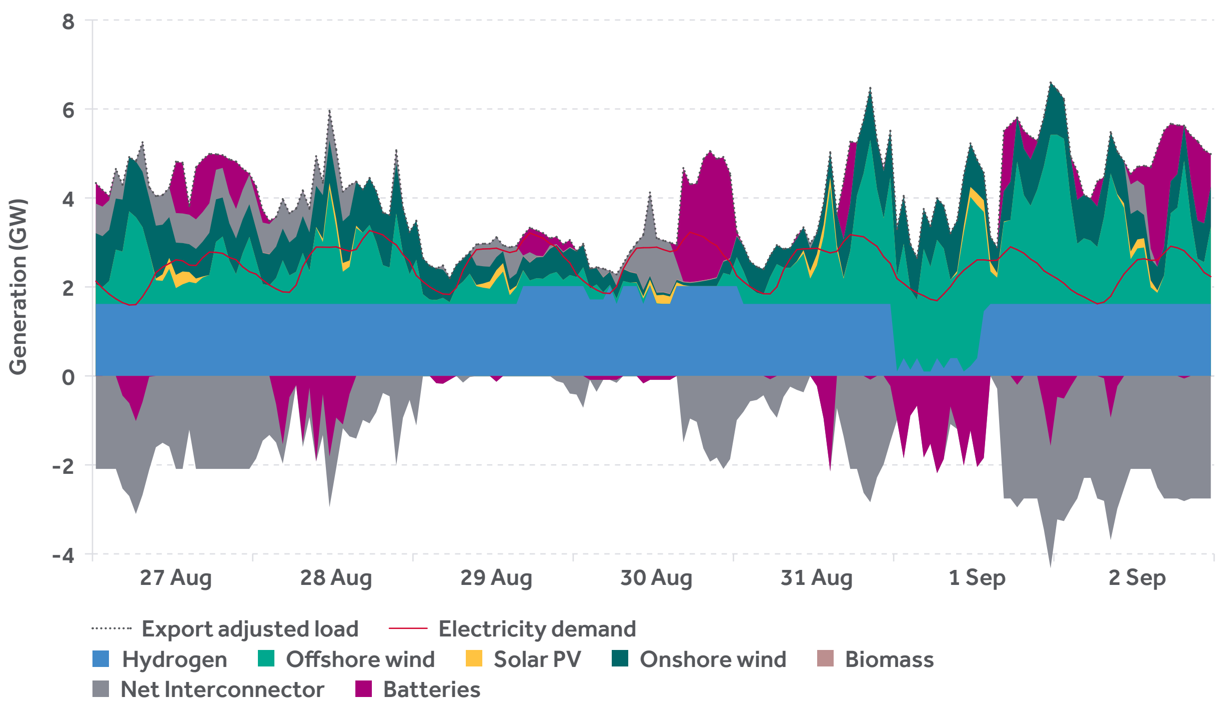

Figure 6.48: Gas Evolution, weekly timeseries in 2045 – low renewables in winter (NI)

6.7 Carbon emissions summary

Each scenario in TES has a specific target date for achieving net-zero power system emissions. Achieving net-zero emissions is a challenging task, as the closer the power system gets to net-zero emissions, the more difficult it is to make the final reductions needed to reach zero.

Each scenario's carbon emissions are shown in Tables 6.4 and 6.5 below.

Table 6.4: CO_2 emissions for Ireland (MT)

	2035	2040	2045	2050
Self-Sustaining	0.84	-1.07	-1.47	-2.18
Offshore Opportunity	0.47	-1.09	-0.88	-0.89
Gas Evolution	0.71	0.30	0.00	0.00
Constrained Growth	2.55	1.76	0.68	-0.37

Table 6.5: CO_2 emissions for Northern Ireland (MT)

	2035	2040	2045	2050
Self-Sustaining	0.13	-0.35	-0.47	-0.74
Offshore Opportunity	0.12	-0.26	-0.25	-0.26
Gas Evolution	0.16	0.07	0.00	0.00
Constrained Growth	0.54	0.37	0.12	-0.13

Self-Sustaining and Offshore Opportunity

These two scenarios have the most ambitious net-zero targets in TES. Both scenarios aim to have a net-zero power system from 2040. Following on from this, the emissions become negative through the use of BECCS. This captures and stores CO_2 emissions to help decarbonise sectors that have processes that are very challenging to electrify or move to a sustainable fuel source.

Gas Evolution

Gas Evolution has a net-zero target of 2045. This is due to an assumed slower transition from natural gas and a slower rollout of RES with more of a focus on developing a hydrogen network. More offshore wind is committed to producing hydrogen to be used as a fuel source. There are no negative emissions technologies in this scenario.

Constrained Growth

Constrained Growth has a net-zero target of 2050. This scenario has the slowest rollout of RES and slowest electrification of demand, therefore requiring more use of conventional fossil fuel plant to meet electricity demand at times of low wind and solar generation.

7. Conclusions and next steps

This report presents the results of Tomorrow's Energy Scenarios 2023 for consultation. It includes our latest thinking on long term energy scenarios for Ireland and Northern Ireland.

Our scenarios consider how electricity demand and generation might evolve from 2035 to 2050. The preceding sections explain the approach we have taken to developing our scenarios and what they could mean for electricity generation, storage and interconnection supported by different technologies.

7.1 Conclusions

TES 2023 includes four distinct scenarios that follow different pathways to decarbonise our power system between 2040 to 2050. Our key conclusions are:

1. TES 2023 scenarios show electricity demand more than doubling by 2050

Electricity demand is forecast to increase significantly due to a growing population and increasing electrification in all sectors of the economy as per Ireland's Climate Action Plan 2023 targets and the Climate Change Act in Northern Ireland.

2. In a renewables dominated power system, demand will need to follow renewable output to a greater extent than at present

Measures to improve energy efficiency and demand flexibility will be vital to help reduce pressure on the electricity system and manage peak loads – we anticipate requiring 20–50% demand flexibility.

3. Our scenarios show a net zero power system for Ireland and Northern Ireland being achieved from 2040–2050

Achieving a net zero power system will be challenging and assumes very significant development of network capacity and zero carbon system services.

4. A balanced portfolio of generation technologies will be required, with renewables supported by energy storage, firm dispatchable capacity and interconnection

Decarbonising the electricity system will require:

- A large and rapid rollout of **renewable generation** capacity, particularly offshore wind as well as utility-scale and domestic solar PV.
- Significant growth of **energy storage capacity**, including short, medium and long duration batteries
- The acceleration of **green fuels** (hydrogen, biomass and biomethane) to offer reliability and flexibility to the power system.
- **Negative emissions technologies** to capture and store carbon and balance emissions from remaining conventional plant.
- Significant increases in **electricity interconnection** to continental Europe and Great Britain to enable energy imports and exports.

7.2 TES 2023 consultation

TES has an important role to play in stimulating debate and we want to hear your feedback as part of this consultation. With your feedback on board we will update our analysis and publish a final scenario report for TES 2023. We will use the findings to guide our technical assessments of the electricity system going forward to plan what we need to prioritise to enable a sustainable, secure and affordable energy transition for Ireland and Northern Ireland.

How to respond

To respond to the consultation, complete the form on https://consult.eirgrid.ie/ or https://consult.soni.ltd.uk/.

You can complete the form in full or in part.

Where applicable we ask that one response is provided per organisation.

Where relevant, please provide evidence, such as reports and your analysis, to support your feedback. Supporting evidence can be emailed to the TES team in Ireland at scenarios@eirgrid.com and in Northern Ireland at info@soni.ltd.uk.

Deadline for responding

We will be accepting feedback on the Consultation until 12 December 2023.

Confidentiality and data protection

Please note your response will be publicly available for viewing on the relevant consultation portal. If you require your response to remain confidential, please clearly state this in your response.

Layout

We have arranged the Response Form into the following sections:

- Purpose of TES.
- Scenario framework.
- Electricity demand.
- Electricity generation.
- Other.

For more information, please visit our website, or email us in Ireland at scenarios@eirgrid.com and in Northern Ireland at info@soni.ltd.uk.

TES consultation questions

Name

Please enter your name here

Organisation

Please enter your organisation here

Email Address

Please enter your email address here

Area of interest

Are you principally interested in the future of the electricity sector in:

- [ ] Ireland
- [ ] Northern Ireland
- [ ] All-Island

Purpose of Tomorrow's Energy Scenarios

1. Have we adequately explained:

(i) Why EirGrid and SONI employ scenario planning?

[ ] Yes [ ] No [ ] Unsure

(ii) The scenario development process?

[ ] Yes [ ] No [ ] Unsure

(iii) How scenarios fit into our grid development process?

[ ] Yes [ ] No [ ] Unsure

(iv) Where the TES publications fit in the suite of planning publications?

[ ] Yes [ ] No [ ] Unsure

Please provide further feedback and details on the reasons for your choice here

Scenario framework

2. Do you think the scenarios Self-Sustaining, Offshore Opportunity, Gas Evolution and Constrained Growth cover a range of credible futures for Ireland's and Northern Ireland's electricity sector?

   ☐ Yes ☐ No ☐ Unsure

   Please provide further feedback and details on the reasons for your choice here

3. Do you agree with the selection of 2035 to 2050 as the period of study for TES 2023?

   ☐ Yes ☐ No ☐ Unsure

   Please provide further feedback and details on the reasons for your choice here

4. Do the scenarios capture the most important factors that will influence the future electricity sector in Ireland and Northern Ireland?

   ☐ Yes ☐ No ☐ Unsure

   Please provide further feedback and details on the reasons for your choice here

5. Do you agree with our approach to carbon emissions reductions for the power system described in the scenarios?

   ☐ Yes ☐ No ☐ Unsure

   Please provide further feedback and details on the reasons for your choice here

Electricity demand

6. Do you agree with our overall approach to forecasting electricity demand set out in Section 5?

   ☐ Yes ☐ No ☐ Unsure

   Please provide further feedback and details on the reasons for your choice here

(i) Assumptions for Total Electricity Requirement (TER)

   ☐ Yes ☐ No ☐ Unsure

(ii) Assumptions for peak electricity demand

   ☐ Yes ☐ No ☐ Unsure

(iii) Assumptions for energy efficiency

   ☐ Yes ☐ No ☐ Unsure

(iv) Assumptions for residential and tertiary sector electricity demand

   ☐ Yes ☐ No ☐ Unsure

(v) Assumptions for transport sector electricity demand

   ☐ Yes ☐ No ☐ Unsure

(vi) Assumptions for industrial and New Technology Load electricity demand

   ☐ Yes ☐ No ☐ Unsure

Please provide further feedback and details on the reasons for your choices here

Electricity generation

7. Do you agree with our overall approach to forecasting future electricity generation set out in Section 6?

☐ Yes ☐ No ☐ Unsure

Please provide further feedback and details on the reasons for your choice here

8. Have we considered the right balanced portfolio of generation technologies?

☐ Yes ☐ No ☐ Unsure

Please provide further feedback and details on the reasons for your choice here

9. Do the scenarios include credible capacities and build out rates for generation technologies?

☐ Yes ☐ No ☐ Unsure

Please provide further feedback and details on the reasons for your choice here

10. Do you agree with our overall approach to forecasting future interconnection and energy storage needs?

☐ Yes ☐ No ☐ Unsure

Please provide further feedback and details on the reasons for your choice here

11. Do the scenarios include credible capacities and build out rates for interconnection with other countries?

☐ Yes ☐ No ☐ Unsure

Please provide further feedback and details on the reasons for your choice here

12. Do the scenarios include credible capacities and build out rates for energy storage?

☐ Yes ☐ No ☐ Unsure

Please provide further feedback and details on the reasons for your choice here

13. Is there any aspect of electricity generation that you disagree with, or any aspect that you believe we have not considered, or any further aspect that you would like us to include in the final publication?

☐ Yes ☐ No ☐ Unsure

Please provide further feedback and details on the reasons for your choice here

14. Do you agree with our overall approach to modelling decarbonisation for a net zero power system?

☐ Yes ☐ No ☐ Unsure

Please provide further feedback and details on the reasons for your choice here

15. Do you think the pathways presented for emissions reduction are credible?

☐ Yes ☐ No ☐ Unsure

Please provide further feedback and details on the reasons for your choice here

Other

16. Is there any other information not referred to above that you would like us to provide in our final publication?

Please provide further feedback and details on the reasons for your choice here

17. Have you any other comments on the consultation or on TES?

Please provide further feedback and details on the reasons for your choice here

The Oval, 160 Shelbourne Road,
Ballsbridge, Dublin 4, D04 FW28, Ireland
+353 (0) 1 627 1700 | eirgrid.ie

Castlereagh House, 12 Manse Road,
Belfast, BT6 9RT, Northern Ireland
+44 (0) 28 9079 4336 | soni.ltd.uk