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Tomorrow's Energy Scenarios 2023

Final Report

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This document is intended to provide potential future scenarios for SONI and EirGrid 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 six sections and supporting appendices and attachments.

Key changes following consultation

This section explains the key changes that have been made following the stakeholder consultation in autumn 2023.

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.

Northern Ireland

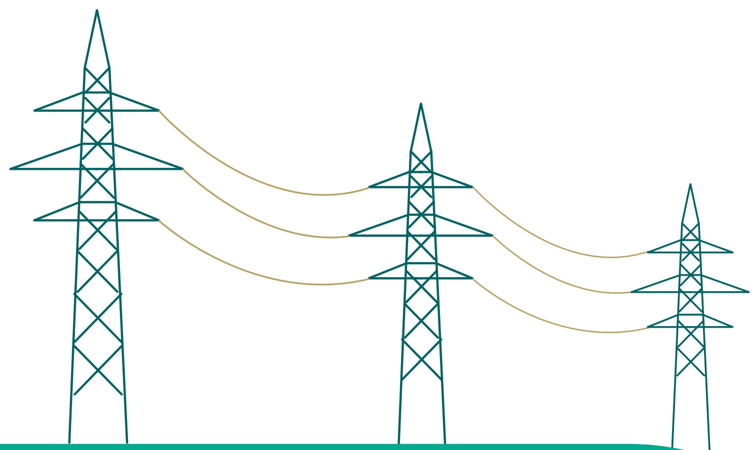
Ireland

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 negative emissions technologies.

Key insights

This report has been released as part of the TES 2023 development process. In this section, we summarise key insights from our analysis that can inform ongoing dialogue with stakeholders in the energy transition.



Scenario framework

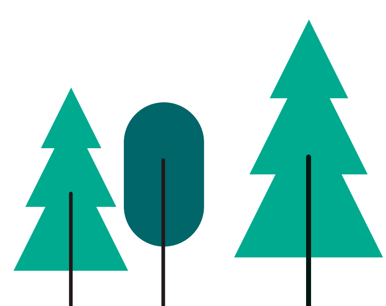
This section explains the overall framework for our scenarios, including aspects such as RES-E generation mix, demand growth and decarbonisation targets. There is also a discussion on the economic model used and some of the assumptions we have applied to the scenarios.

Northern Ireland

Ireland

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.



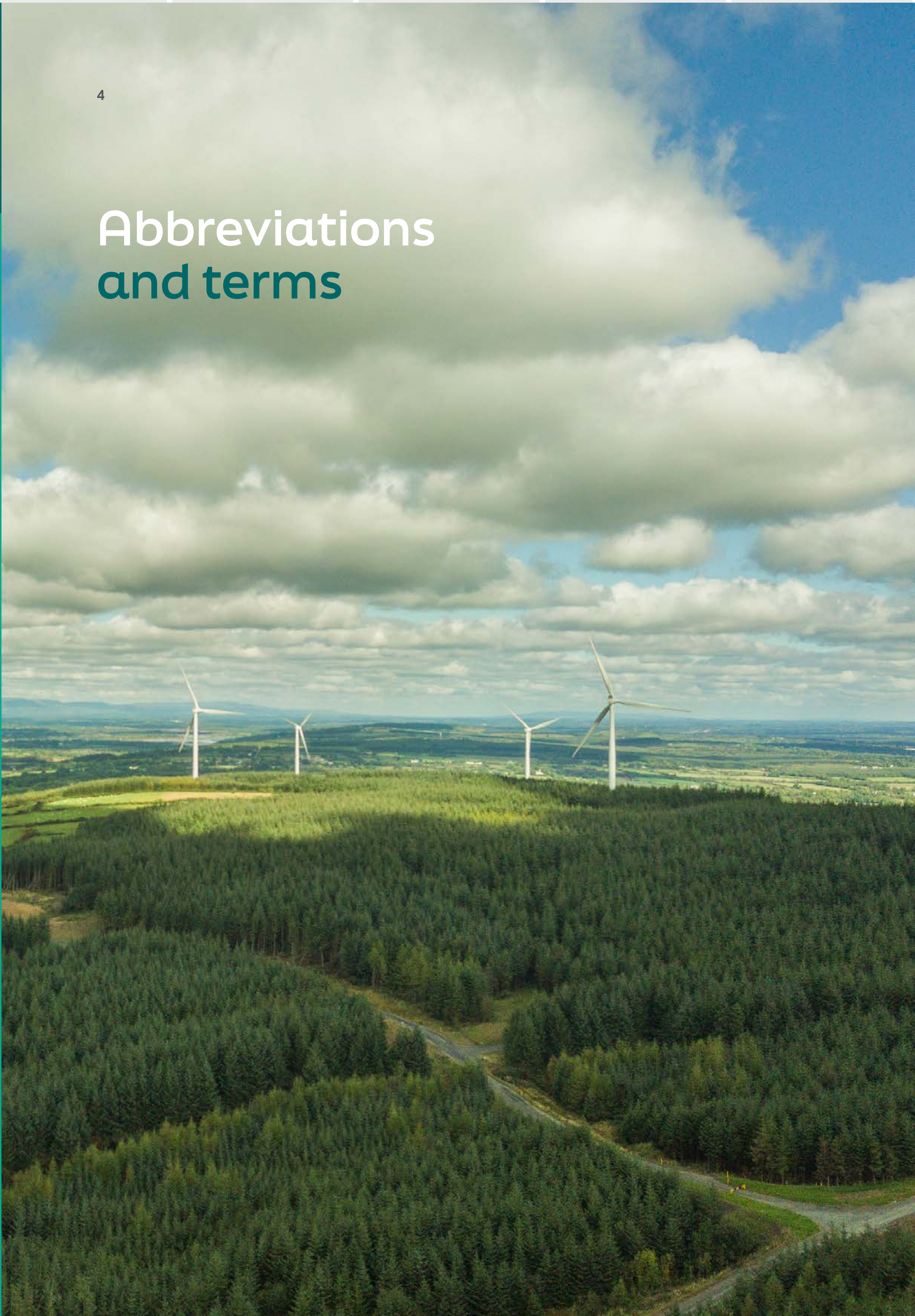
Appendices

A summary of consultation feedback and EirGrid's and SONI's response is provided. Additionally, a summary of sensitivity analysis is also provided. This shows analysis of two scenarios that achieve a net zero power system from 2035.

Attachments

Attachments accompanying the final report are available via the SONI and EirGrid website. These include a Databook detailing results of our analysis and stakeholder 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 2030, 2040 and 2050 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	Photovoltaic	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.

EirGrid Chief Executive's foreword

We are pleased to present the 2023 edition of Tomorrow's Energy Scenarios.

This publication represents a significant body of work that explores different scenarios for enabling a cleaner energy system based on renewables that will meet growing demand.

It will also support Government and Regulatory Authorities in the development of energy policy and market design development required to decarbonise the power system. Future iterations of Tomorrow's Energy Scenarios will reflect any changes to government policy and advances in technology.

Today's climate challenges are unprecedented. In the last 50-years, temperatures have increased rapidly with human activity being the primary driver. Holistic transformation needs to occur at a significantly accelerated pace in order for Ireland to meet the Government's climate ambitions. These include obtaining 80% of our energy from renewable sources by 2030 and achieving net-zero emissions no later than 2050.

To do this, it's vital we find new ways to meet the increasing demand for energy without relying on burning fossil fuels. EirGrid, as the transmission system operator for Ireland, has a unique role to play in transforming our power system to help meet the needs of today as well as the future.

In Tomorrow's Energy Scenarios, we explore four distinct energy scenarios for enabling our transition to a decarbonised power system. This builds on our previous research and provides greater insight into how tomorrow's targets can become a reality.

Undoubtedly, we face a number of challenges in getting there. Our research, detailed in this document, forecasts that electricity demand will more than double by 2050. This is due to a rapidly growing population as well as increasing electrification in all sectors of the economy.

Martin Corrigan,
Interim Chief Executive,
EirGrid Group

Furthermore, moving away from fossil fuels will require deployment at scale of clean, sustainable fuels such as green hydrogen to increase energy security. Finally, as we become more reliant on renewable energy sources, we will need to employ innovative methods of energy storage as well as significantly leverage our electricity interconnections with continental Europe and Great Britain.

This document provides a clear breakdown of the issues as well as the identification of viable, well-researched routes that detail how a cleaner energy future for Ireland can be attained. Each scenario places a different emphasis on key elements such as interconnection and offshore as well as what would be required in terms of the development of new technologies. By doing this, we've outlined what would be required for each outcome, the benefits and the challenges.

Following consultation, we have received comprehensive input from the likes of industry, other system operators and academia, deepening our exploration of each scenario. We would like to thank all of the consultees for their contributions and for supporting the substantial innovation and analysis that goes into this publication.

We hope you find Tomorrow's Energy Scenarios useful and that it offers an informed lens on how Ireland can approach the transition to a climate neutral economy.

Martin Corrigan,
Interim Chief Executive, EirGrid Plc

SONI Chief Executive's foreword

As Northern Ireland's Transmission System Operator, we welcome the opportunity to publish the 2023 edition of Tomorrow's Energy Scenarios.

The Energy Strategy published in 2021 and the passage of the Climate Change (Northern Ireland) Act 2022 marked seminal moments in Northern Ireland's decarbonisation journey.

As our work to deliver on Northern Ireland's near-term goals continues and intensifies, it is important we maintain our focus on realising our longer-term objective of achieving our climate objectives.

The last 50 years have seen a rapid increase in global temperatures. Significant social and economic change needs to occur for Northern Ireland to transition to a cleaner ecosystem based on renewables as well as meet Government targets.

This publication represents a significant body of work that explores the different pathways for delivering a cleaner, cheaper and more secure energy future. As a trusted adviser to government, we hope the analysis contained within Tomorrow's Energy Scenarios can support today's decision-makers with the formation and implementation of energy policy.

Exploring four distinct energy scenarios for enabling our transition to a decarbonised power system, this publication builds on our previous research and is a strong step forward in making tomorrow's targets a reality.

Undoubtedly, we face a number of short-term challenges in getting there.

Our research, detailed in this publication, shows that electricity demand will more than double by 2050. This is due to an increased reliance on electricity as we move away from oil, gas, petrol and diesel.

Furthermore, moving away from fossil fuels will require development that goes beyond the grid, with green hydrogen and other technologies playing a critical role as a clean, sustainable source of fuel to increase energy security.

Alan Campbell
Chief Executive,
SONI Ltd

Finally, as we become more reliant on renewable energy sources, we will need to employ innovative methods of energy storage as well as leverage our interconnection potential to ensure we maintain a safe, secure and reliable supply of electricity for consumers.

This research provides a clear breakdown of the issues as well as the identification of viable, well-researched routes that detail how we can attain our mission of a cleaner energy future for communities, farms and businesses across Northern Ireland.

Each scenario places a different emphasis on key elements such as interconnection and offshore wind as well as what would be required in terms of the development of new technologies. In doing so, we've outlined what would be required for each outcome, the benefits and the challenges.

An extensive process of consultation and engagement with the likes of industry, government and regulatory partners, system operators elsewhere, academia, has enabled us to further deepen our exploration of each scenario. We would like to thank all of the consultees for their contributions and for supporting the great deal of innovation and analysis that goes into this publication.

In summary, we hope you find Tomorrow's Energy Scenarios informative, proactive and thorough in supporting Northern Ireland's collective endeavour to meet our clean energy ambitions.

Alan Campbell,
Chief Executive, SONI Ltd

Contents

1. Executive summary

Welcome to the final 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 out to 2050. The report explains what this could mean for the electricity system supported by different technologies, including storage and interconnection.

The scenarios presented are mindful of the fact that in Ireland SEAI will report to the Department of the Environment, Climate and Communications on an evidence-based decarbonisation pathway for the electricity system to reach net zero. In Northern Ireland, legislation requires the introduction of carbon budgets and a Climate Action Plan to be published by June 2024. 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

Welcome to the Tomorrow's Energy Scenarios (TES) 2023 final report. The report outlines possible future pathways for the electricity system out to 2050. For TES 2023, we updated our scenarios to reflect developments in energy policy to consider how electricity demand may change and how generation and supply will need to respond with support from decarbonised technologies.

In autumn 2023, we held a consultation on our scenarios and initial analysis. We received a wide range of stakeholder feedback and we want to thank everyone who engaged with us and shared their insights as part of this process. Following the consultation, we reviewed and considered the feedback and subsequently carried out further sensitivity analysis for this final TES 2023 report.

Our TES 2023 scenarios 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 scenario sees a faster and larger development of offshore wind and results in the power system becoming a significant net electricity exporter through interconnection. Offshore Opportunity also shows a net zero power system from 2040.

Gas Evolution follows a steadier pace of 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 speed in development 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.

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 analysis shows 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. This is as per Ireland's Climate Action Plan 2023 targets and the Climate Change Act in Northern Ireland. With electricity increasingly being supplied from renewable sources, this will lead to a reduction in demand for fossil fuels. We also expect to see an overall increase in energy efficiency. However, meeting the increased demand for electricity, will mean we need to significantly develop our power system.

2. There will be an increasing need for efficiency and demand flexibility

In a renewables-dominated power system, demand will need to be sufficiently flexible to account for fluctuations in renewable generation. This means, when there is less energy available from natural sources such as wind or sun, we need ways of managing this, particularly during times of peak demand. Measures to improve energy efficiency and demand flexibility will be vital to help manage peak loads on the power system.

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

Achieving a net zero power system requires significant development of the entire electricity sector. This is because we will need to shift from a grid based around large fossil-fuel powered generators to a system led by renewables located across our island and our seas. Due to the complexities involved for the whole energy system, we expect this transformation to be achieved no earlier than 2040.

4. We will need a balanced portfolio of generation technologies, led by renewables and 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 increases in **electricity interconnection** to continental Europe and Great Britain.
- A massive growth of **energy storage capacity**, including short, medium and long duration forms of storage.
- 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 plants.

5. Renewable fuels, such as green hydrogen, offer an opportunity to reduce dependence on fossil fuel imports and support increasing energy security

As we move away from fossil fuels, green hydrogen has the potential to play an important future role in the power system, especially when supplies from wind and solar are not sufficient to meet electricity demand. Our green hydrogen dispatch modelling shows how we might incorporate green hydrogen – which is relatively new to the power system – via renewable generators, electrolysers (to extract hydrogen from water) and green hydrogen storage.

This is important because our analysis shows that the grid will need renewables to be supported by firm dispatchable low-carbon power generation. This is energy that can help balance electricity supply and demand and can be turned off when it is not required, for example, when there is sufficient wind or sun to meet our energy needs.

6. A whole energy system transition

SONI and EirGrid's team, who have led the development of TES 2023, have benefited from significant contributions from a number of key stakeholders in Northern Ireland and Ireland. Their support has been essential to the quality of the TES 2023 analysis and the insights we are able to draw. Consultation feedback emphasised the need for further strategic planning to consider critical interdependencies across the whole energy system. Future studies provide an opportunity for energy system stakeholders to collaborate in strategic planning for our energy transition.

Summary

Going forward, Tomorrow's Energy Scenarios 2023 provides a solid foundation to inform our planning for the energy transition in Ireland. We hope you find this report useful, and that our valuable insights can support decision makers in the development of current and future energy policy.

For EirGrid, the next stage is our System Needs Assessment (TESNA) which will follow in 2024. We will be using the results from TES 2023 and TESNA to shape our thinking about more detailed planning for the electricity system and what this means across our networks.

2. Introduction

Welcome to the final 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[1,2] 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[3], SONI and EirGrid have published a roadmap on the work which, subject to and in alignment with energy policy, 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 SONI's and EirGrid's technical research and modelling, each scenario considers how much electricity we might need and how it could be provided.

We will use the findings in this report to guide our technical assessments of the electricity system going forward, in determining what we need to prioritise to enable a sustainable and secure energy transition for Ireland and Northern Ireland. They will also enable SONI and EirGrid to continue to support Governments and Regulatory Authorities in the development of energy policy and market design development required to achieve net zero.

1 Climate Action Plan 2023
2 Climate Change Act (Northern Ireland) 2022
3 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, SONI and EirGrid 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 only 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 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[4] and Tomorrow's Energy Scenarios Northern Ireland 2020[5], 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.

In development of this report, we have considered policy change across many sectors with the aim of producing the most informed report possible.

4 Tomorrow's Energy Scenarios Ireland 2019
5 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. The grid is 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 located in areas of the island with relatively little demand, has increased the importance of transmission infrastructure and requires 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. SONI and EirGrid have 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. Key changes following consultation

3.1 Tomorrow's Energy Scenarios consultation

In November 2023, we published the TES 2023 consultation report outlining four draft scenarios for Ireland's and Northern Ireland's clean energy transition.

We received a comprehensive and wide range of feedback from stakeholders in Ireland and Northern Ireland. We want to thank everyone who took part and shared their insights and views on our consultation report. We have reviewed the feedback and used this to inform further sensitivity modelling and to update of our technical analysis.

The final results of our study for TES 2023 are provided in this report. We will also use this feedback to help shape future TES publications.

3.2 Summary

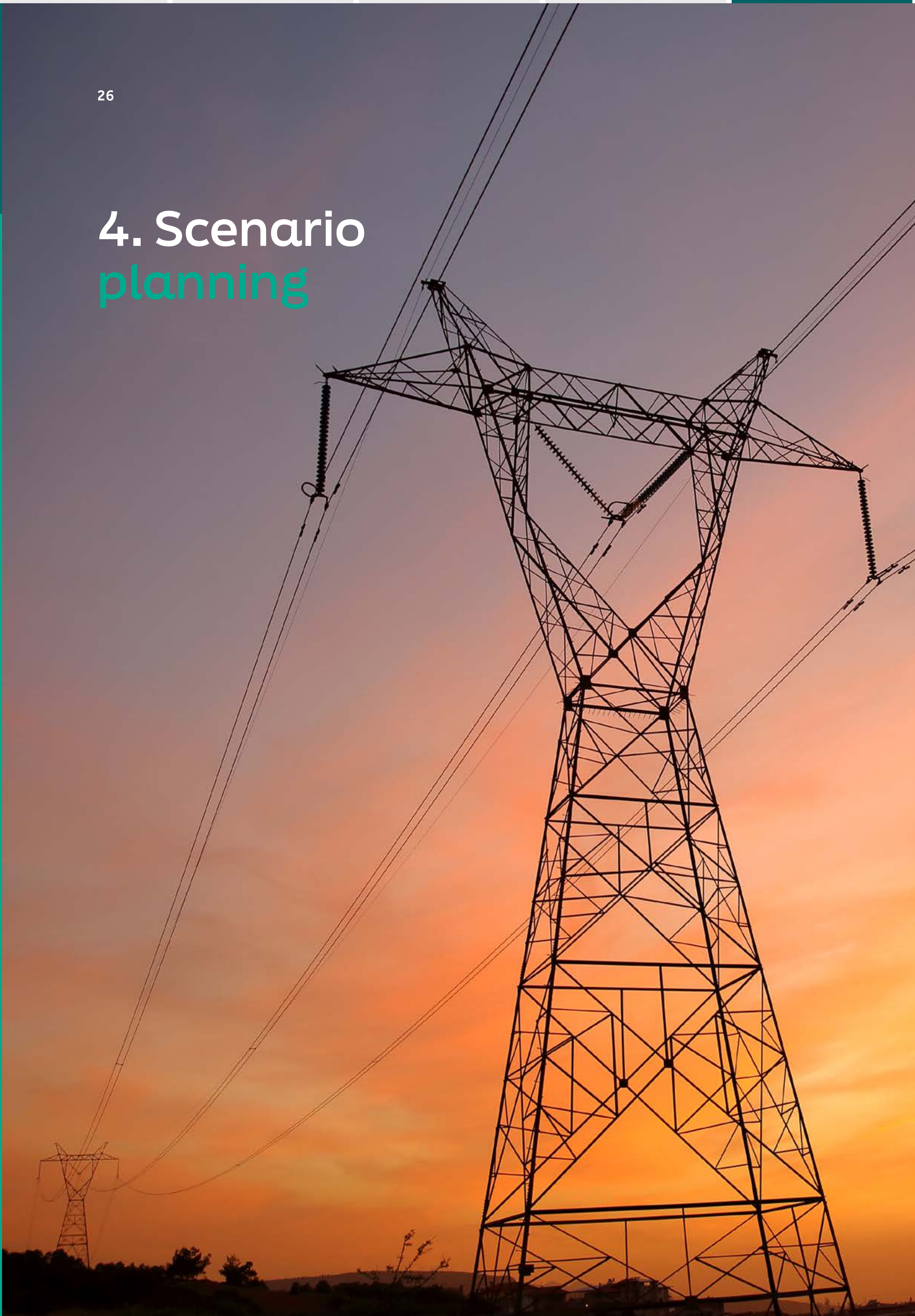
This final TES 2023 report contains additional information, which has been developed since the consultation, seeking to address stakeholder feedback received.

Table 1 below summarises the key changes to the scenarios, our analysis, assumptions and findings by report chapter.

Table 1: Summary of changes developed in TES 2023 following consultation

Theme	Section	Change
Hydrogen modelling	Section 5 & 7	To complement our electricity system modelling, we developed a model of hydrogen dispatch. This assesses for hydrogen supply, storage, and demand. Results are provided on an All-Island basis.
Demand assumptions	Section 6	The demand profile for heat pumps was updated to better reflect seasonality using climate profiles from 2009 as an average climate year.
Demand flexibility	Section 6.2.3 & 6.3.3	We have updated our approach to modelling for demand flexibility by increasing the number of hours over which flexible demands act but reducing the peak of their reduction capability in a single hour.
Electricity generation – generation capacity	Section 7.2 & 7.3	We have provided more information about our capacity and expansion assumptions for Great Britain and France in the report and accompanying Databook.
Electricity generation – CCS	Section 7.2, 7.3 & 7.8	The carbon capture rate applied for CCS candidates was adjusted to ~90%. CCS plant efficiency was also adjusted to account for additional energy requirement of emissions capture. This was done for both BECCS (relative to normal biomass) and gas CCS.
Dispatch down	Section 7.2.4 & 7.3.4	Pro-rata dispatch down has been applied within Ireland and Northern Ireland according to power availability in each jurisdiction.
Pace of transition	Appendix – 9.2	Sensitivities of Self-Sustaining and Offshore Opportunity scenarios were investigated in response to consultation feedback requesting analysis of power systems demonstrating net zero from 2035.

4. Scenario planning



SONI and EirGrid are responsible for planning 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 evolve in the future, given the long-term uncertainty over the economy and technological advancements. We then consider the common threads across the different scenarios studied, so the grid can be developed to accommodate a variety of possible futures.

4.1 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, with the expectation that the actual future outcome will take some elements from 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 final report represents Step 4 of the TES 2023 development process (see Figure 4.1 below).

4.2 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[6,7].

Future needs on the energy system are evolving quickly due to increasing focus on sustainability and climate change, affordability, energy security the opportunities provided by new clean low-carbon technologies. In this rapidly changing context, traditional linear predictions and analysis are insufficient for strategic long-term planning.

Scenario planning recognises that we cannot precisely predict the future. It 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.

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 required projects to be taken forward for development of the grid (please see Figure 4.1 on the next page).

6 EirGrid and SONI Group, Strategy 2020–25
7 SONI strategy-2025

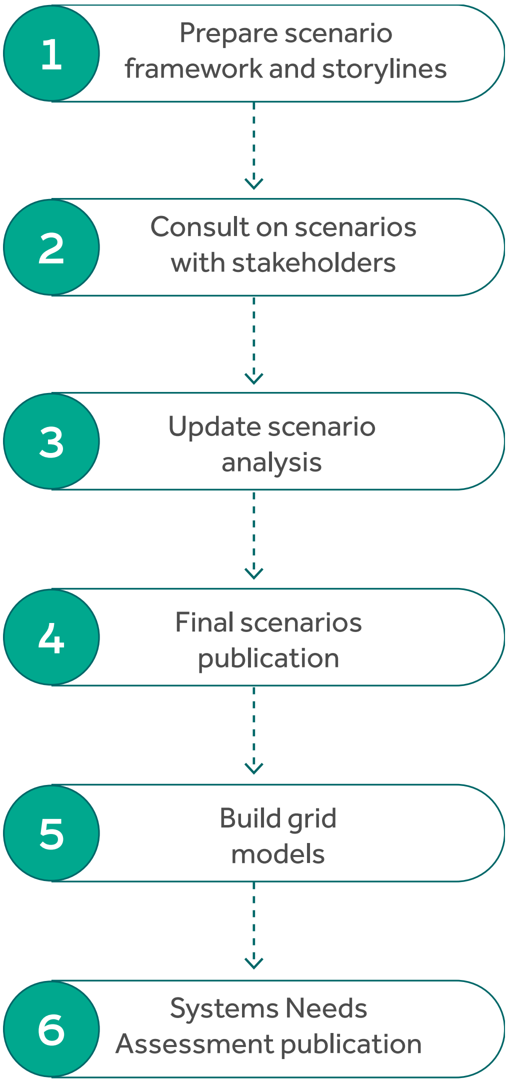


Figure 4.1: Overview of the TES 2023 development process

4.3 Related EirGrid and SONI publications

SONI and EirGrid regularly produce documents associated with the transmission system. TES and the following System Needs Assessment are strategic planning publications considering the long-term future development of the transmission system.

Shaping Our Electricity Future Roadmap Version 1.1[8] (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**[9] (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)[10]. In addition, the revised TEN-E Regulation (2022) requires member states to collaborate on the development of Offshore Network Development Plans. EirGrid and SONI have collaborated with other TSOs and ENTSO-E in support of the Offshore Network Development Plan (ONDP) 2024.

8 Shaping our Electricity Future Roadmap Version 1.1
9 TYNDP 2022 Scenario Report
10 European Commission, Projects of Common Interest

The **All-Island Generation Capacity Statement**[11] (GCS) is an annual report from SONI and EirGrid 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[12] (TYTFS) describes technical network data for Ireland and Northern Ireland, such as network configuration, parameters, and opportunities for connection.

The Transmission Development Plan[13] (TDP) is a statutory document covering a 10-year period which details the investment needs and drivers for grid development. It describes the projects currently progressing through the EirGrid Grid Development Framework as well as candidate solutions identified by studies such as Shaping Our Electricity Future. The TDP also encompasses projects that are currently under development or assessment, aimed at achieving the targets outlined in the Government's Climate Action Plan.

4.4 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[14] in Ireland, with the remainder split reasonably evenly between heat and transport. In Northern Ireland, the value was around 14%[15].

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 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.

11 All-Island Generation Capacity Statement
12 All-Island Ten Year Transmission Forecast Statement (2021)
13 Transmission Development Plan 2023-2032
14 2022 National Energy Balance
15 Energy in Northern Ireland 2022

4.4.1 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.

4.4.2 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.

Domestic and international energy policy is anticipated to continue to evolve to meet the needs of the energy security, affordability, and sustainability. During development of TES 2023, Ireland has recently consulted on and published policies for increasing electricity interconnection with neighbouring countries[16] and the National Hydrogen Strategy[17].

DECC published the Offshore Renewable Energy Future Framework Policy in May 2024, outlining actions within the offshore renewable sector to support Ireland's journey to a net zero transition. This includes publication of an Offshore Transmission Strategy later in 2024. These policy papers sit within the context of the draft National Energy & Climate Plan and National Adaptation Framework, both recently consulted upon.

16 National Policy Statement on Electricity Interconnection 2023
17 National Hydrogen Strategy 2023

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.

4.4.3 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.

4.4.4 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 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 requires that Northern Ireland publish a Climate Action Plan by June 2024[18].

18 DAERA consulted on carbon budgets for Northern Ireland in 2023

4.5 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 of the wider economy.

We now need to plan for an electricity system that can deliver a power system with 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.

SONI and EirGrid 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, subject to and in alignment with government policies and targets. Cost assessment is not included in the scope of TES 2023 and our analysis of the scenarios. Working with government and regulators, cost and benefits assessment will be considered as part of future transmission grid development planning informed by TES 2023.

5. Scenario framework

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 consider the uncertainty around factors such as demand electrification, the timelines for building 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. The study horizon is out to 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.

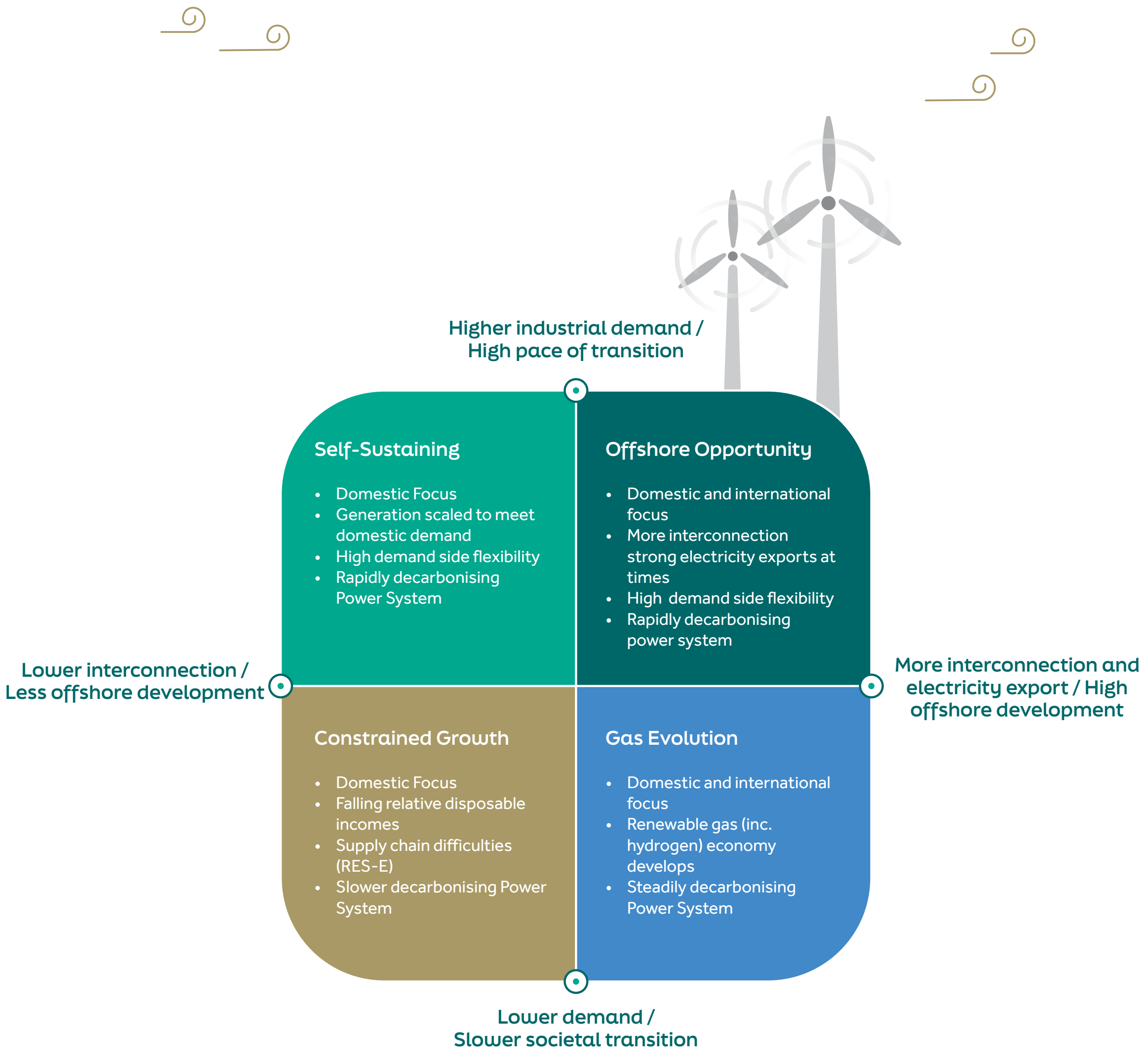


Figure 5.1: TES 2023 scenarios

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.

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 is 2050.

Offshore Opportunity

Offshore Opportunity is similar to Self-Sustaining, where 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 renewable generation 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.

Please note: in line with some consultation feedback, assessment of a faster pace of power sector decarbonisation has been undertaken. The results from two sensitivities of our faster decarbonising scenarios are included in Appendix 9.2 which show a net zero power system from 2035.

5.1 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.

As shown in Figure 5.1, for TES 2023 we developed our scenario framework around two axes. This was chosen to reflect the pace of transition (vertical axis) and increasing levels of offshore development including interconnection (horizontal axis).

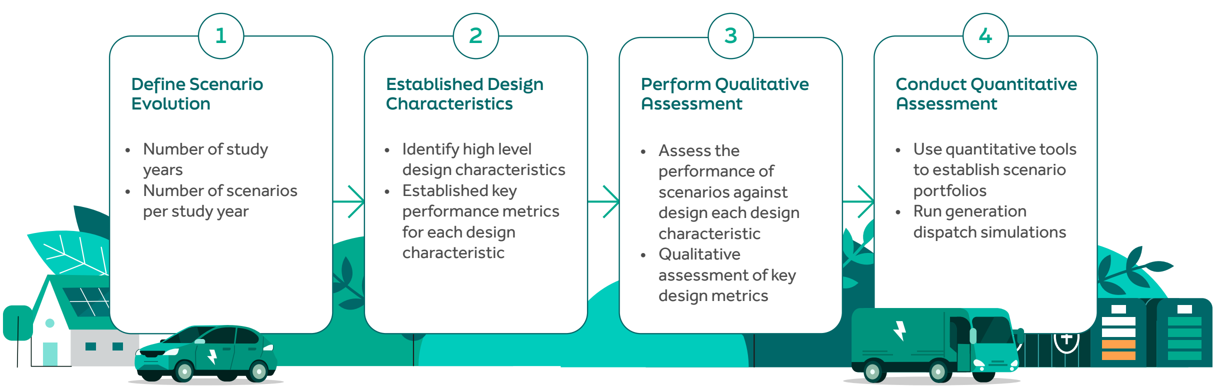


Figure 5.2: TES scenario building process

5.2 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 for Ireland and Northern Ireland. For the study horizon, demand 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 the different technologies and their characteristics are available for the model to choose from[19].

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. 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 narratives 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.

Over the study horizon, the model takes one-hourly intervals every day to determine the most appropriate dispatch and build-out of generation that meets the constraints and emission limits that we have set in each scenario.

19 TYNDP 2022 Scenarios Report

5.3 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.

Our modelling includes the potential use of negative emissions technology – bioenergy with CCS – where carbon neutral biofuels are supplemented with CCS to become a net absorber of CO_2. In addition to long and short duration batteries, we also assume pumped storage at Turlough Hill is available and the proposed pumped storage unit at Silvermines is developed. 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 findings from the analysis should be considered from this perspective.

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 2022 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 optimises Ireland and Northern Ireland with their 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.

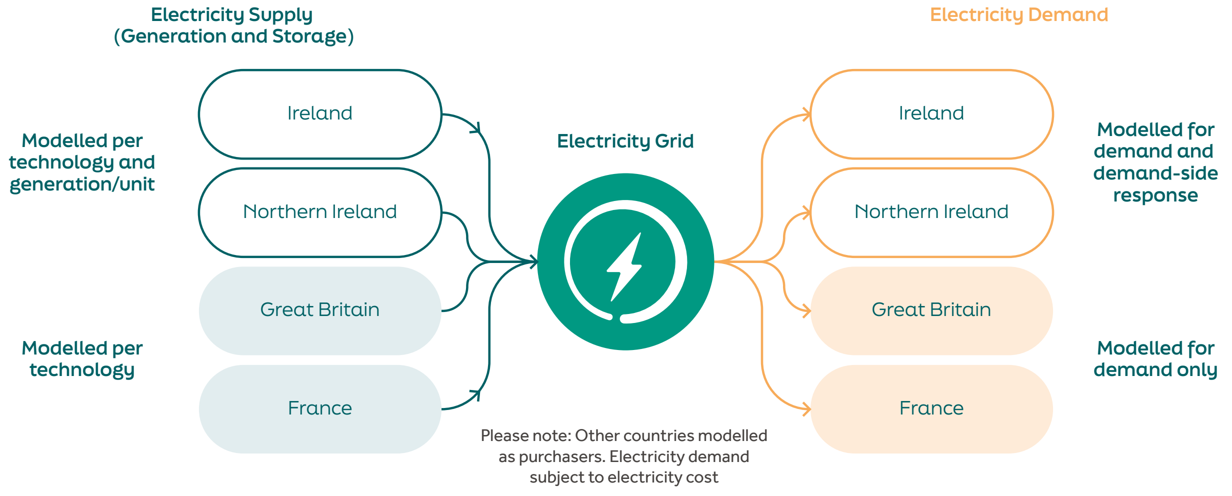


Figure 5.3 – Electricity model framework

Hydrogen model

In the final TES analysis, we have included more detailed assessment of the potential role that green hydrogen could play as part of the future electricity system. The structure of the model is shown below in Figure 5.4. In line with the electricity modelling, our assessment of hydrogen is based on capacity expansion modelling which optimises across renewable generators, electrolysers and storage.

Our hydrogen modelling also considers the potential for surplus renewable energy – the volumes of which are taken from our electricity modelling to power electrolysers.

In developing the hydrogen modelling we engaged with GNI and Mutual Energy as Gas System Operators to develop our modelling assumptions.

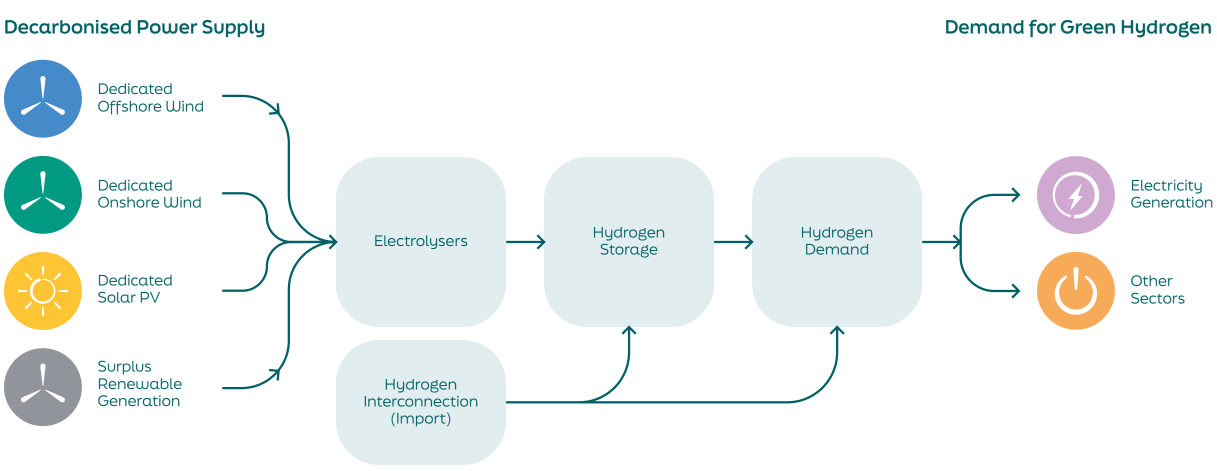


Figure 5.4 – Green Hydrogen Model Framework

Hydrogen demand

It is anticipated that demand for hydrogen will not develop until potential off-takers can be confident that a reliable supply will be available to meet their demand requirements.

Demand requirements for hydrogen will vary by sector. Our modelling for hydrogen is informed by power sector demands from our electricity model.

These show highly variable demands that peak in the winter when electricity demand is higher.

In other sectors, such as industry and transport, demand is anticipated to be more stable and predictable. Our scenarios include an assessment of hydrogen demand across each sector.

Our dispatch model is asked to meet hydrogen demand on a weekly basis, i.e., it must balance supply and demand over each week of the year as opposed to each day or hour. This level of granularity is appropriate given the potential of flexibilities in the hydrogen system such as demand side storage and line packing.

Hydrogen storage and import

As a fuel, balancing supply and demand for green hydrogen will require storage and transmission infrastructure. For this study, storage infrastructure has been considered (salt caverns and tanks) as well as potential for import via repurposed gas interconnectors that link the island of Ireland and Great Britain.

Interconnectors can provide security of hydrogen supply should there be an unexpected and significant issue affecting domestic hydrogen production. While hydrogen interconnector(s) would likely also provide capability to export hydrogen, this has not been modelled in this study due to limitations in the data required to model external hydrogen markets.

Hydrogen Import – repurposing existing gas interconnectors

The island of Ireland is linked to Great Britain via two gas interconnectors (IC1 and IC2). With the energy transition away from fossil fuels, repurposing of existing gas infrastructure is being explored by policymakers and gas sector stakeholders[20], Repurposing of the interconnectors are significant projects and these need to be planned carefully considering whole system costs and benefits. This should include an assessment of impacts on sectors that rely on natural gas supply to meet their energy needs.

Our modelling for hydrogen includes for repurposing of existing natural gas interconnection between Great Britain and the island of Ireland. In discussion with Gas System Operators the following assumptions have been developed for the sole purpose of TES 2023 modelling:

1. Capacity of a repurposed IC1 to flow hydrogen would be 6GW.
2. Capacity of a repurposed IC2 to flow hydrogen would be 12GW.

Recognising this, our scenario modelling has included the following dates for availability of the repurposed interconnectors:

	IC1 (6GW)	IC2 (12GW)
Self Sustaining	2037	–
Offshore Opportunity	2037	–
Gas Evolution	2035	2045

Please note that no hydrogen assessment has been included for the Constrained Growth scenario.

Provision of interconnection capacity reduces the potential need for hydrogen production and storage infrastructure to be built on the island of Ireland in the short term.

Hydrogen production – electrolysis

For Ireland and Northern Ireland, domestic production of hydrogen is planned via electrolysers powered by renewable energy.

20 European Hydrogen Backbone 2022

5.4 Limitations of TES modelling

While the findings from TES 2023 are important, it is necessary to recognise some 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 2022 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

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.

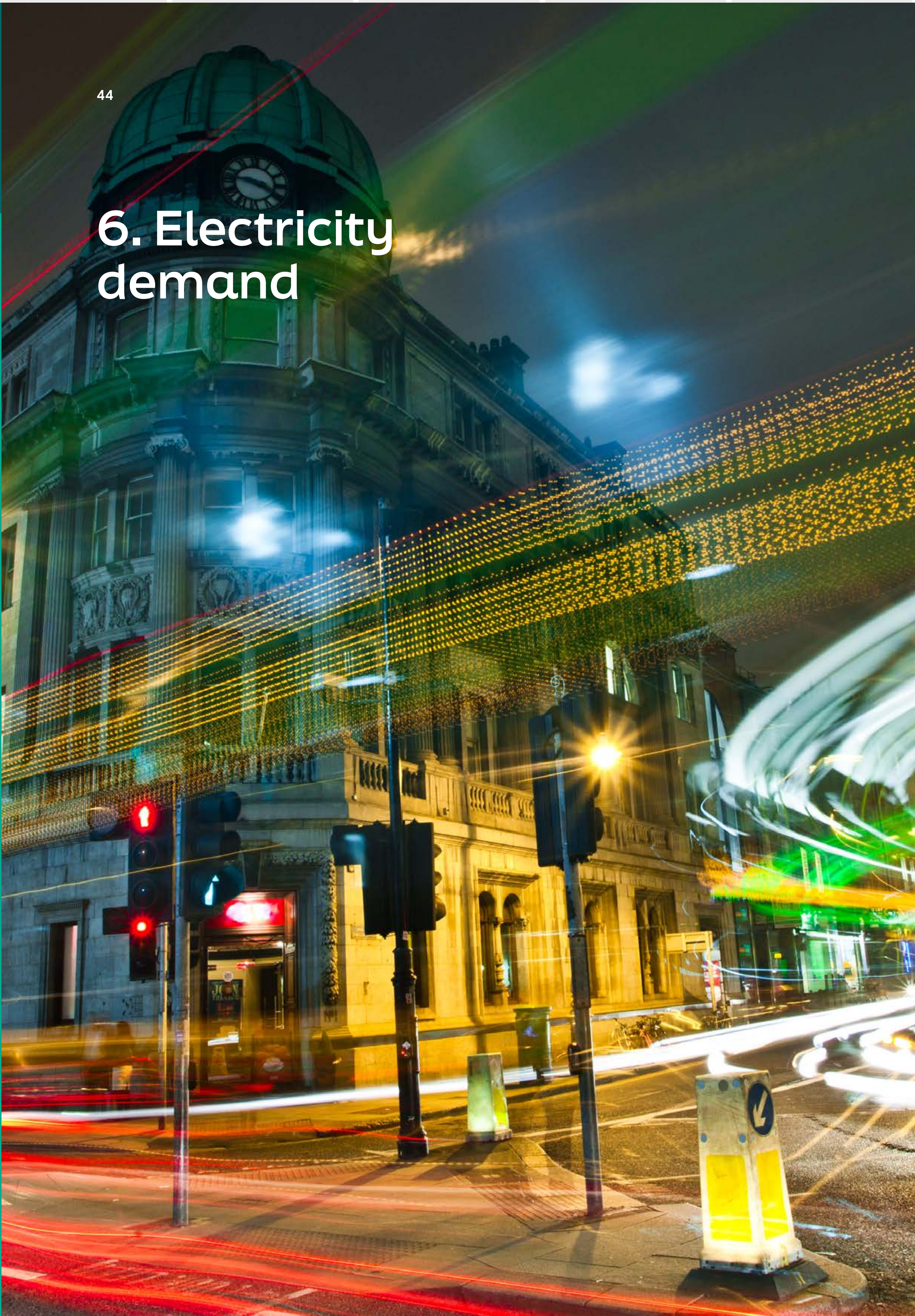
Natural gas and hydrogen

Natural gas, currently provides a key resource to meet the needs of consumers in Ireland and Northern Ireland. The energy transition away from fossil fuels will lead to consumer demand for natural gas shifting to other fuels – including electricity and potentially renewable gases such as green hydrogen. The wider implications for the natural gas system have not been considered as part of the scope of this study. It is recommended that further analysis of the energy transition for the gas system be carried out.

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 change some of our assumptions and analysis. These changes and limitations noted above may be considered in future technical studies.

6. Electricity demand



Key insights

TES 2023 analysis shows 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. This is as per Ireland's Climate Action Plan 2023 targets and the Climate Change Act in Northern Ireland. With electricity increasingly being supplied from renewable sources, this will lead to a reduction in demand for fossil fuels. We also expect to see an overall increase in energy efficiency. However, meeting the increased demand for electricity, will mean we need to significantly develop our power system.

There will be an increasing need for efficiency and demand flexibility

In a renewables-dominated power system, demand will need to be sufficiently flexible to account for fluctuations in renewable generation. This means, when there is less energy available from natural sources such as wind or sun, we need ways of managing this, particularly during times of peak demand. Measures to improve energy efficiency and demand flexibility will be vital to help manage peak loads on the power system.

A key input into TES 2023 is the forecast of future electrical demand throughout the study period. The first part of this section covers Ireland's electrical demand, with the second section covering Northern Ireland's electrical demand.

6.1 Introduction

The demand growth assumption in TES 2023 is consistent with European scenario studies such as the TYNDP 2022. This is due to several factors, the most important factor being the increased government targets and ambitions on decarbonising energy generation and demand 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 will add 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. The rate of decarbonisation in each scenario is a key driver in the rate of increase of electricity demand seen in the analysis.

6.2 Demand forecast Ireland

Electricity demand is forecasted to significantly increase by 2050, ranging from 72 TWh to 86 TWh[21]. 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 6.1. Growth rates take account of economic factors and personal consumption rates and have been informed by assumptions considered previously for the GCS[22]. 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 6.2.3 Demand flexibility and Energy Efficiency).

21 Please note that these figures do not include for the provision of reserves that will be required.
22 Generation Capacity Statement 2023–2032

The forecasted population growth used in TES is based on the Central Statistics Office's Population and Labour Force Projections 2017 – 2051[23]. 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 significantly increase year on year. Thus, overall growth in residential demand is anticipated to outweigh energy efficiency improvements.

Table 6.1: Per annum electricity demand 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%

23 Population and Labour Force Projections 2017 – 2051

6.2.1 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, the installed capacity from self-consumption is optimised by scenario, therefore micro generation is an output of the TES 2023 model.

Figure 6.1 illustrates how demand is built up from various components[24]. 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. Electricity demand for electrolysers is not included in the TER. Please refer to Section 7.5.

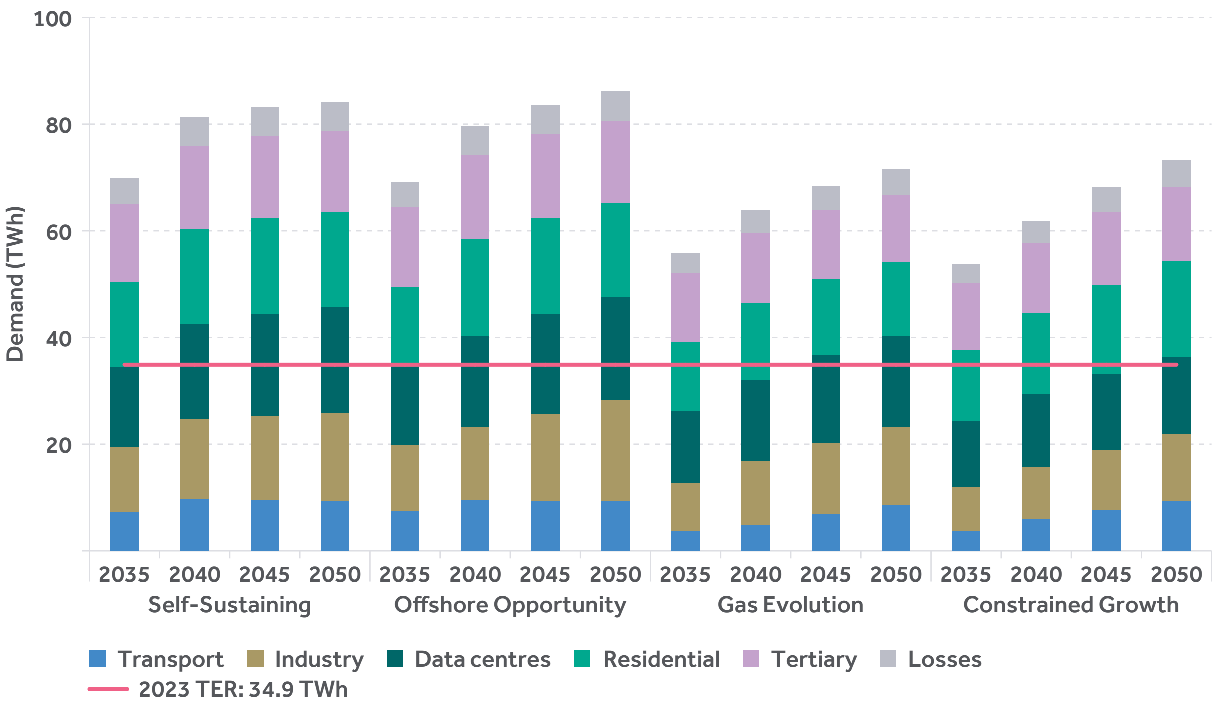


Figure 6.1: Annual Total Electricity Requirement (IE)

24 Figures do not include the provision of reserves modelled as a fixed load of 4.6 TWh.

6.2.2 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. 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 6.2 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 Self-Sustaining, and is driven by rapid electrification of the heating and the transportation sectors.

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 red line on the graph indicates the 2023 peak demand in Ireland.

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 6.2.3.

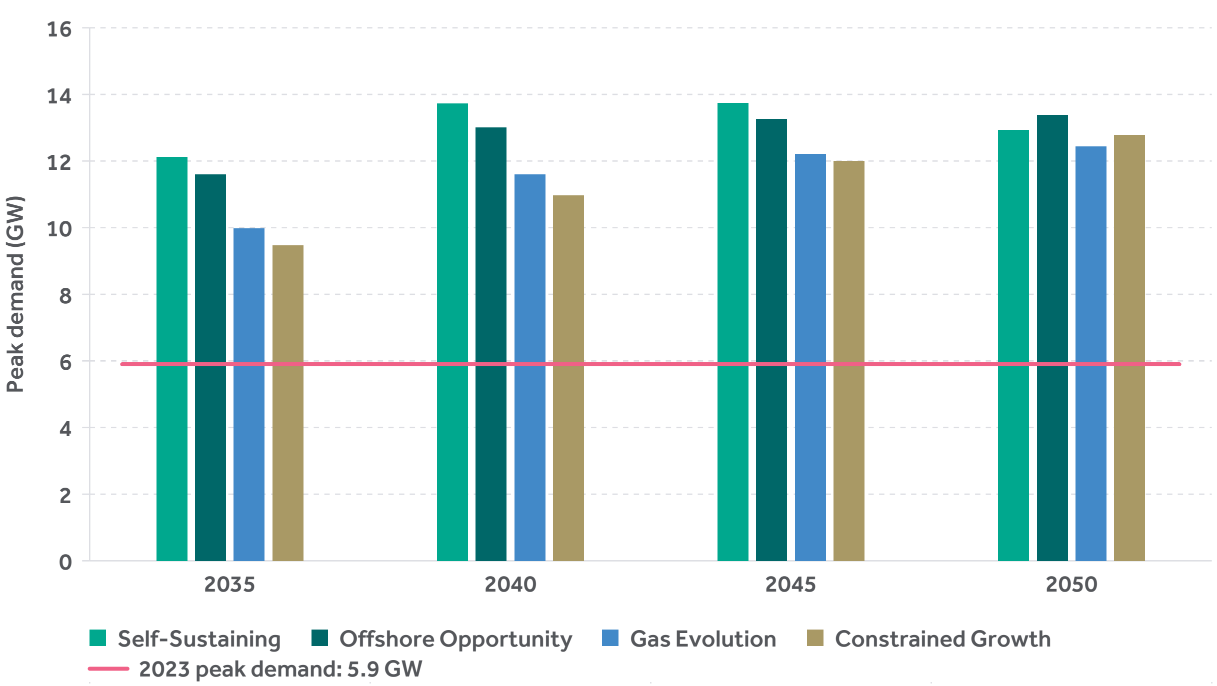


Figure 6.2: Forecasted peak demand (the red line on the graph indicates the 2023 peak demand in Ireland)

6.2.3 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 a 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, the heat pump demand profile is designed to reflect seasonality. In addition, efficiency savings with improved Building Energy Ratings (BERs) from new builds and retrofits have also been considered.
- 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 6.2.5.
- While challenges exist to enable high adoption of vehicle-to-grid and demand-side storage in the future, they will be important to make the grid more flexible. Enabling demand flexibility outcomes will involve the take-up of new technologies and complementary demand behaviours. Policymakers, regulators, the energy industry and consumers will all play important roles. Our scenarios include assumptions for adoption and application of these demand-side storage technologies. This allows demand-side storage to 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 centres and New Tech Load (NTL) demand.[25]

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:

Table 6.2: Demand flexibility potential

	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
Demand Side Units (DSU)	1,200	1,200	1,200	1,200
Vehicle to Grid (V2G) and demand Side Storage	3,190	3,190	1,130	240
Total	**5,460**	**5,280**	**2,850**	**2,110**

25 Please note that Climate Action Plan and the emerging National Energy Demand Strategy include objectives to increase the flexibility of electricity demand from data centres and NTL.

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 4.4 Energy and climate policy).

Table 6.3 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 6.3: 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%

6.2.4 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.

Electricity demand from heat pumps was calculated from consideration of overall heating demand per year and the projected percentage of residential and tertiary properties and industrial facilities 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 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 6.4. These COP assumptions were based on the SEAI National Heat Study Low Carbon Heating and Cooling Technologies Report[26], with rates of technological improvement assumed to be consistent across Ireland and Northern Ireland. Note that these improvements occur primarily between 2022 and 2030. The COP for heat pumps has been assumed to be the same throughout the year, it is not based on seasonal temperature shifts.

Table 6.4: Heat pump Coefficient of Performance (COP)

Heat pump	COP
Air source	2.6
Ground source	2.94

26 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. The heat pump demand profile is designed to reflect seasonal changes over the year. This provided a forecast of electrical heat pump demand in TWh.

Figure 6.3 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 6.3 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.

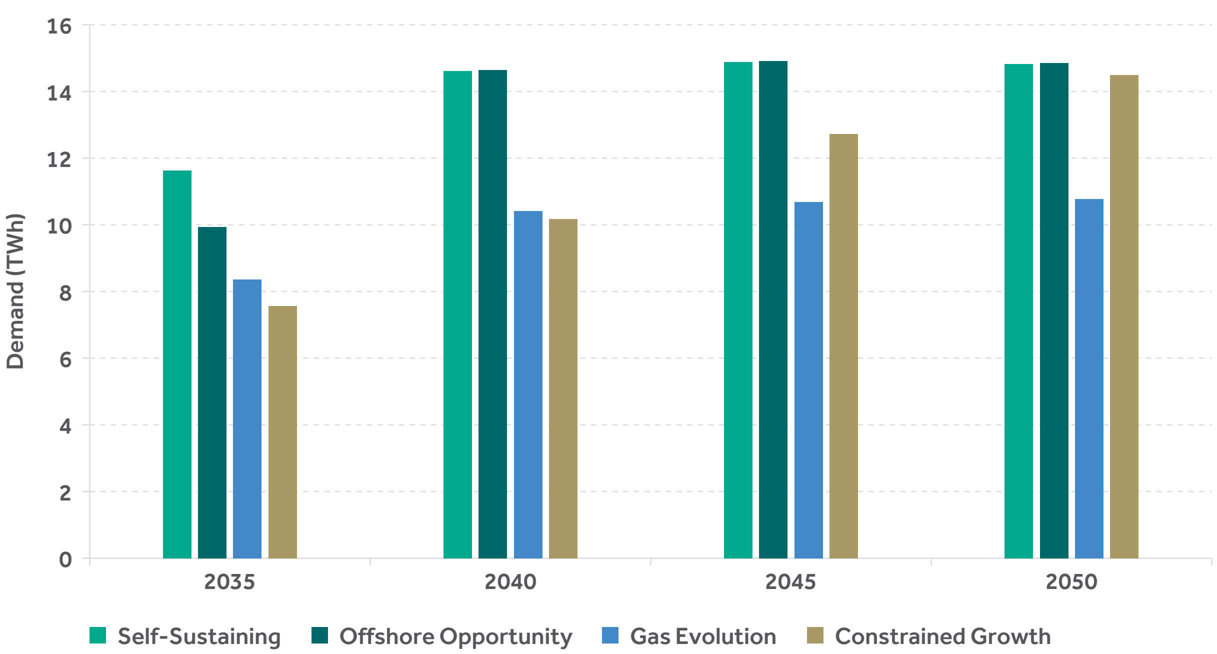


Figure 6.3: Overall heat pump electrical demand (IE)

6.2.5 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 6.4.

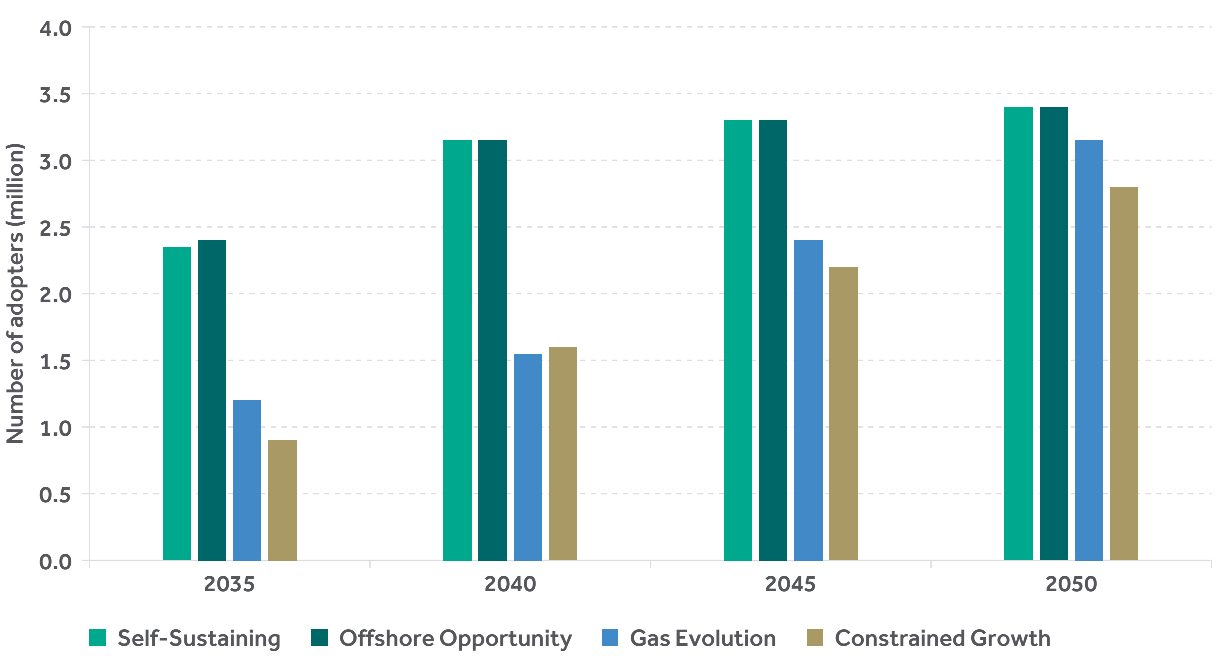


Figure 6.4: Projected number of EVs (IE)

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

Table 6.5: 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 6.6. 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 6.6: 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%

6.2.6 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[27]. The current trends in electrical industrial demand remain steady with no significant increase.

However, due to the increasing climate ambitions of the Irish government[28], the percentage of electricity that supplies industrial demand is set to rise as more industrial processes are decarbonised and electrified.

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

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, Large Energy Users (LEUs) and New Technology Loads (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.

It is recognised that this area is changing quickly with the growth of technologies such as Artificial Intelligence (AI). AI and other emerging new technologies may lead to additional demands that are not possible to accurately forecast over extended time horizons. For the purposes of scenario planning, allowances have been included and these can be kept under review for future scenario assessments, strategic planning studies and alignment with developing policy.

6.3 Demand forecast Northern Ireland

Electricity demand in Northern Ireland is forecasted to significantly increase by 2050, ranging from 21 TWh 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 6.7. Growth rates take account of economic factors and personal consumption rates and have been informed by assumptions considered previously for the GCS[29].

29 Generation Capacity Statement 2023–2032

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 6.2.3 Demand Flexibility and Energy Efficiency).

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[30]. These projections were used to forecast a slight overall rise in population from 1.90 million in 2021 to 1.93 million by 2050.

Table 6.7: Per annum electricity demand 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%

30 2021 Census

6.3.1 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, the installed capacity from self-consumption is optimised by scenario, therefore micro generation is part of the output.

Figure 6.5 below illustrates how the TER for Northern Ireland's demand is built up from the various components in keystone years over the study horizon[31]. 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. Electricity demand for electrolysers is not included in the TER. Please refer to Section 7.5.

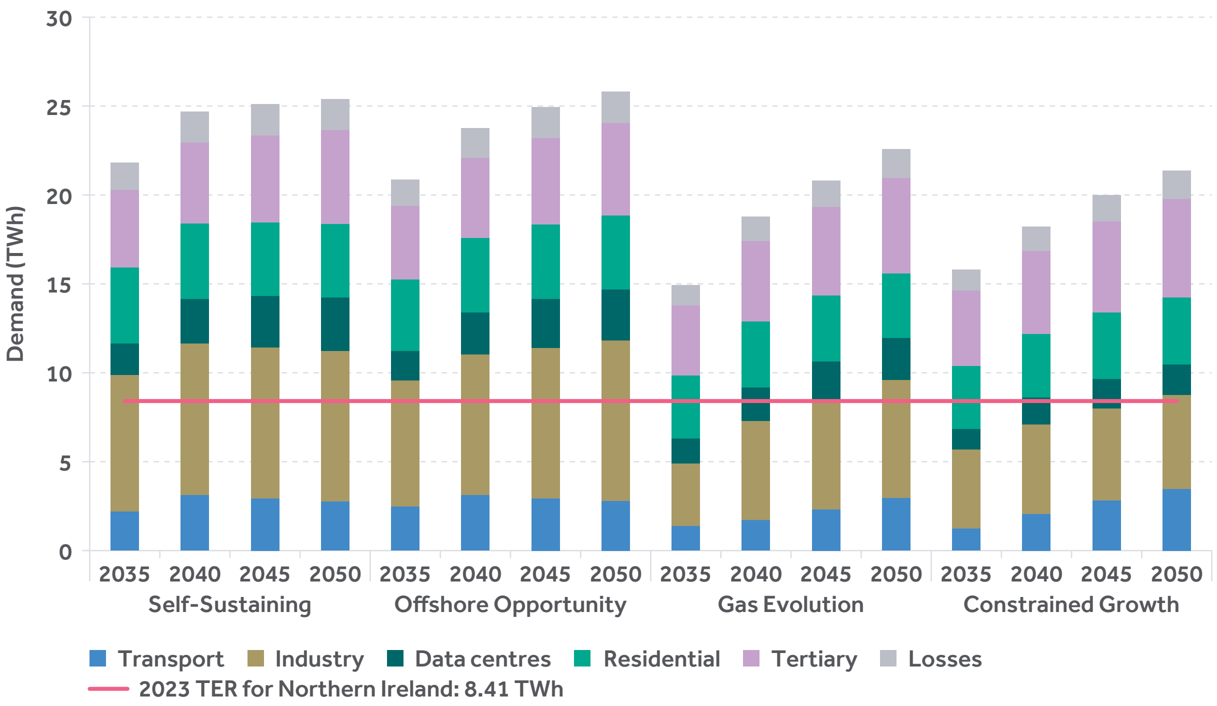


Figure 6.5: Annual Total Electricity Requirement (NI)

31 Figures do not include the provision of reserves modelled as a fixed load of 1.5 TWh.

6.3.2 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. 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. 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 6.6 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 Self-Sustaining, and is driven by rapid electrification of the heating and the transportation sectors. 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 red line on the graph in Figure 6.6 indicates the 2023 peak demand in Northern Ireland.

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 6.3.3.

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 Self-Sustaining scenario.

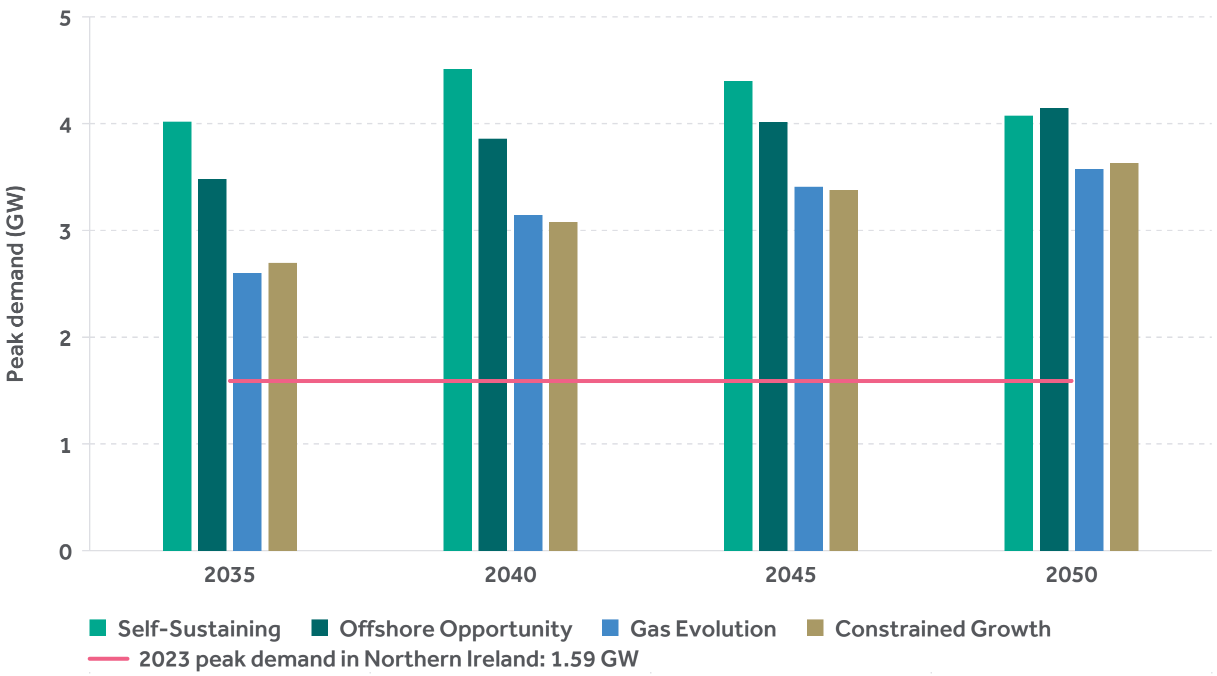


Figure 6.6: Forecasted peak demand (the red line on the graph indicates the 2023 peak demand in Northern Ireland)

6.3.3 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 6.3.5.
- 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 New Technology 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:

Table 6.8: Demand Flexibility potential for Northern Ireland

	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
Demand Side Units (DSU)	380	380	380	380
Vehicle to Grid (V2G) and Demand Side Storage	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 6.9 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 and behavioural change.

Table 6.9: 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 Northern Ireland Department for the Economy intend to develop a plan for the rollout of electricity smart meters and systems, following a cost benefit analysis conducted in late 2022.[32]

Assuming 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.

32 Smart meters update, Department for the Economy Northern Ireland

6.3.4 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 and industrial facilities 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 6.10. These COP assumptions were based on the SEAI National Heat Study Low Carbon Heating and Cooling Technologies Report[33], with rates of technological improvement assumed to be consistent across Ireland and Northern Ireland. Note that these improvements occur primarily between 2022 and 2030. The COP for heat pumps has been assumed to be the same throughout the year, it is not based on seasonal temperature shifts.

Table 6.10: Air- and ground-source heat pump COP

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

33 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. The heat pump demand profile is designed to reflect seasonal changes over the year. This provided a forecast of electrical heat pump demand in TWh.

Figure 6.7 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 6.7 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.

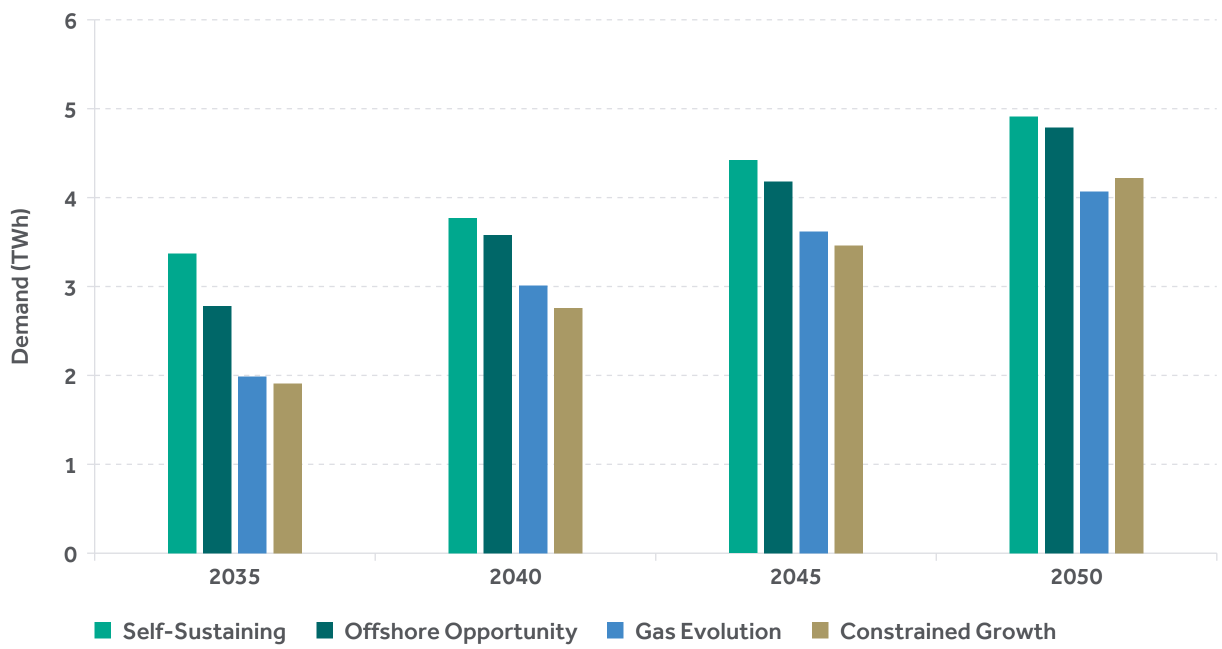


Figure 6.7: Overall heat pump electrical demand (NI)

6.3.5 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 6.8.

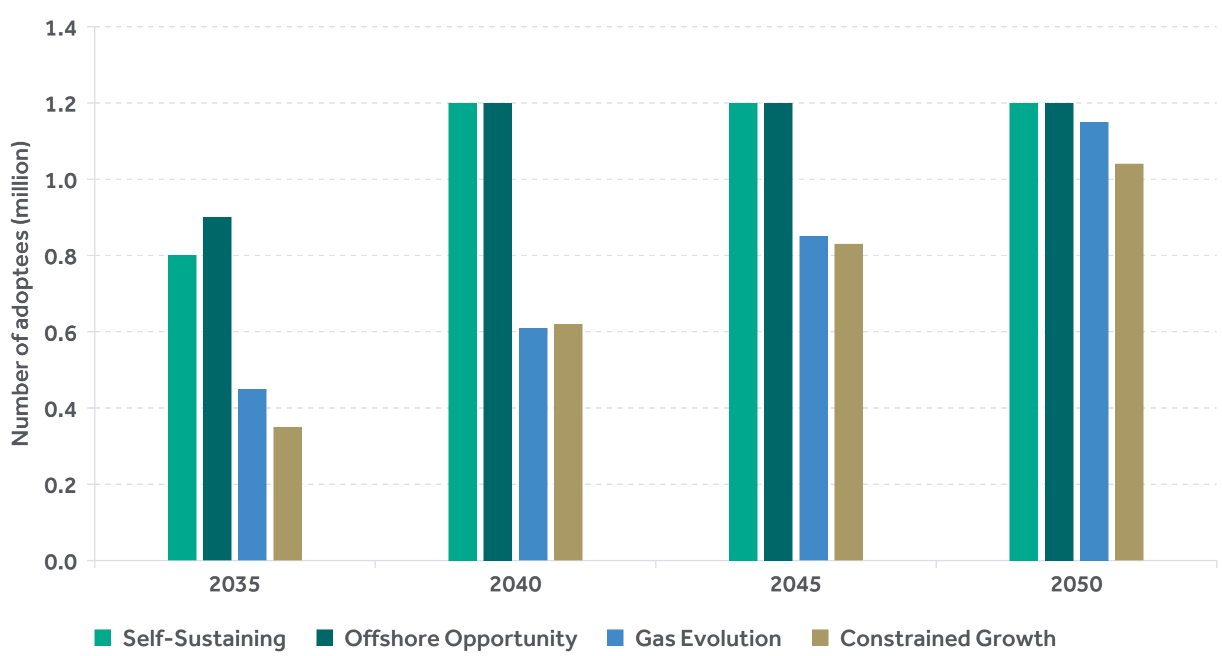


Figure 6.8: Projected number of EVs (NI)

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 6.11 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 6.11: 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 6.12. 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 6.12: 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%

6.3.6 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[34], 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.

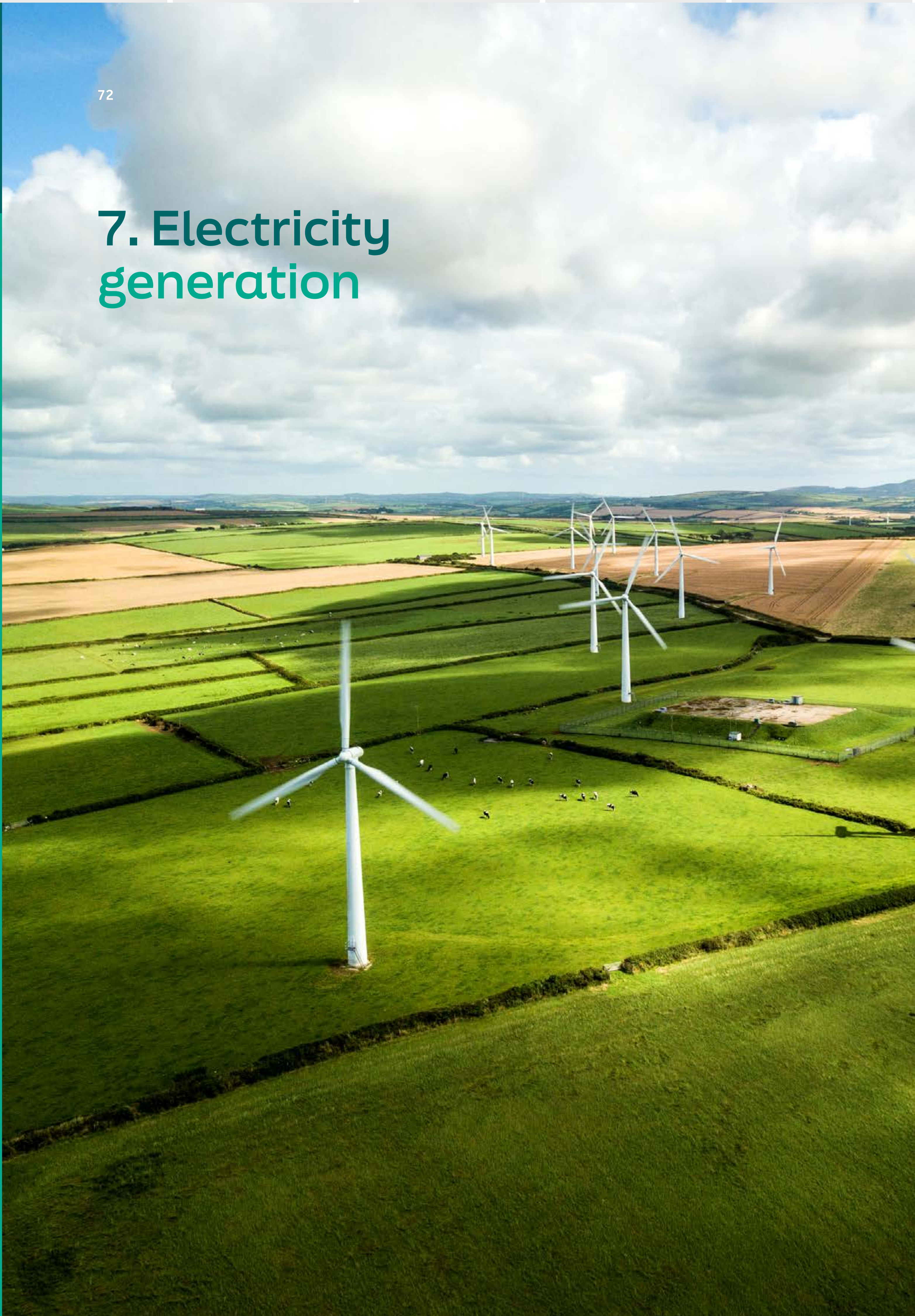
34 Tomorrow's Energy Scenarios Northern Ireland 2020, SONI

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, Large Energy Users (LEUs) and New Technology Loads (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.

7. Electricity generation



Key insights

We will need a balanced portfolio of generation technologies, led by renewables and 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 increases in electricity interconnection to continental Europe and Great Britain.
- A massive growth of energy storage capacity, including short, medium and long duration forms of storage.
- 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 plants.

Renewable fuels, such as green hydrogen, offer an opportunity to reduce dependence on fossil fuel imports and support increasing energy security

As we move away from fossil fuels, green hydrogen has the potential to play an important future role in the power system, especially when supplies from wind and solar are not sufficient to meet electricity demand. Our green hydrogen dispatch modelling shows how we might incorporate green hydrogen – which is relatively new to the power system – via renewable generators, electrolysers (to extract hydrogen from water) and green hydrogen storage. This is important because our analysis shows that the grid will need renewables to be supported by firm dispatchable low-carbon power generation. This is energy that can help balance electricity supply and demand and can be turned off when it is not required, for example, when there is sufficient wind or sun to meet our energy needs.

A whole energy system transition

SONI and EirGrid's team, who have led the development of TES 2023, have benefited from significant contributions from a number of key stakeholders in Northern Ireland and Ireland. Their support has been essential to the quality of the TES 2023 analysis and the insights we are able to draw. Consultation feedback emphasised the need for further strategic planning to consider critical interdependencies across the whole energy system. Future studies provide an opportunity for energy system stakeholders to collaborate in strategic planning for our energy transition.

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 as the power sector decarbonises.

7.1 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 CCS (Carbon Capture and Storage). A key enabler of achieving a net zero power system is the introduction of these technologies at scale.

7.1.1 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.

Costs for each technology are sourced from TYNDP 2022, a study carried out by ENTSO-E and ENTSO-G[35] and supplemented by the Australian Energy Market Operator (AEMO) Integrated System Plan 2022[36] and further European Commission reports on energy sector technology costs[37].

Table 7.1: IE 2022, 2030 and scenario installed generation capacities (all figures in MW)

Generation type	2022 capacity	SS 2030	OO 2030	CG 2030	GE 2030
Solar PV	167	8,000	8,000	5,090	5,090
Onshore wind	4,480	9,000	9,000	6,729	6,729
Offshore wind	25	5,000	5,000	2,015	5,000
Gas	4,636	5,906	5,906	5,906	5,906

Table 7.2: NI 2022, 2030 and scenario installed generation capacities (all figures in MW)

Generation type	2022 capacity	SS 2030	OO 2030	CG 2030	GE 2030
Solar PV	285	914	914	428	428
Onshore wind	1,430	2,458	2,458	1,902	1,902
Offshore wind	0	500	500	500	500
Gas	1,013	2,151	2,151	2,151	2,151

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.

As noted in Section 5, we have also developed a hydrogen dispatch model that is linked to our electricity model.

35 TYNDP 2022 Scenario Report
36 AEMO | 2022 ISP inputs, assumptions and scenarios
37 Technology pathways in decarbonisation scenarios – Publications Office of the EU (europa.eu)

7.1.2 Structure of this section

Section 7.2 summarises the installed capacity for Ireland in each scenario and Section 7.3 provides the same report for Northern Ireland.

Section 7.4 presents our findings for electricity interconnection between Ireland and Northern Ireland with Great Britain and Continental Europe.

Section 7.5 presents our results for the development of green hydrogen capacity to complement and support the electricity sector. These are presented on an all-island basis and include for renewable generators dedicated to powering electrolysers supported by surplus renewable generation available from the grid.

Sections 7.6 and 7.7 explain 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 7.8 summarises the results of our analysis in terms of carbon emissions reductions.

7.2 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 7.2.1–7.2.4).
- Energy Storage (Subsection7.2.5).
- Flexible thermal generation technology such as natural gas, hydrogen, and biomass (Subsection 7.2.6–7.2.9 and section 7.5).
- Electricity Interconnection (Section 7.4).

7.2.1 Onshore wind

Since 2000, over 4.5 GW of onshore wind generation has been installed in Ireland[38]. 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 of total installed capacity was used.

Figure 7.1 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 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.

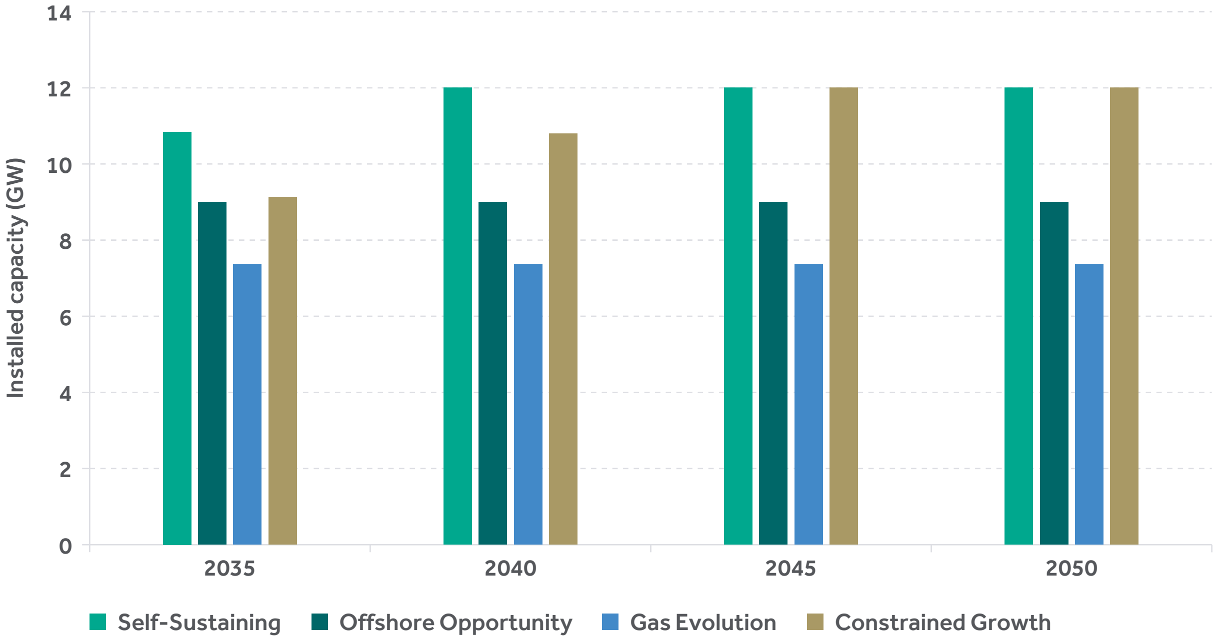


Figure 7.1: Installed onshore wind capacity (IE)

38 EirGrid and SONI Group, System and Renewable Data

7.2.2 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 gigawatts 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 in development 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 North Seas Energy Cooperation (NSEC), Ireland has agreed non-binding targets for further development of offshore renewable generation of up to 37 GW[39]. 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 (Section 7.4).

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.

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, which results in offshore wind being directed more towards hydrogen production.

39 Joint Statement on the North Seas Energy Cooperation

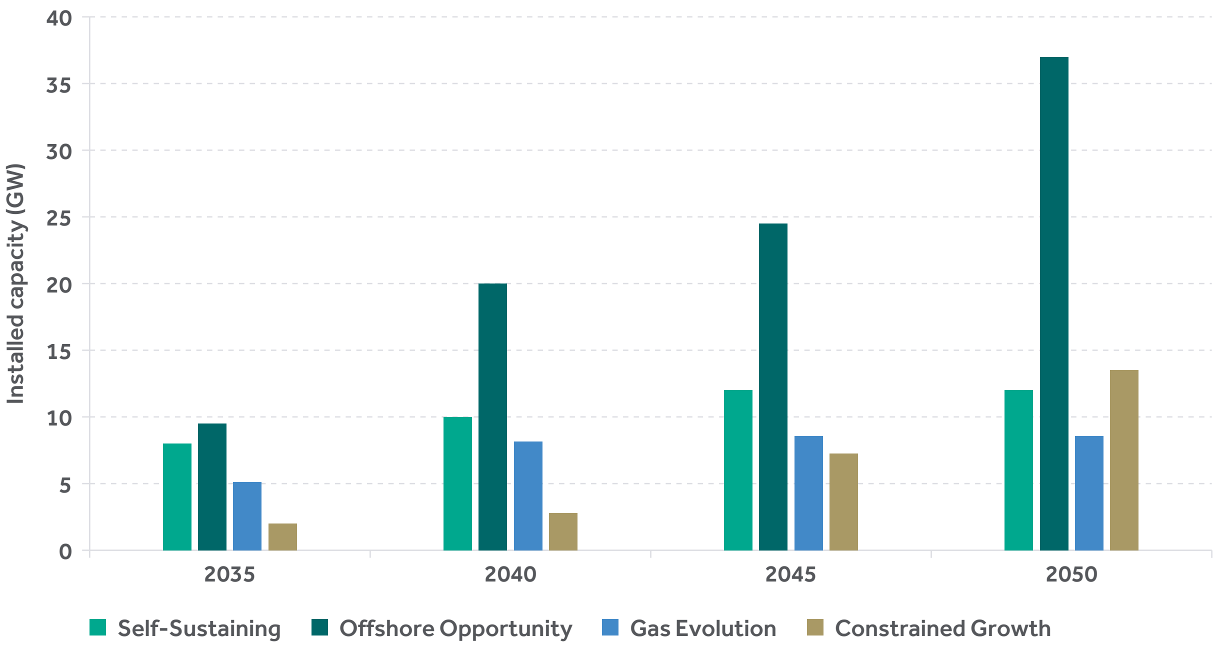


Figure 7.2: Installed offshore wind capacity (IE)

7.2.3 Solar Photovoltaic

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[40]. 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, with appropriate levels of storage, solar contribution towards meeting energy demand can be well forecasted. The total installed capacity of utility scale PV has been limited to 12 GW based on site suitability (similar to onshore wind build constraints). In spatial terms, this equates to up to circa 20,000 hectares[41].

40 Solar PV power capacity in the Net Zero Scenario
41 Frequently Asked Questions on Solar Photovoltaics

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[42]. 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.

Figure 7.3 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.

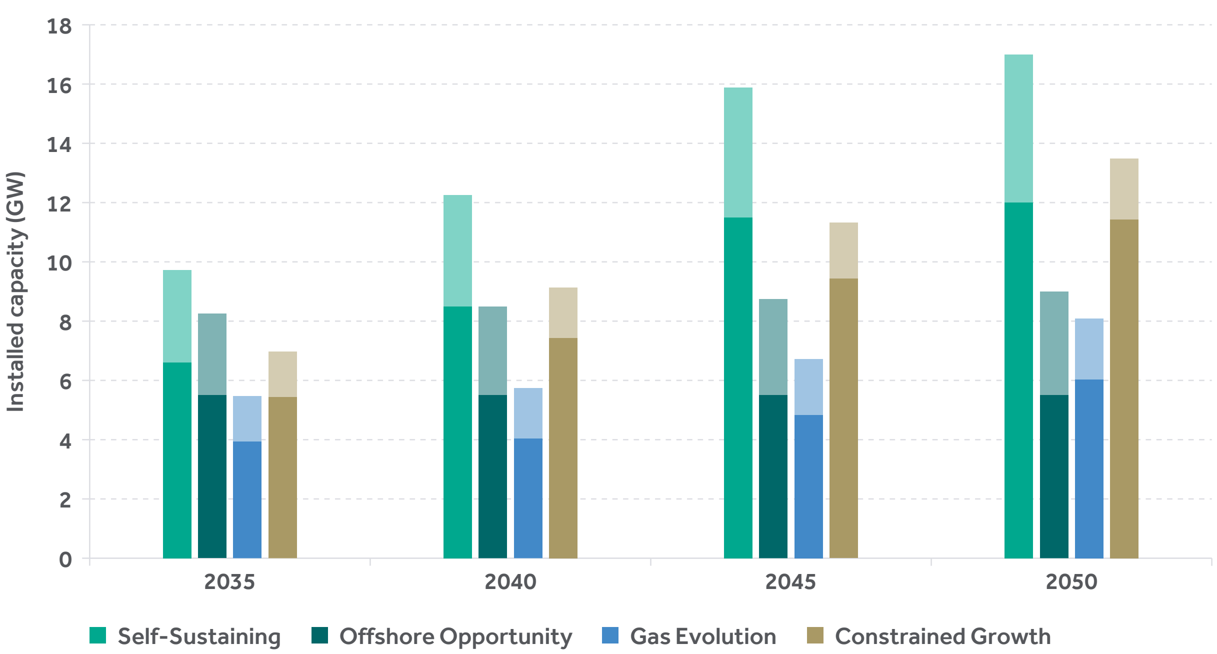


Figure 7.3: Installed solar PV capacity (IE) (lighter colour denotes non-utility scale solar PV)

42 [ISEA – Scale of Solar]

7.2.4 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 7.4 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.

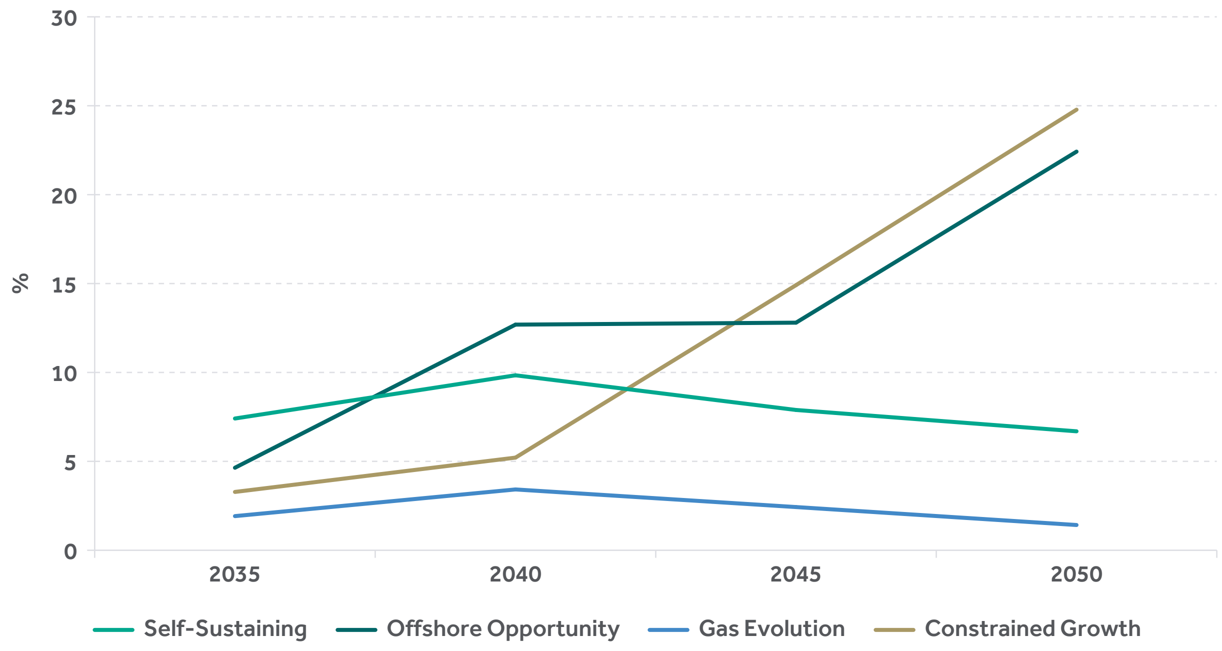


Figure 7.4: Dispatch down of renewable generation assumed to be done on an all-island basis. Constraints and curtailment not included

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

Figure 7.5 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.

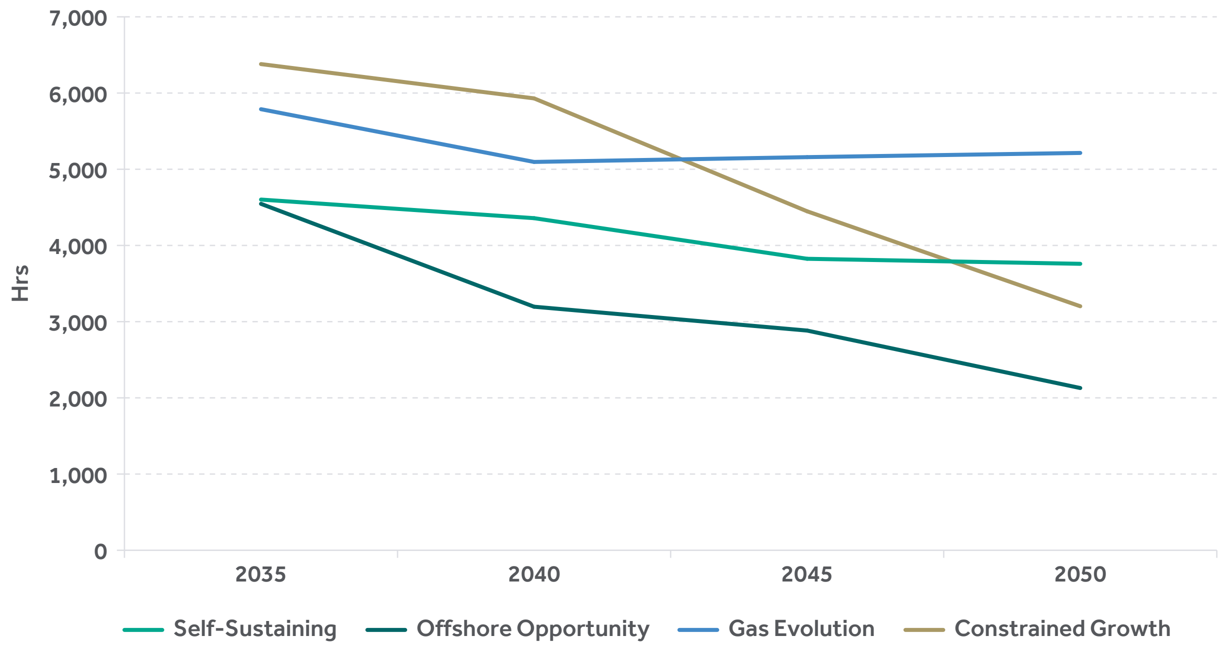


Figure 7.5: Hours of demand where wind and solar generation needs to be supplemented by other sources (i.e., energy storage, interconnection, thermal capacity) (IE)

7.2.5 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 to develop 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). The role and deployment of energy storage technologies is likely to continue to change and become a more important feature of power system planning during the energy transition. This will need to be considered alongside investments in new generation capacity including for hydrogen infrastructure.

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 2022 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) and Demand-Side Storage –** additional energy storage can be discharged to meet demand from through vehicle to grid and demand-side 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 7.6. This 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.

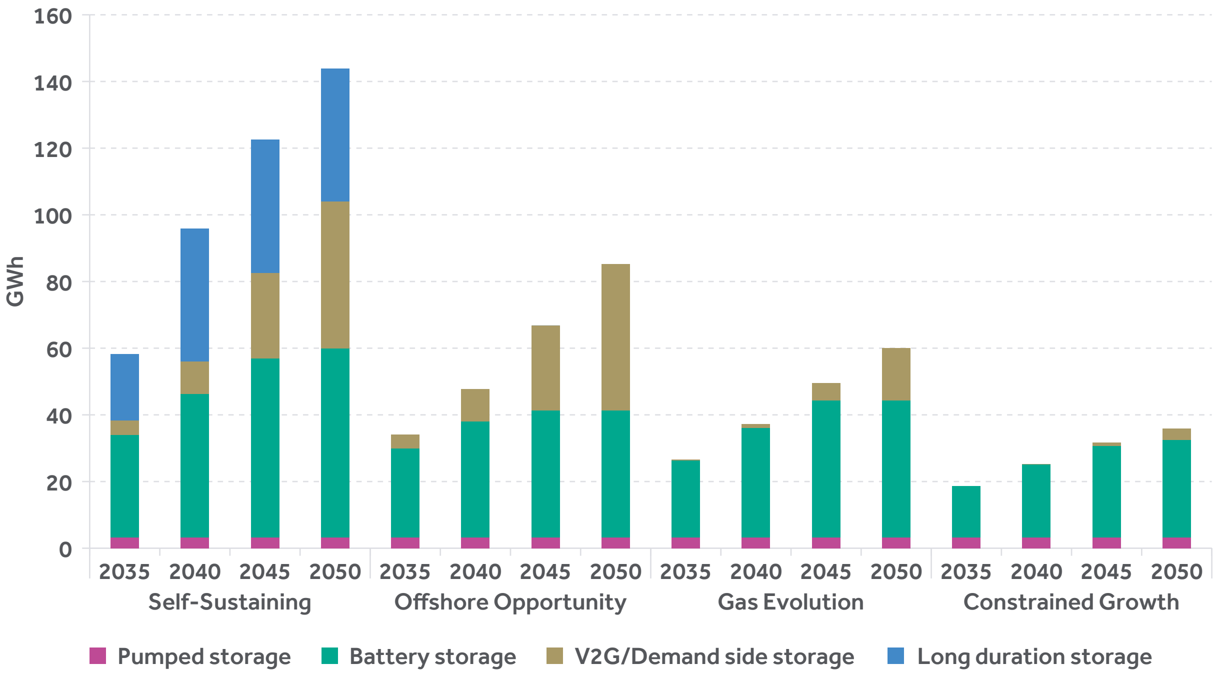


Figure 7.6: Installed storage capacity (IE)

7.2.6 Natural gas

Natural gas is the dominant non-renewable fuel source used in electricity generation in Ireland at present.

The natural gas capacity in Ireland is expected to increase to 5750 MW by 2030. This is based on the findings in SOEF v1.1, which are assessed on a balanced portfolio needed to meet demand in 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 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 these scenarios. In Gas Evolution, it is assumed that gas units are converted to, or replaced by, hydrogen units. Figure 7.7 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 approximately 90% of emissions released from burning fossil fuels in generation can be captured from the flue[43].

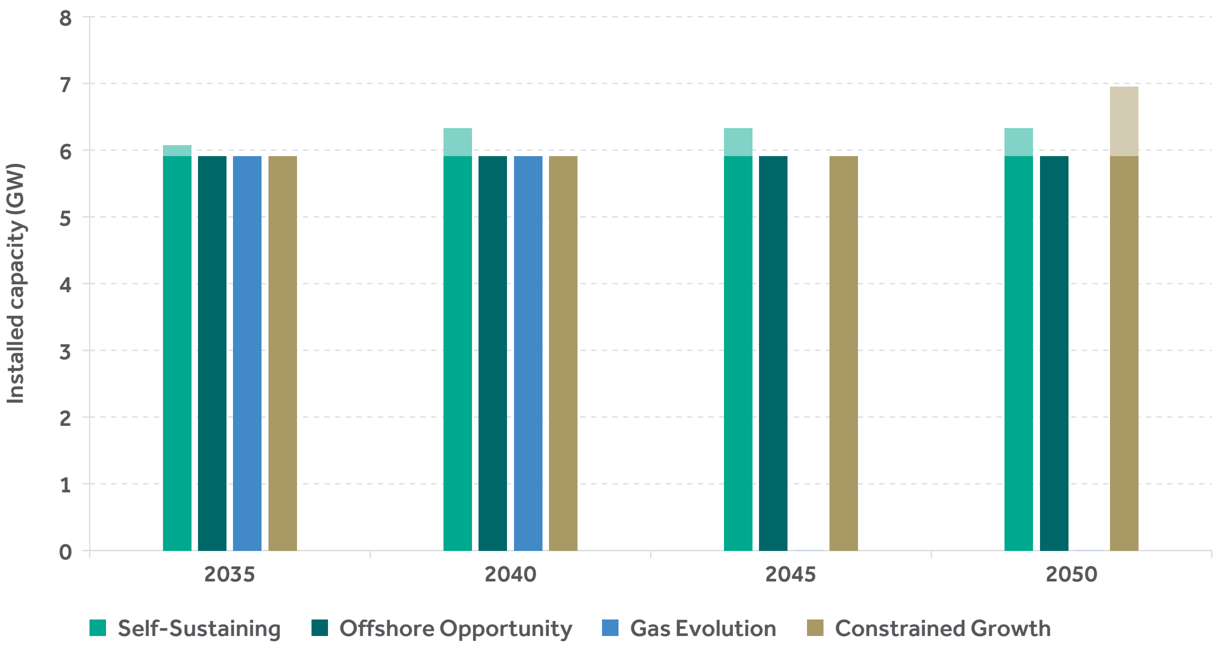


Figure 7.7: Installed gas thermal generation capacities (IE) (lighter colour denotes gas thermal generation equipped with CCS)

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

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

Globally, the International Energy Agency (IEA) reports 40 commercial facilities are in operation applying CCS processes with a further 500 projects in development[45]. 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. It should be noted that biomethane can also be blended with regular natural gas and burned in existing gas generators.

7.2.7 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 will change 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. 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.

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.

44 Assessment of the Potential for Geological Storage of CO_2 for the Island of Ireland
45 Carbon Capture, Utilisation and Storage

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%[46]

TES 2023 features a more detailed analysis of the interactions between the electricity system and a future hydrogen system (please see Section 7.5).

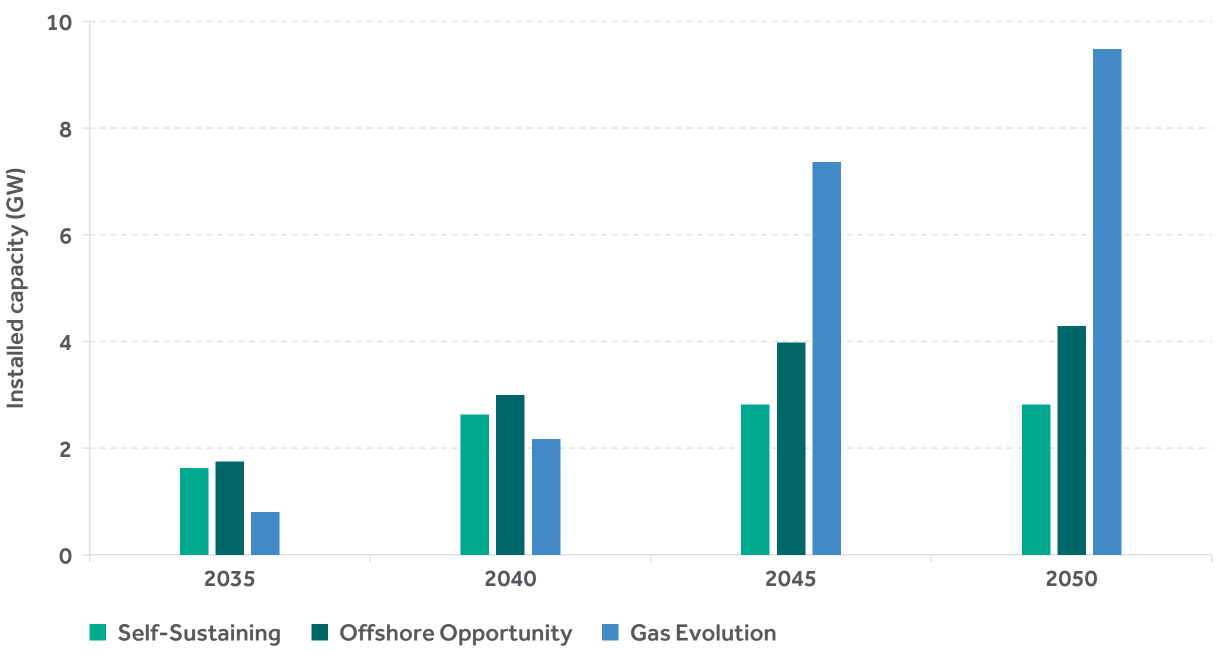


Figure 7.8: Installed hydrogen thermal generation capacities (IE)

46 [Hydrogen or batteries for grid storage? A net energy analysis]

7.2.8 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. However, we note the intention of the plant operator (Bord na Móna) to maintain the plant beyond 2031 and explore the potential of equipping post combustion carbon capture equipment on site that would enable it to become a BECCS generation facility.

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 7.9 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

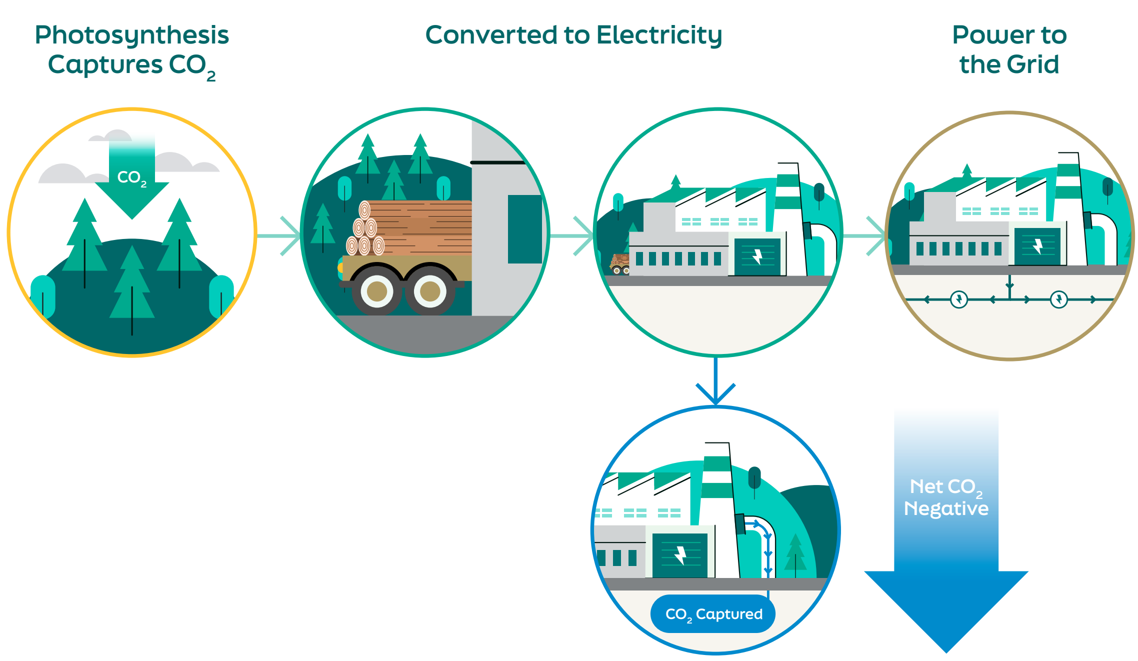


Figure 7.9: Negative emissions technology – biomass with carbon capture and storage

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 7.10 below. All capacities installed in each scenario are entirely met by Biomass with CCS capability.

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.

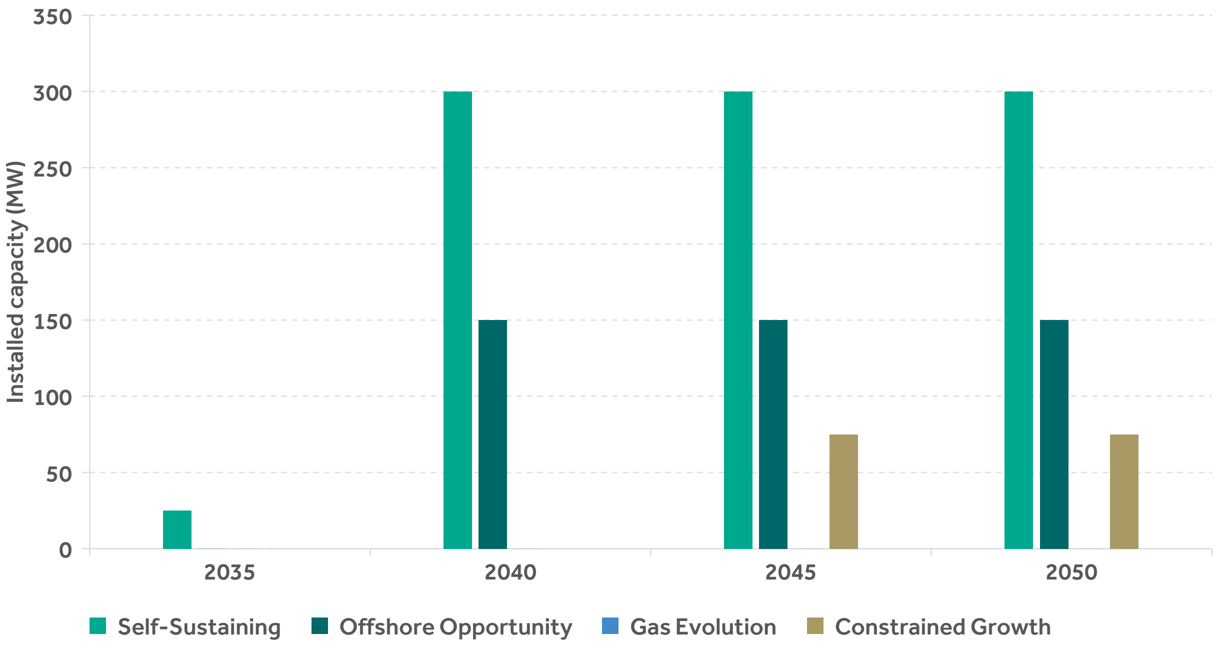


Figure 7.10: BECCS Capacity (IE)

7.2.9 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.

7.3 Generation technologies – Northern 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 (Section 7.3.1–6.3.4).
- Energy storage (Section 7.3.5).
- Flexible thermal generation technology such as natural gas, hydrogen and biomass (Section 7.3.6–7.3.9).
- Electricity interconnection (Section7.4).

7.3.1 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 7.11 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 reach this level in onshore wind and instead rely on a larger growth of offshore wind to decarbonise the system.

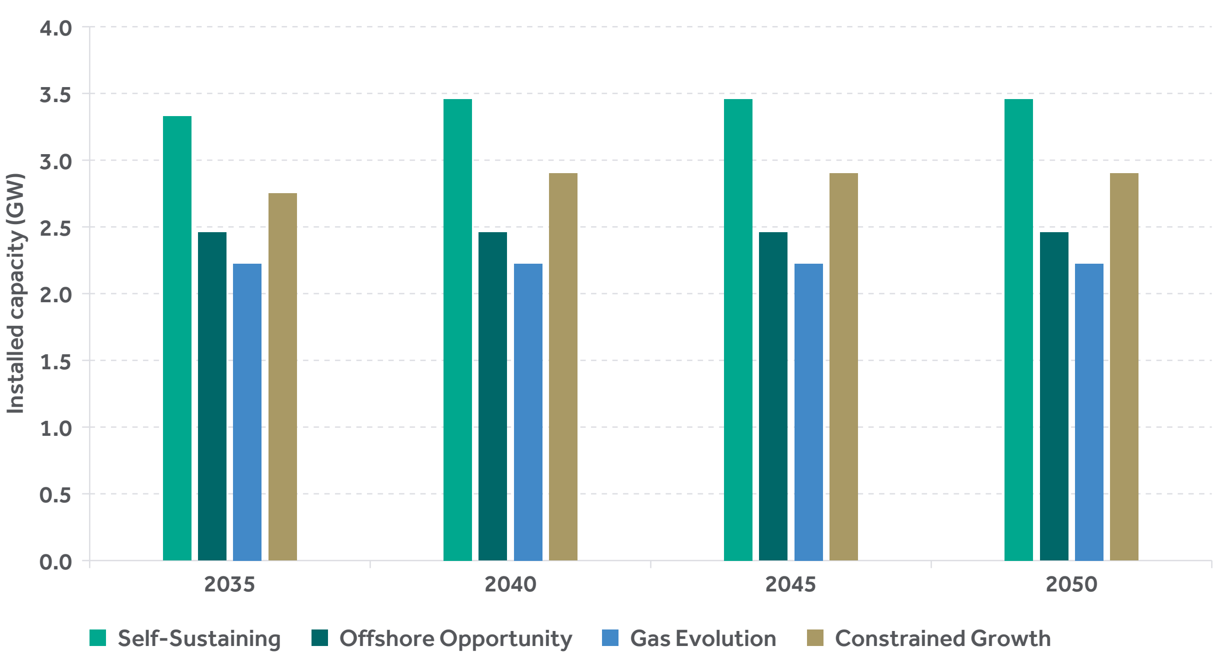


Figure 7.11: Installed onshore wind capacity (NI)

7.3.2 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 gigawatts 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 coast of Northern Ireland. For the purpose of this analysis, an upper limit of 4 GW transmission connected capacity has been applied.

Figure 7.12 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.

Offshore Opportunity sees the fastest initial offshore wind build, reaching the 4 GW limit by 2045. Following this, Self-Sustaining and Constrained Growth scenarios build out 4 GW by 2050.

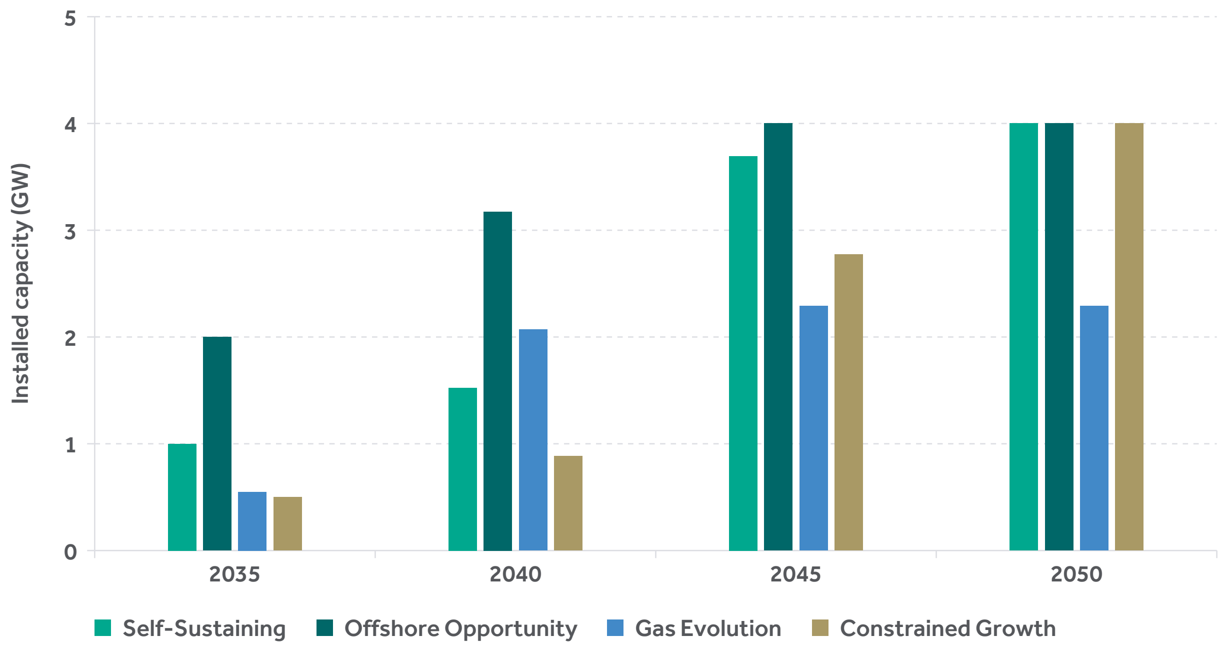


Figure 7.12: Installed offshore wind capacity (NI)

7.3.3 Solar Photovoltaic

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[47], including over 250 MW in Northern Ireland[48]. While PV generation in Northern Ireland has a relatively low capacity factor compared to sunnier 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, with appropriate levels of storage, solar 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 7.13 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.

47 Solar PV power capacity in the Net Zero Scenario
48 GCS 2023-2032

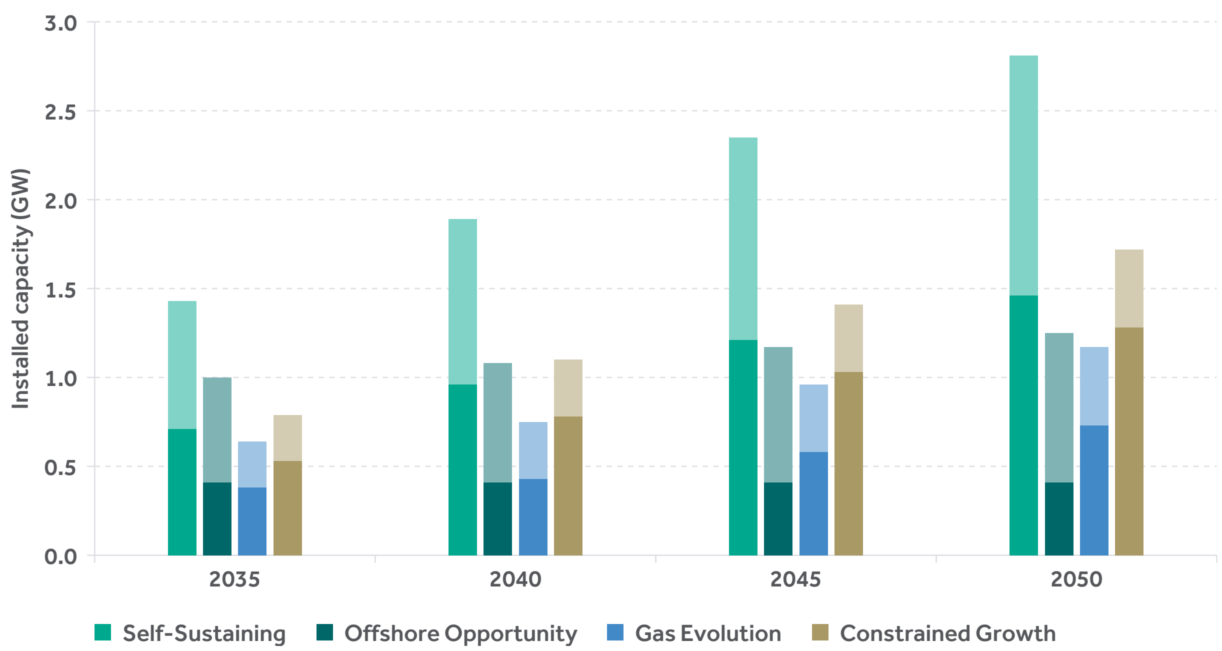


Figure 7.13: Installed solar PV capacity (NI) (lighter colour denotes non-utility scale solar PV)

7.3.4 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 7.14 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.

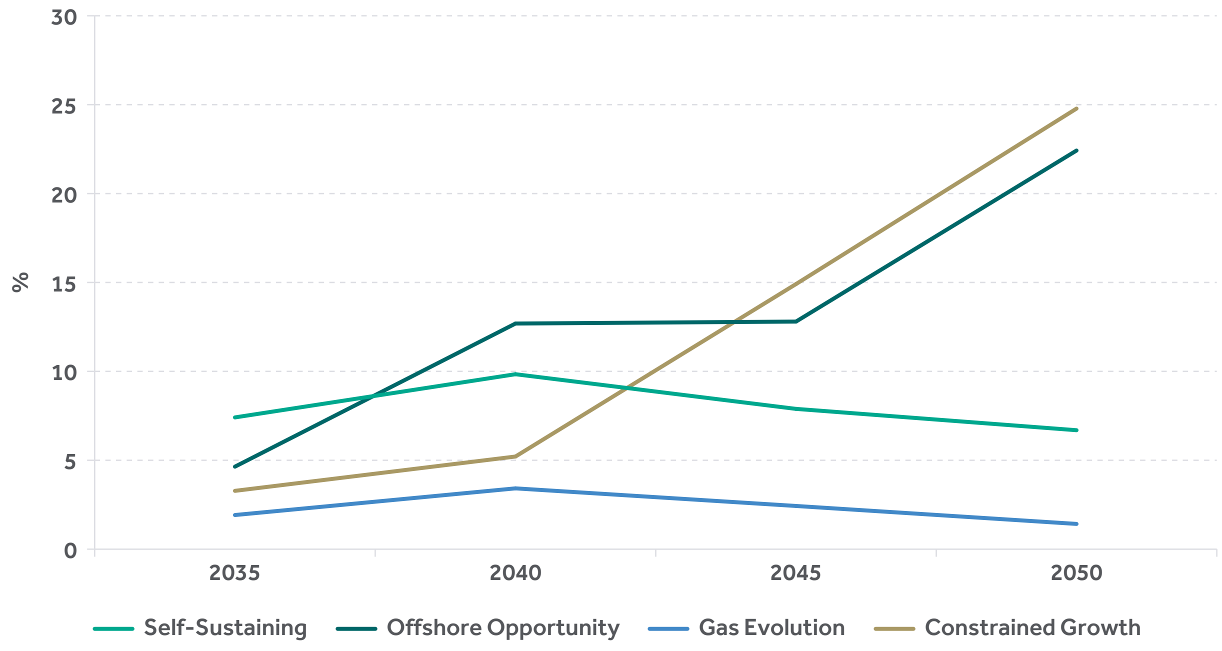


Figure 7.14: Dispatch down of renewable generation assumed to be done on an all-island basis. Constraints and curtailment not included

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 7.15 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.

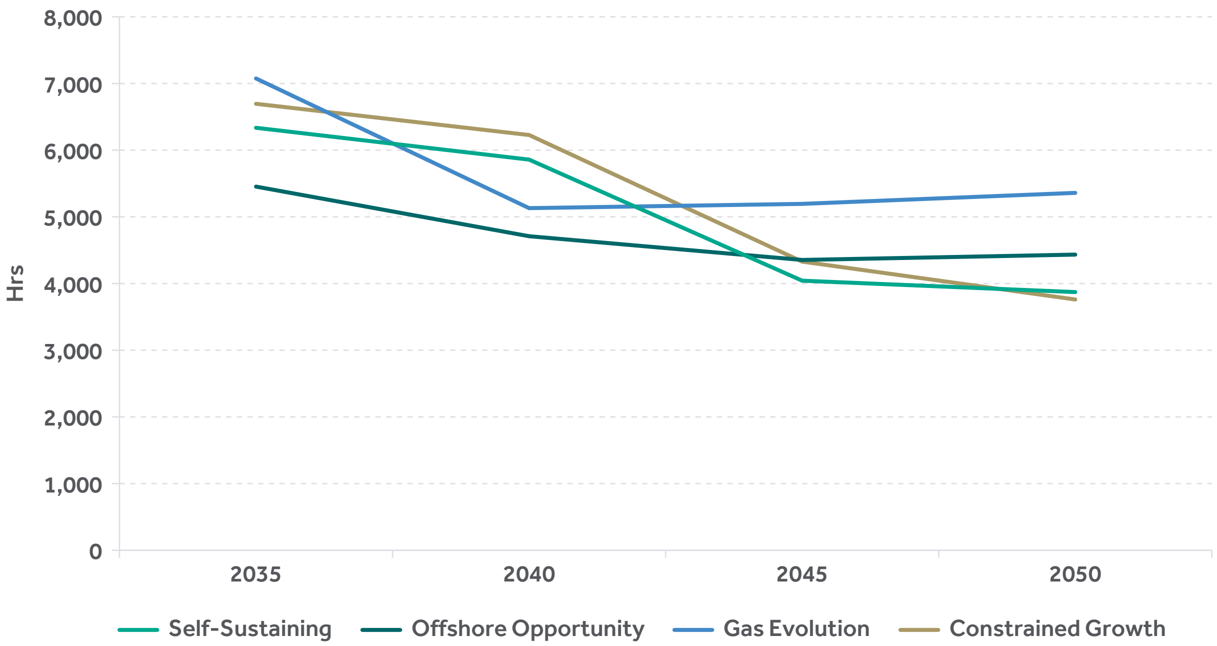


Figure 7.15: Hours of demand where wind and solar generation needs to be supplemented by other sources (i.e., energy storage, interconnection, thermal capacity) (NI)

7.3.5 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 to develop 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) and Demand-Side Storage** – additional energy storage can be discharged to meet demand through vehicle to grid and demand-side 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 7.16. 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.

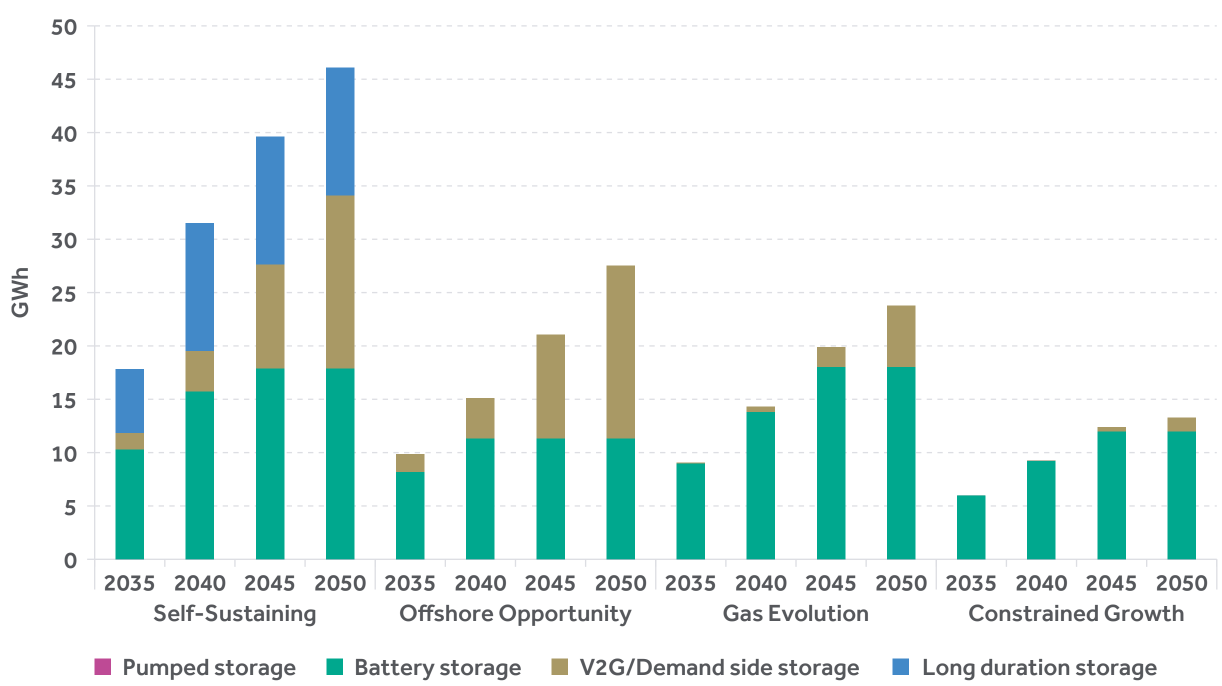


Figure 7.16: Installed storage capacity (NI)

7.3.6 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. The exception to this is the Gas Evolution scenario where gas plant is replaced by hydrogen. Any new additions to natural gas fired capacity 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% of emissions released from burning fossil fuels in generation can be captured from the flue[49]. 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[50].

Globally, the IEA reports 40 commercial facilities are in operation applying CCS processes with a further 500 projects in development[51]. 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

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

Figure 7.17 below shows the natural gas fired generation capacity in each scenario.

In Self-Sustaining, Offshore Opportunity and Constrained Growth, installed capacity without CCS is stable at 2.2 GW across the study horizon. The expansion of gas fired capacity occurs only in the Constrained Growth scenario where there is an addition of CCS plant post 2045.

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.

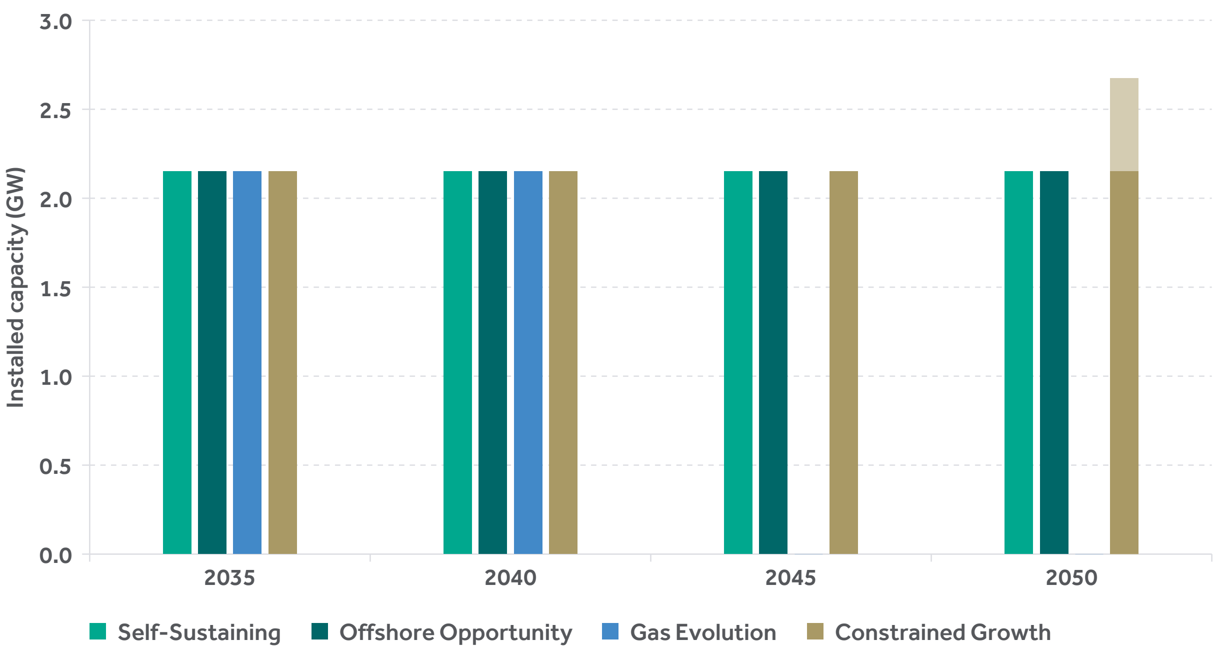


Figure 7.17: Installed gas thermal generation capacities (NI) (lighter colour denotes gas thermal generation equipped with CCS)

7.3.7 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 was 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 7.18 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%[52].

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.

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

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.

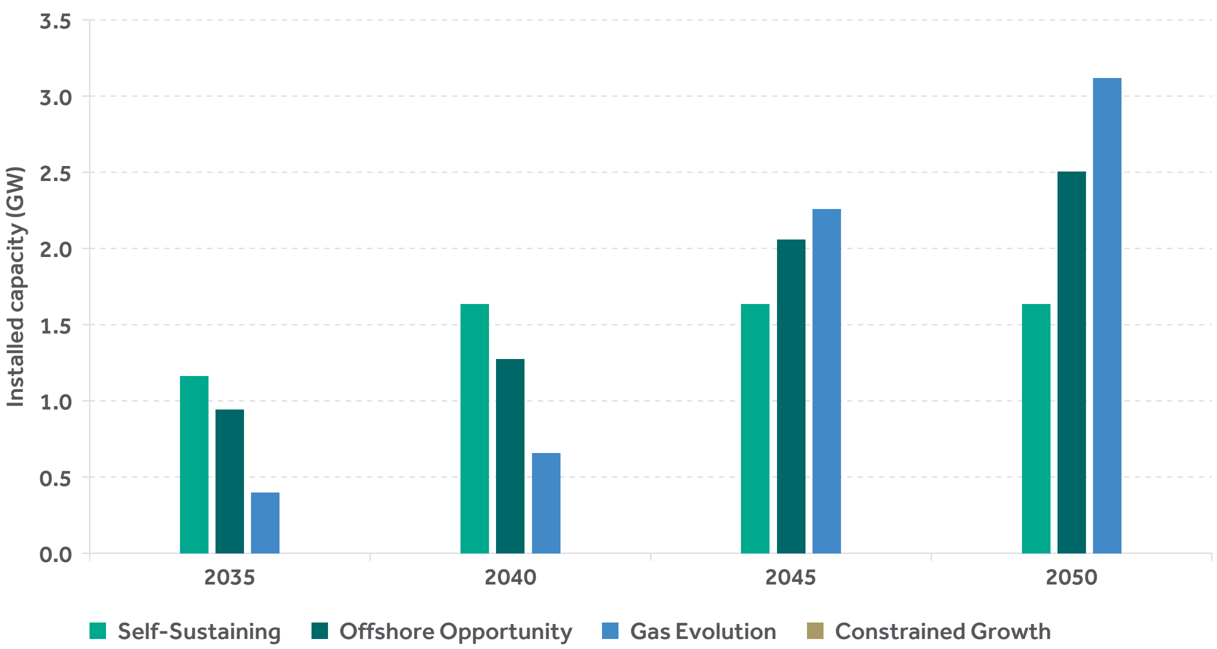


Figure 7.18: Installed hydrogen thermal generation capacities (NI)

7.3.8 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.

As Figure 7.19 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

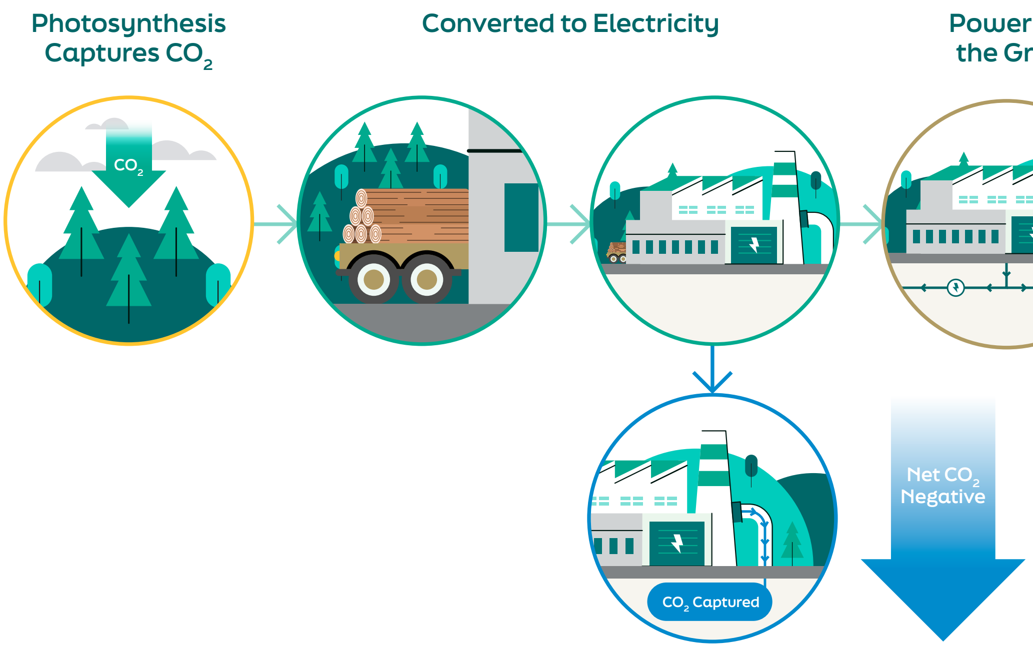


Figure 7.19: Negative emissions technology – biomass with carbon capture and storage

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 7.20 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.

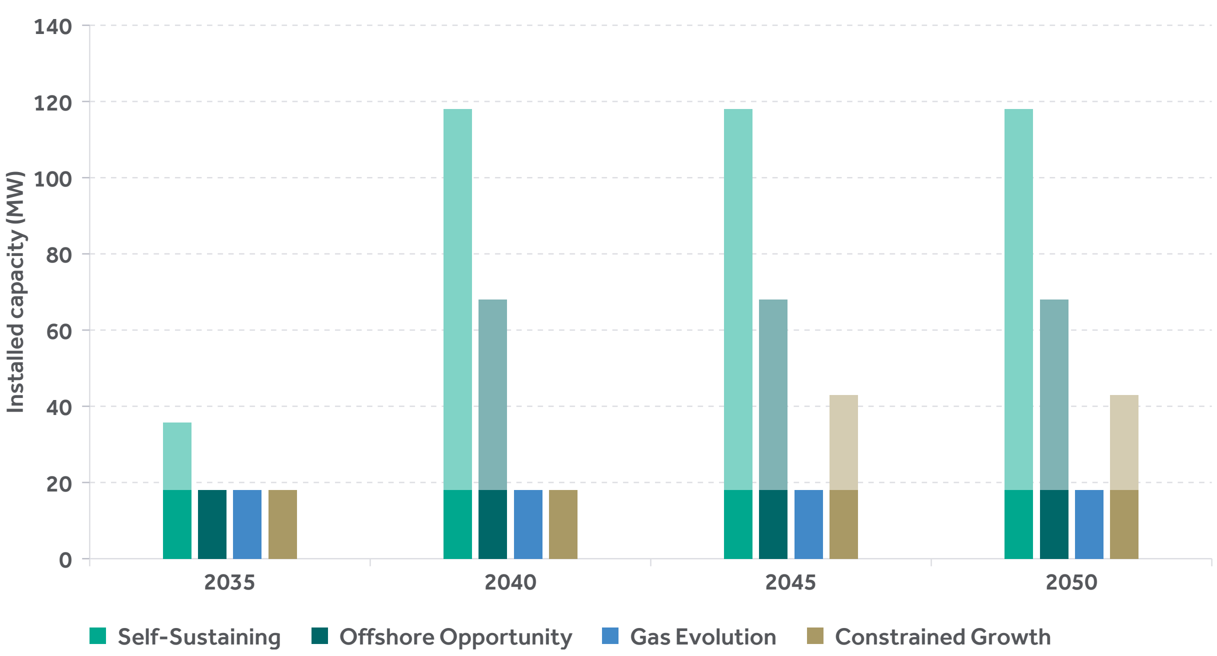


Figure 7.20: Biomass and BECCS capacity (NI) (lighter colour denotes BECCS)

7.4 Interconnection

7.4.1 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 Greenlink interconnector between Ireland and Wales is due to be commissioned by the project promoters in 2024. 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.

Table 7.3 below shows the interconnection capacities modelled for 2035-2050 in each scenario. 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 v1.1. 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 7.3. It should be noted that while increasing interconnection can provide multiple benefits including wholesale electricity price reduction, very high levels of interconnection may have the potential to introduce uncertainties in other aspects of long term planning. For example, if France or Great Britain have significantly different market prices than the Single Electricity Market (SEM) this may impact the business model for generation investments Ireland and Northern Ireland.

Table 7.3: Interconnection capacities (MW)

	Self-Sustaining				Offshore Opportunity				Constrained Growth				Gas Evolution			
	2035	2040	2045	2050	2035	2040	2045	2050	2035	2040	2045	2050	2035	2040	2045	2050
IE-NI	700	700	700	700	700	700	700	700	700	700	700	700	700	700	700	700
IE-GB	1,750	1,750	3,250	3,750	2,600	5,100	5,750	5,750	1,750	2,250	2,450	2,450	1,900	2,200	2,250	3,200
IE-CE	1,400	1,400	3,750	3,900	2,650	3,200	5,900	7,400	700	1,400	1,400	1,400	2,150	2,750	3,400	3,400
NI-GB	1,300	1,600	2,200	2,200	1,650	2,500	2,900	3,200	1,200	1,800	1,850	1,900	1,400	1,500	1,500	2,100

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.

7.4.2 Flows between Ireland and Northern Ireland

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.

7.5 Green hydrogen

TES 2023 has analysed the way that the rapid development and deployment of green hydrogen infrastructure can complement the electricity system and support Ireland's and Northern Ireland's energy transition. For this study, consideration of hydrogen produced from fossil fuels has not been included (i.e., blue or grey).

As the energy transition progresses it becomes increasingly important to co-ordinate the planning of different energy vectors such as electricity and gas in order to deliver the most efficient, sustainable, and reliable energy system to customers in Ireland and Northern Ireland. In our role as TSOs, SONI and EirGrid are conscious of the interdependencies between the electricity system and any future hydrogen system and as such we consider it appropriate to analyse the potential scale and dynamics of such a hydrogen system and how it may impact on our planning for the electricity transmission system.

During the development of our green hydrogen modelling, we engaged with the gas system operators in both Ireland and Northern Ireland to ensure their views on the potential development of hydrogen were captured in our analysis and modelling assumptions.

Our analysis considers the following elements:

- Forecast demand for hydrogen in power generation.
- Forecast demand for hydrogen in other sectors, such as industry, heat and transport.
- The capacity of dedicated renewable generators, supported by renewable energy from the grid needed to power electrolysers.
- The capacity of hydrogen storage infrastructure required to balance supply of and demand for hydrogen. For our analysis we have assumed these storages will be salt caverns.
- The availability of imported hydrogen, potentially from conversion of existing natural gas interconnection with Great Britain.

Please note that our green hydrogen modelling was carried out on an all-island basis.

Figure 7.21 below shows the high-level architecture of the hydrogen model that was developed. Similarly, to the electricity modelling carried out in this study there is a long-term capacity expansion phase of the modelling that optimises the capacity of dedicated renewables, electrolysis, and storage. There is also a short-term dispatch modelling phase that models each hour in more detail. In our electricity modelling demand and supply must be matched each hour but for our hydrogen modelling demand and supply must be matched each week. This is due to the inherent flexibilities in hydrogen networks and hydrogen demands that we were not fully able to represent in our modelling.

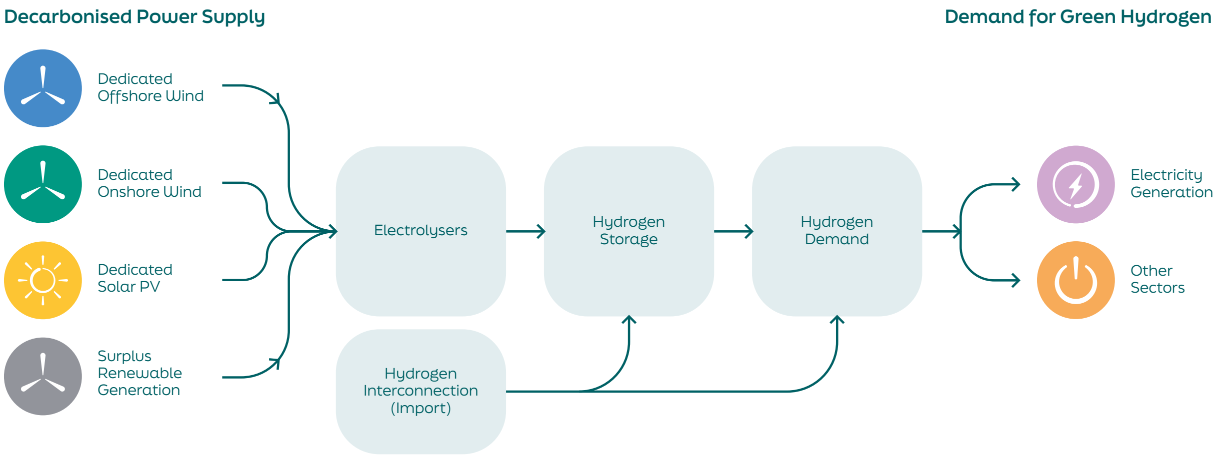


Figure 7.21 Diagrammatic view of our hydrogen model

7.5.1 Green hydrogen in our scenarios

Each scenario assumes different levels of hydrogen demand and therefore the requirements on the power system and hydrogen related infrastructure will vary.

Self-Sustaining and Offshore Opportunity both include hydrogen use in industry and in the production of synthetic fuels as well as in power generation (displacing unabated methane powered generation).

Gas Evolution includes hydrogen use in industry, synthetic fuel production as well as some use in heating and fuel cell vehicles. It also features the highest level of hydrogen use in power generation.

Constrained Growth does not feature in our hydrogen modelling as there is assumed to be only a minimal role for hydrogen in this scenario and no use at all in power generation.

7.5.2 Results of hydrogen analysis

Our analysis provides high-level results for potential future hydrogen supply, storage and demand in Ireland and Northern Ireland. The findings provide valuable insight to help inform and stimulate debate about potential future energy scenarios which may include green hydrogen. Summary results for 2035–2050 are provided below. If you would like to see more detailed information for each scenario, please refer to the accompanying Databook.

Planning the energy transition for natural gas is complex will take detailed planning for both gas and hydrogen infrastructure. In 2022, annual natural gas demand in Ireland was 52.0 TWh[53], and 17.6 TWh in Northern Ireland[54]. Repurposing of gas infrastructure for hydrogen operations is complex and will need to be carefully co-ordinated with demands for hydrogen.

53 SEAI Energy-in-Ireland-report 2023
54 GMO-NI NIGCS 2022-2023

To help develop a clearer understanding of the energy transition for natural gas and the role for hydrogen further collaboration co-ordination will be required between key stakeholders in Ireland, Northern Ireland and Great Britain.

7.5.3 Demand for green hydrogen

Table 7.4 below summarises our analysis of demand for green hydrogen in our scenarios in 2035, 2040, 2045 and 2050.

Table 7.4: All-island hydrogen demand

Hydrogen TWh[55]	SS	OO	GE
2035	18.9	23.4	29.9
2040	25.1	24.7	43.8
2045	31.2	28.3	66.5
2050	37.6	36.3	77.2

A key observation of our analysis is the significance of fluctuations in hydrogen demand (see figure 7.22). While certain sectors such as industry and transport may be assumed to be quite consistent in terms of their load profile there is a massive level of variability in demand in the power sector. This is to be expected as hydrogen generators may have to respond very quickly to variations in renewable generation from wind and solar. This creates a challenge for any potential hydrogen system in that demand levels are likely to be very low for extended periods of time (perhaps several days) but then ramp up to very high levels with only limited foresight of when these high levels of hydrogen demand will occur.

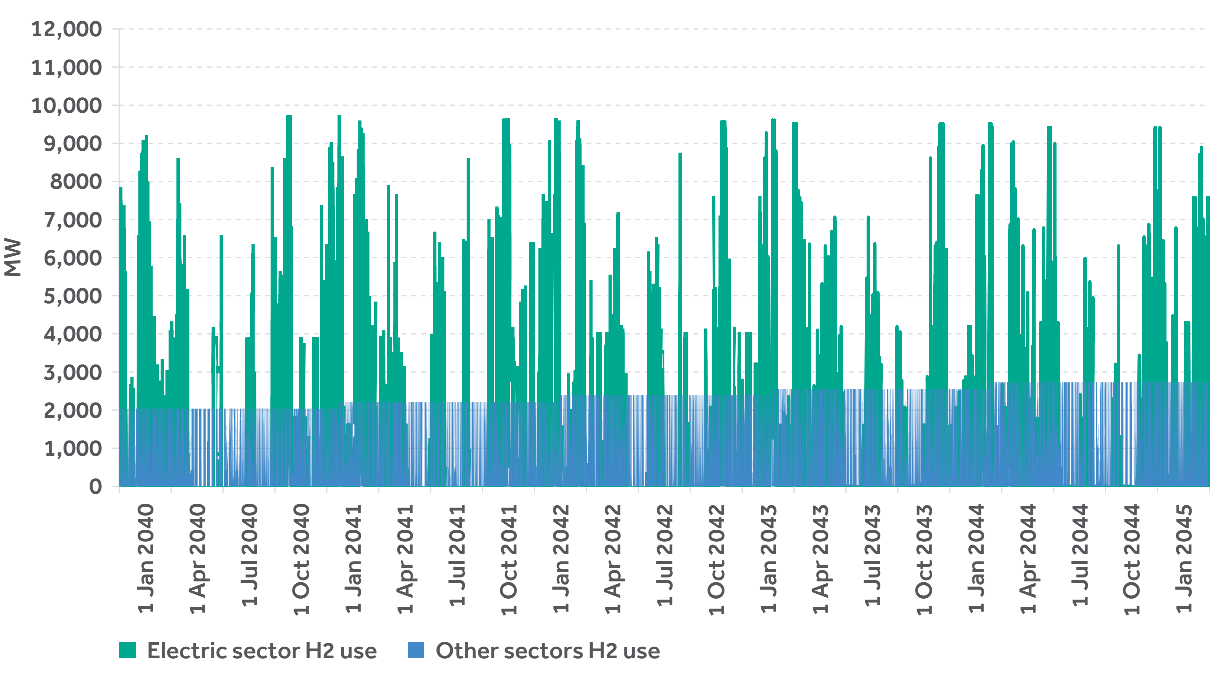


Figure 7.22: Hydrogen demand profile for Self-Sustaining (2040-2044) showing peaks of demand from power generation

55 This refers to primary energy demand for Hydrogen.

7.5.4 Surplus renewable generation

One way to supply hydrogen that is often discussed is to use surplus renewable energy from the electricity grid to power electrolysers and avoid what would otherwise be the waste of this energy. As highlighted in Section 7.2.4 and Section 7.3.4 as the levels of renewable capacity on the power system grows it is likely that the level of renewable surplus will also grow. Our analysis investigates the possibility to use this energy to create green hydrogen (see table 7.5 below). It should be noted that there is an assumption that electrolysers can physically access this surplus energy.

The key finding is that a large portion of surplus energy can be used to meet hydrogen demand. When hydrogen demand is high and levels of surplus relatively low, as seen in Gas Evolution then virtually all surplus energy can be utilised. Where levels of surplus are much higher there is still a significant amount of energy that cannot be utilised to make hydrogen as seen in Offshore Opportunity. There may be other opportunities to utilise this energy that have not been considered in this study.

Table 7.5: Surplus generation used for green hydrogen production

	Self-Sustaining (SS)		Offshore Opportunity (OO)		Gas Evolution (GE)	
TWh	Surplus energy used	Surplus energy not used	Surplus energy used	Surplus energy not used	Surplus energy used	Surplus energy not used
2035	4.0	2.1	3.0	0.9	0.9	0.0
2040	6.6	2.8	7.8	7.7	2.1	0.2
2045	6.1	2.9	8.7	9.5	1.7	0.0
2050	5.3	2.7	22.8	20.4	0.9	0.0

7.5.5 Dedicated renewable generation

While surplus energy can play a role in meeting green hydrogen demand there is a very significant requirement for additional renewable generation not accounted for in our electricity modelling. Given the volumes of onshore renewables already assumed to be needed to decarbonise the power system it is likely that hydrogen supply will be dominated by offshore wind where the potential to achieve significant capacity levels is greater especially when considering the potential of floating wind.

Table 7.6 below summarises our analysis additional dedicated renewable capacity required for the production of green hydrogen in our scenarios in 2035, 2040, 2045 and 2050.

Table 7.6: Dedicated renewable generation capacities

	Self-Sustaining (SS)			Offshore Opportunity (OO)			Gas Evolution (GE)		
GW	Offshore wind	Onshore wind	Solar PV	Offshore wind	Onshore wind	Solar PV	Offshore wind	Onshore wind	Solar PV
2035	4.1	1.0	0.1	5.0	1.3	0.4	6.7	1.7	1.2
2040	4.1	1.0	1.0	5.0	1.3	0.4	10.5	1.7	1.5
2045	5.5	2.5	2.5	5.0	1.3	0.4	15.5	2.0	3.0
2050	7.1	4.0	4.0	5.0	1.3	0.4	17.6	2.0	4.2

7.5.6 Hydrogen storage

In our analysis we observe the inverse correlation between the availability of renewable generation and the demand for hydrogen in Ireland and Northern Ireland. That is to say that during periods of high renewable availability demand for hydrogen (in the power sector) is low and during periods of low renewable availability it is high. This points to the importance of storage and interconnection to manage the variation between supply and demand.

The requirements for hydrogen storage are observed to be quite similar in all scenarios. There is a notable difference between the requirements for storage in 2035 between Offshore Opportunity and Gas Evolution. While demand levels for hydrogen are similar at this point in both scenarios, there is a much more variable hydrogen demand present in Offshore Opportunity. This along with the presence of hydrogen interconnection to facilitate imports in Gas Evolution helps to reduce the requirement for storage. Please note that all hydrogen storage is modelled with the properties of salt cavern storage.

Table 7.7: All-island hydrogen storage capacity requirements (modelled as salt caverns)

TWh	SS	OO	GE
2035	2.0	7.8	0.8
2040	2.2	7.8	1.7
2045	2.2	7.8	3.2
2050	2.9	7.8	3.6

7.5.7 Electrolysers

Our analysis determines an appropriate level of electrolysis capacity to help to meet hydrogen demand. Electrolysis capacity grows over time in each scenario as demand for hydrogen increases and reliance on imports of hydrogen to meet that demand decreases (see Table 7.8).

Table 7.8: Optimised capacities for electrolysers producing green hydrogen (All-island)

GW	SS	OO	GE
2035	2.5	3.1	3.3
2040	3.8	3.1	5.3
2045	4.4	3.7	8.8
2050	4.4	6.1	9.8

Given the nature of the modelling used in this analysis (single node for Island of Ireland) it is assumed that electrolysers can access both curtailed energy from the grid and dedicated renewable generation. If the constraints of the transmission system, i.e., all nodes and the limitations on flows between those nodes were to be considered, more or less surplus energy may be available to electrolysers depending on their location which would in turn influence where their optimum location may be.

For the purposes of this modelling, it is assumed that there is a mix of alkaline and PEM (Proton Exchange Membrane) electrolysers. The exact split in market share and assumed electrolyser efficiencies are given in Table 7.9 below based on guidance from TYNDP[56].

Table 7.9: Electrolyser technology assumptions

	2035	2040	2045	2050
Market share alkaline	77%	51%	51%	25%
Market Share PEM	23%	49%	49%	75%
Efficiency of electrolyser fleet	69%	71%	71%	74%

7.5.8 Hydrogen interconnection capacity

In our modelling the role of hydrogen interconnection has been assessed for the purposes of imports only. In reality gas interconnectors may be repurposed in order to flow bi-directionally and so could be used to export hydrogen out of Ireland and Northern Ireland. Should the volumes of renewable generation assumed in these scenarios be achieved it is reasonable to assume that Ireland and Northern Ireland would be net exporters of hydrogen provided there are sufficient demands to act as off takers for that hydrogen. In our modelling we observe the hydrogen interconnectors as playing a very important role in meeting the peaks in hydrogen demand referred to in Section 7.5.1 but they play only a small part in meeting the overall annual hydrogen demand the supply of which is dominated by domestic production of green hydrogen.

Table 7.10: Assumed future capacities of hydrogen interconnection capacity from Great Britain

GW	SS	OO	GE
2035	0	0	6
2040	6	6	6
2045	6	6	18
2050	6	6	18

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7.6 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 7.6.1–7.6.4 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 7.23.

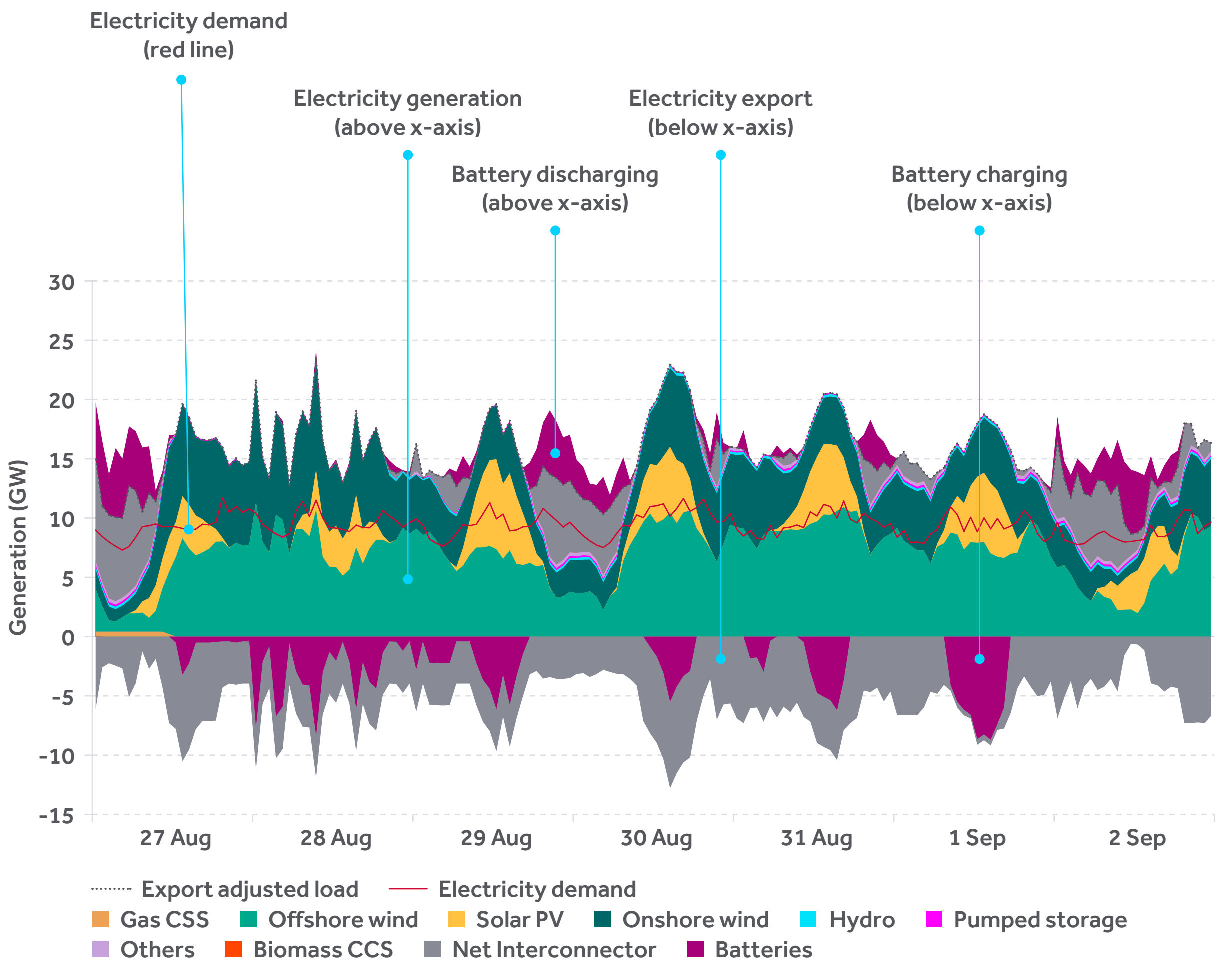


Figure 7.23: Example weekly timeseries showing how overall electricity generation above the x-axis and electricity exports and battery charging below the x-axis

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.

7.6.1 Self-Sustaining 2040

From 2040, the Self-Sustaining scenario achieves a net zero power system. Figure 7.24 shows the annual generation mix. This includes:

- Over 79% of electricity coming directly from variable renewable generation, split between onshore and offshore wind and solar PV;
- Electricity imports; and
- Natural gas, 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.

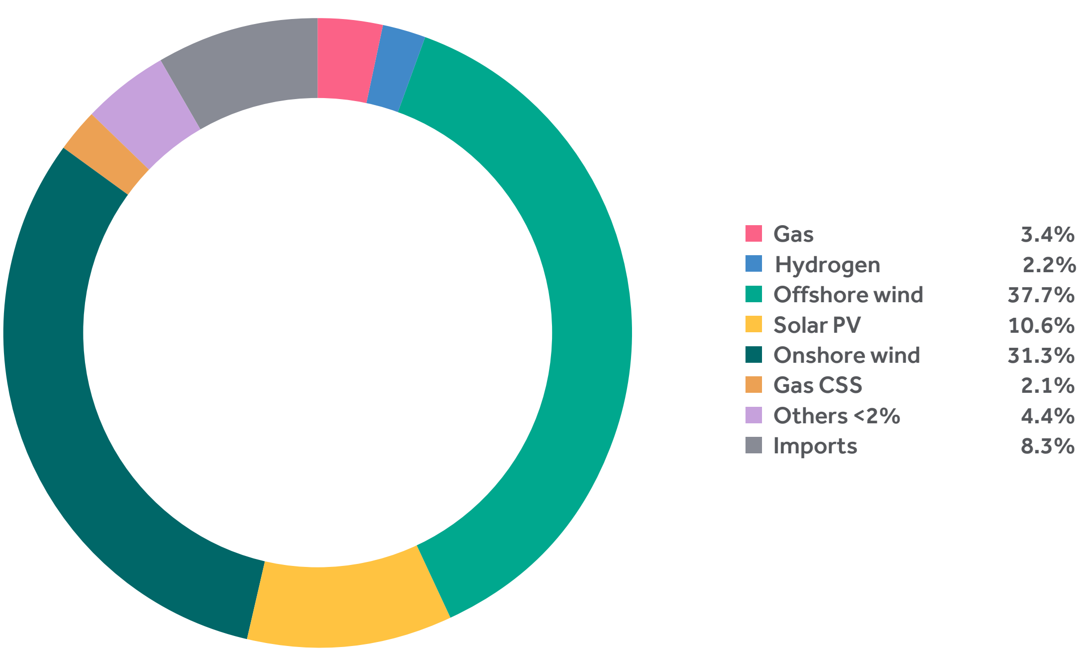


Figure 7.24: Self-Sustaining, annual generation mix in 2040 (net zero power system) (IE)

A week in summer with high wind

The balance of supply and demand across a weekly period is shown in Figure 7.25. 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.

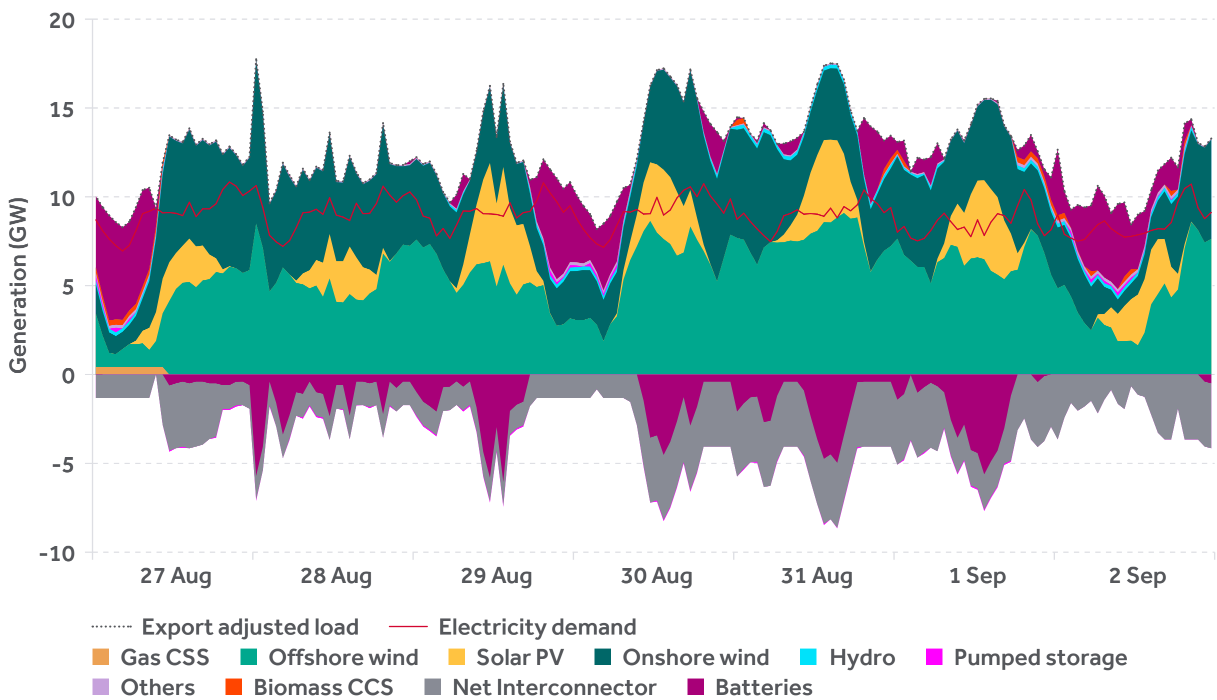


Figure 7.25: Self-Sustaining, weekly timeseries in 2040 – high wind in summer (IE)

A week in winter with low renewable generation

Figure 7.26 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 and green hydrogen 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.

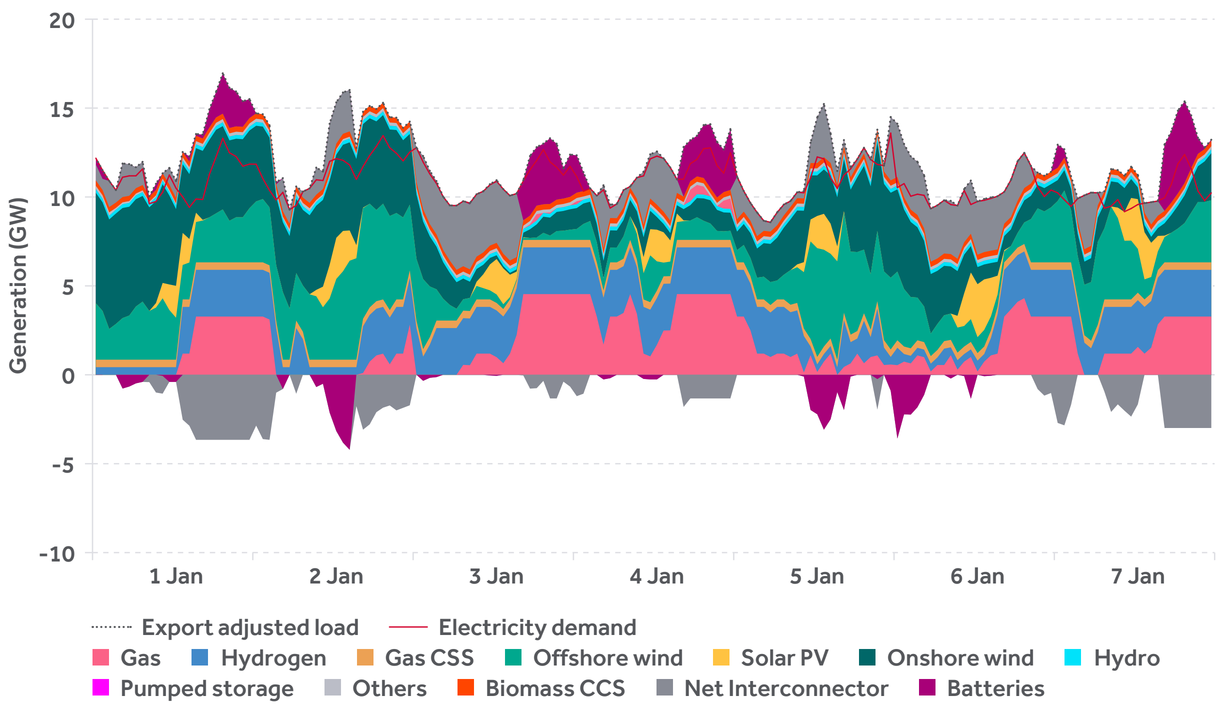


Figure 7.26: Self-Sustaining, weekly timeseries in 2040 – low renewables in winter (IE)

7.6.2 Offshore Opportunity 2040

From 2040, the Offshore Opportunity scenario achieves a net zero power system. Figure 7.27 shows the annual generation capacity. This includes:

- Over 85% 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.

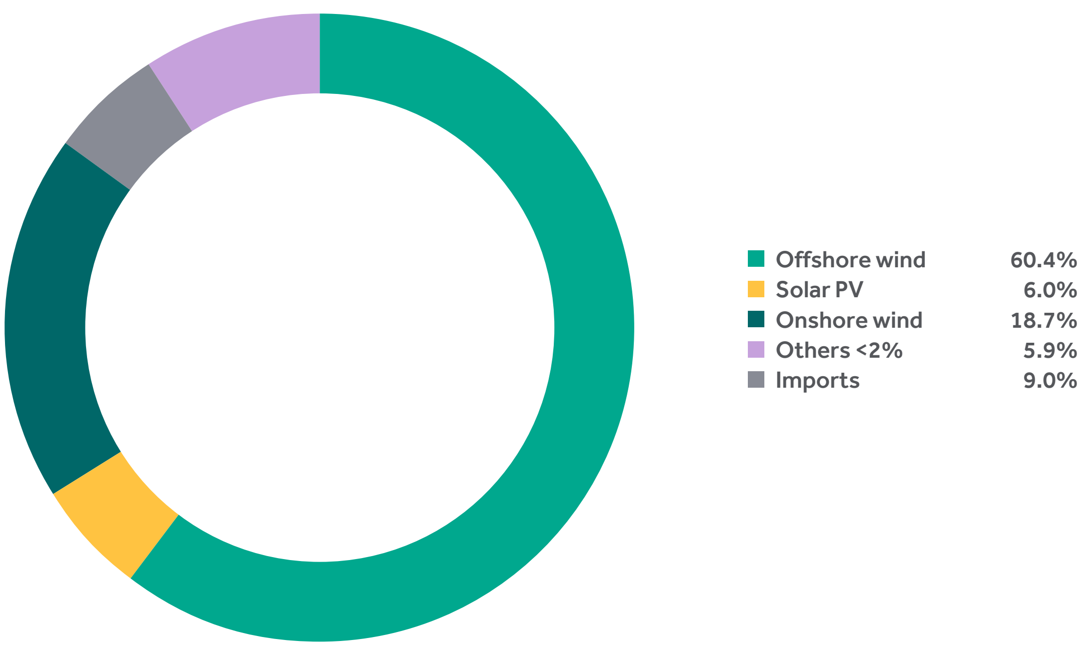


Figure 7.27: Offshore Opportunity, annual generation mix in 2040 (net zero power system) (IE)

A week in summer with high wind

The balance of supply and demand across a weekly period is shown in Figure 7.28. 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.

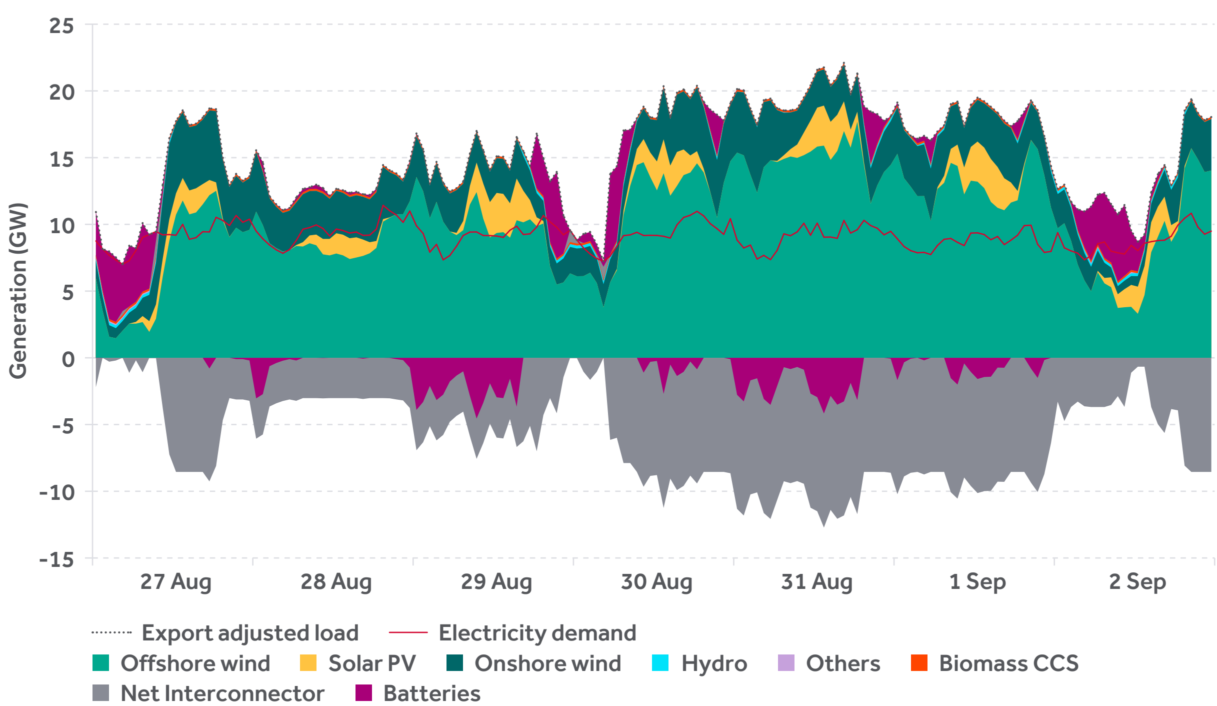


Figure 7.28: Offshore Opportunity, weekly timeseries in 2040 – high wind in summer (IE)

A week in winter with low renewable generation

Figure 7.29 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 green 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.

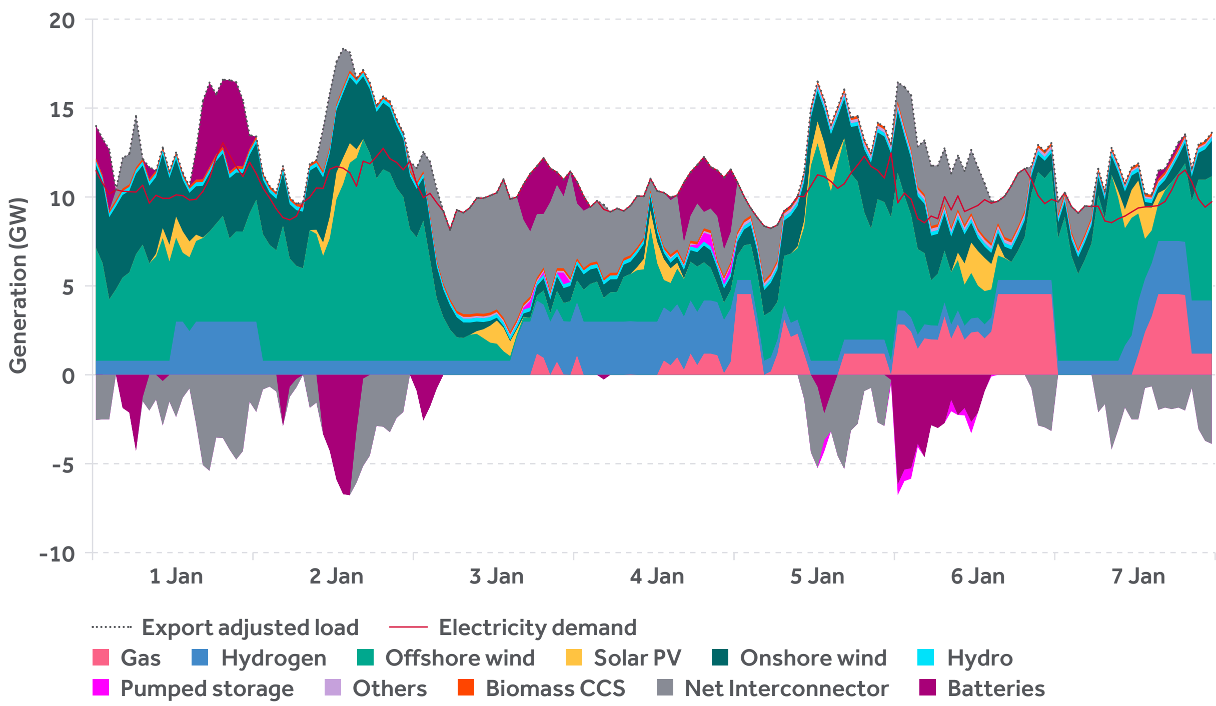


Figure 7.29: Offshore Opportunity, weekly timeseries in 2040 – low renewables in winter (IE)

7.6.3 Constrained Growth 2050

From 2050, the Constrained Growth scenario achieves a net zero power system. Figure 7.30 shows the annual generation mix.

This includes:

- Over 86% 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.

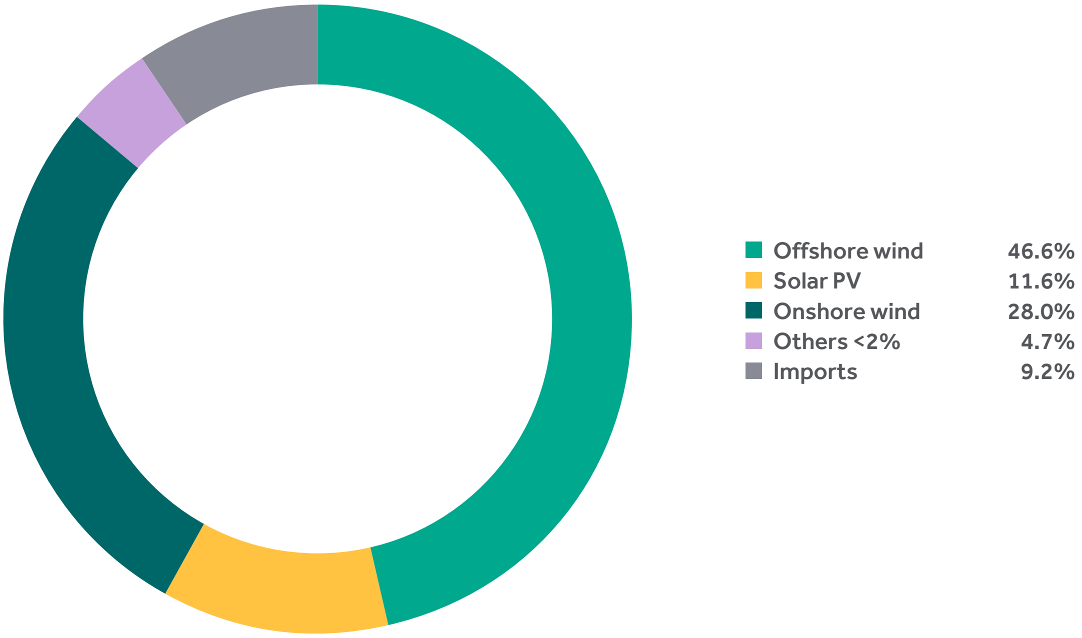


Figure 7.30: Constrained Growth, annual generation mix in 2050 (net zero power system) (IE)

A week in summer with high wind

The balance of supply and demand across a weekly period is shown in Figure 7.31. 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.

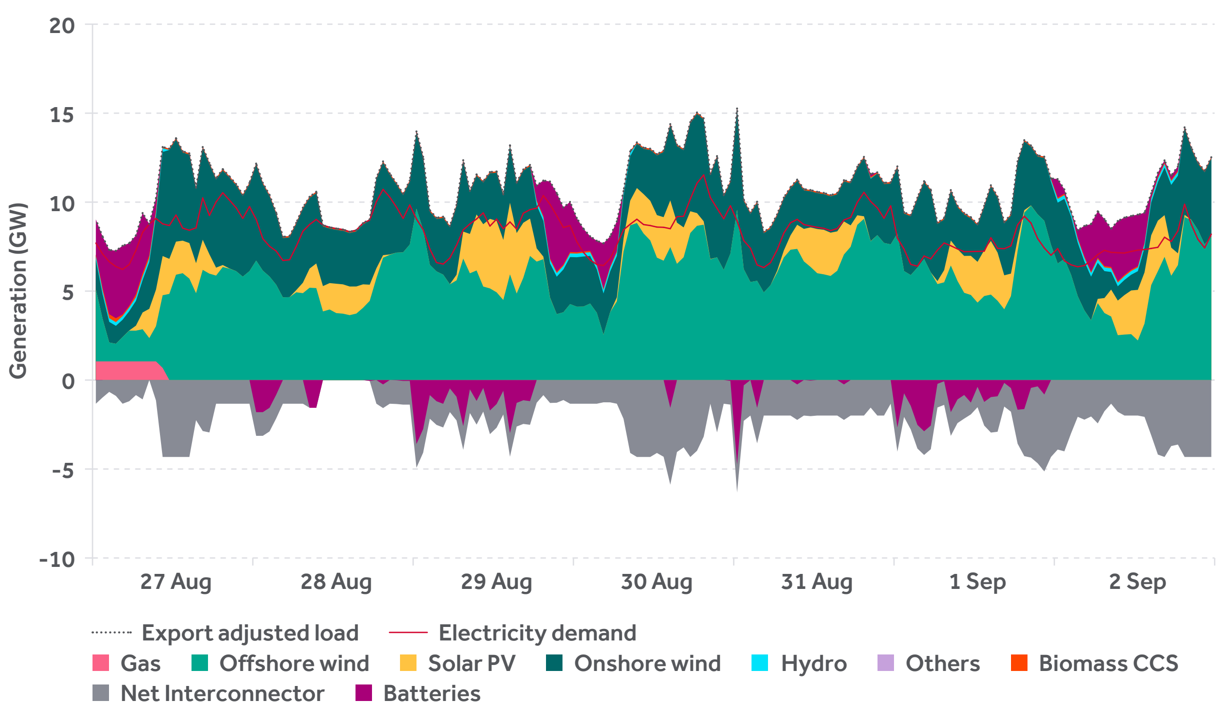


Figure 7.31: Constrained Growth, weekly timeseries in 2050 – high wind in summer (IE)

A week in winter with low renewable generation

Figure 7.32 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 unabated natural gas plants and plants equipped with CCS to secure electricity supplies for periods when renewable generation is not available.

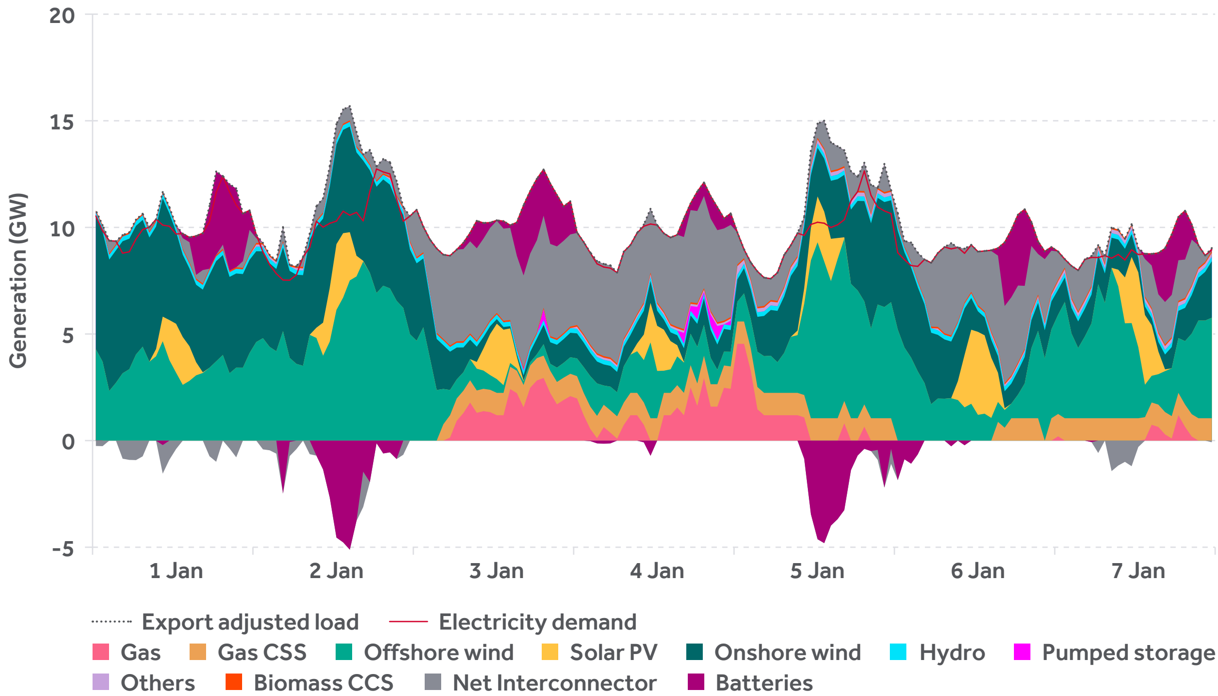


Figure 7.32: Constrained Growth, weekly timeseries in 2050 – low renewables in winter (IE)

7.6.4 Gas Evolution 2045

From 2045, the Gas Evolution scenario achieves a net zero power system. Figure 7.33 shows the annual generation mix. This includes:

- Over 69% 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.

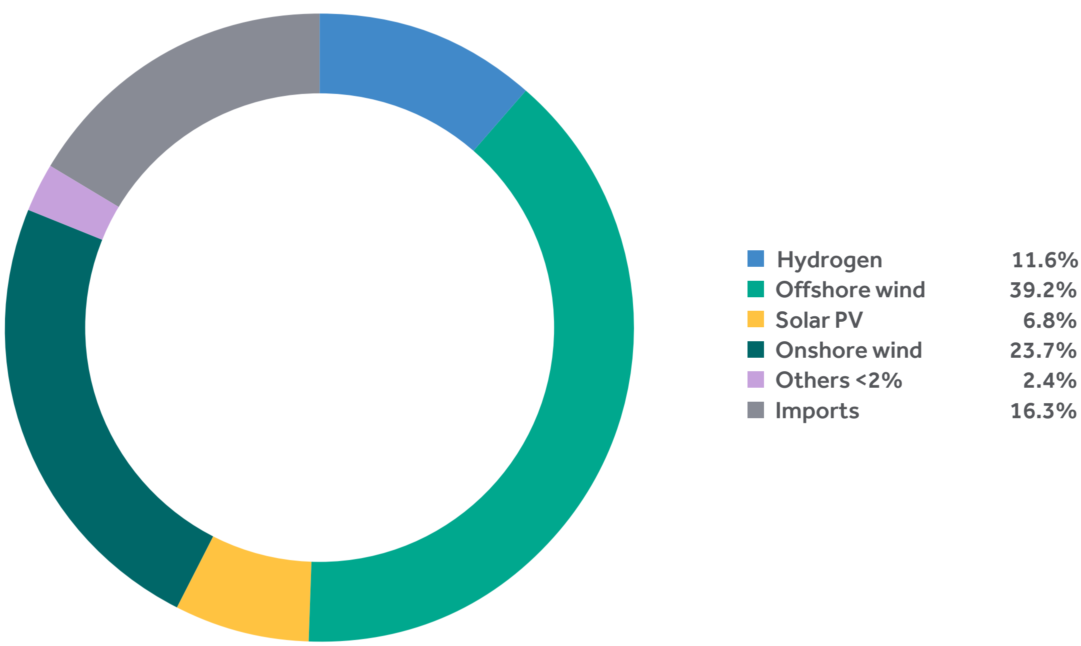


Figure 7.33: Gas Evolution, annual generation mix in 2045 (net zero power system) (IE)

A week in summer with high wind

The balance of supply and demand across a weekly period is shown in Figure 7.34. 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.

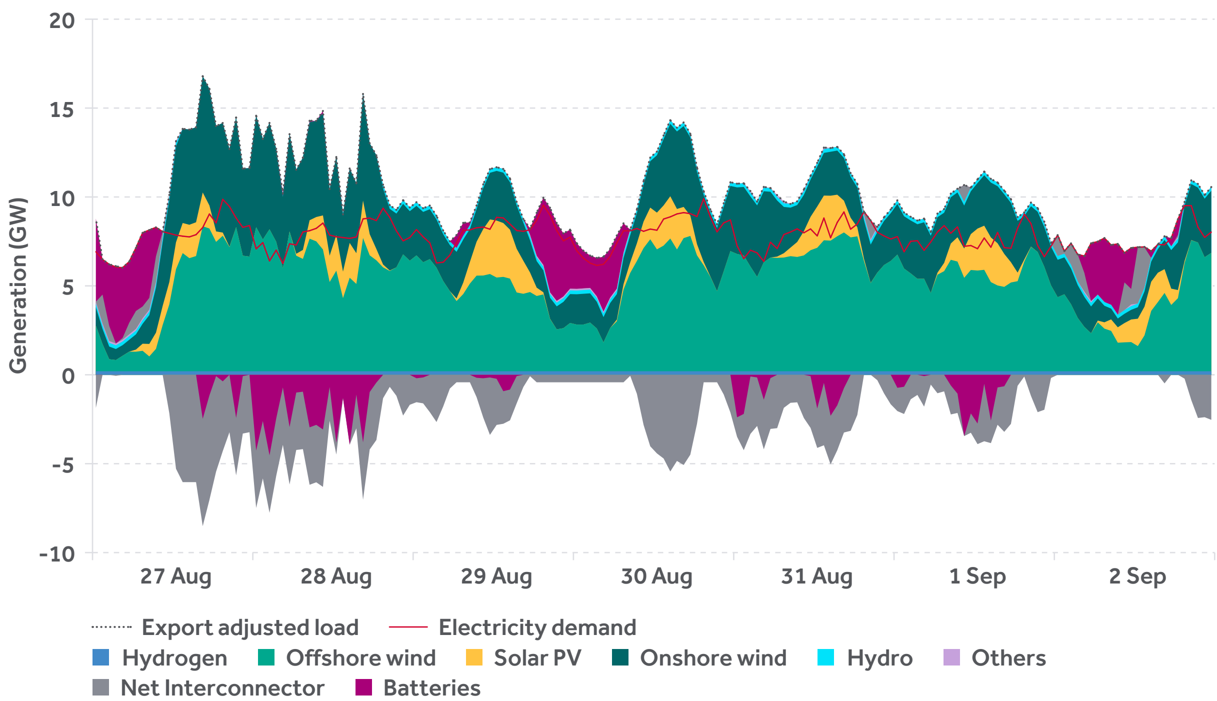


Figure 7.34: Gas Evolution, weekly timeseries in 2045 – high wind in summer (IE)

A week in winter with low renewable generation

Figure 7.35 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.

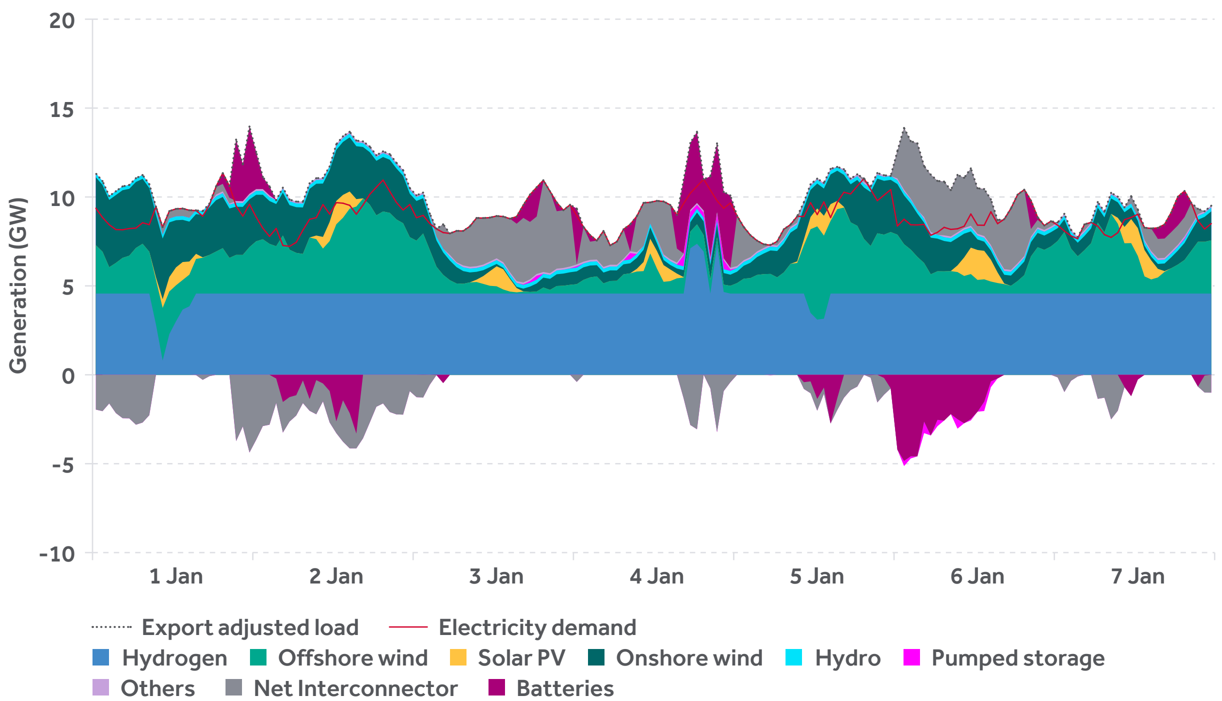


Figure 7.35: Gas Evolution, sample weekly timeseries in 2045 – low renewables in winter (IE)

7.7 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 7.7.1–7.7.4 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 7.36.

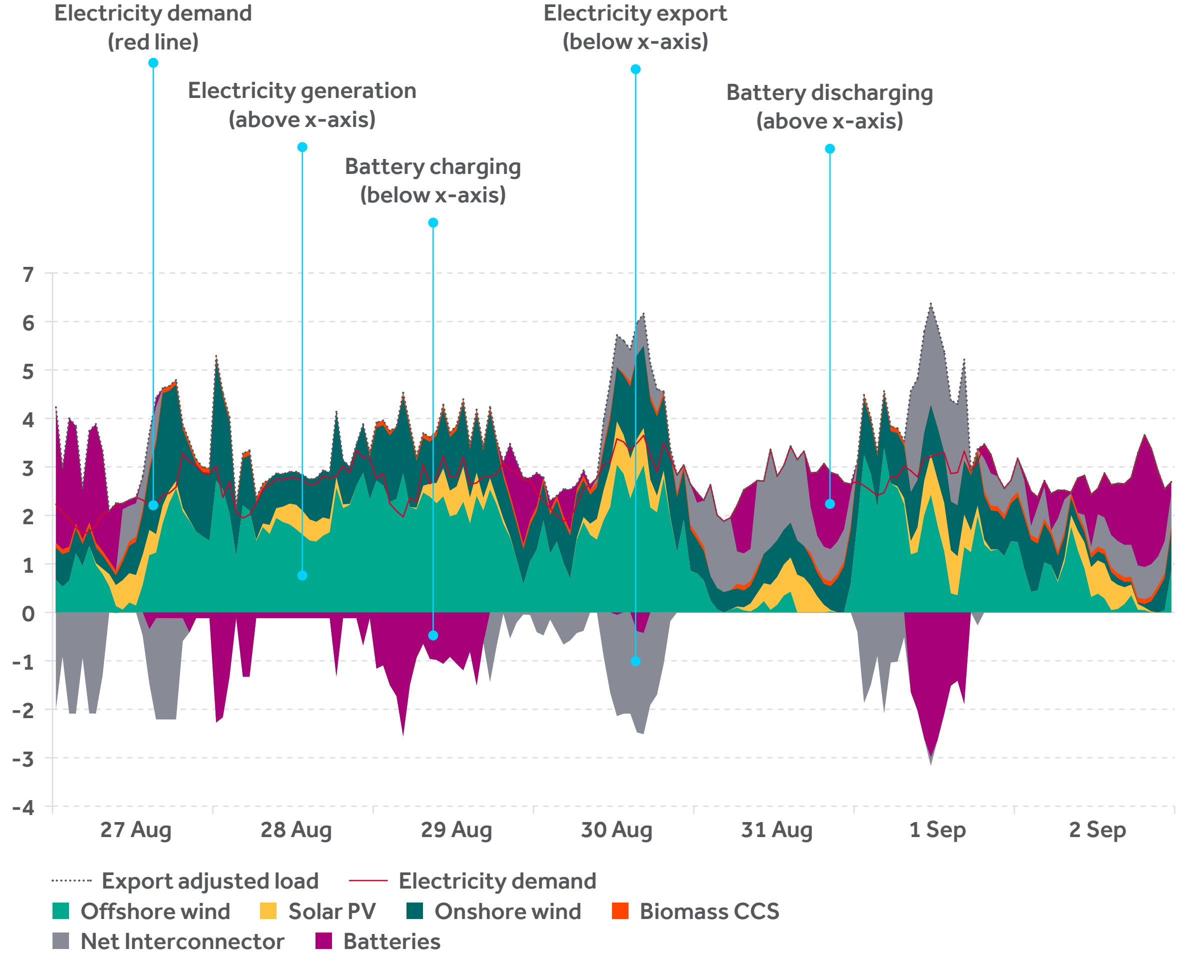


Figure 7.36: Example weekly timeseries showing how overall electricity generation above the x-axis and electricity exports and battery charging below the x-axis (NI)

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.

7.7.1 Self-Sustaining 2040

From 2040, the Self-Sustaining scenario achieves a net zero power system. Figure 7.37 shows the annual generation mix. This includes:

- Over 63% 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.

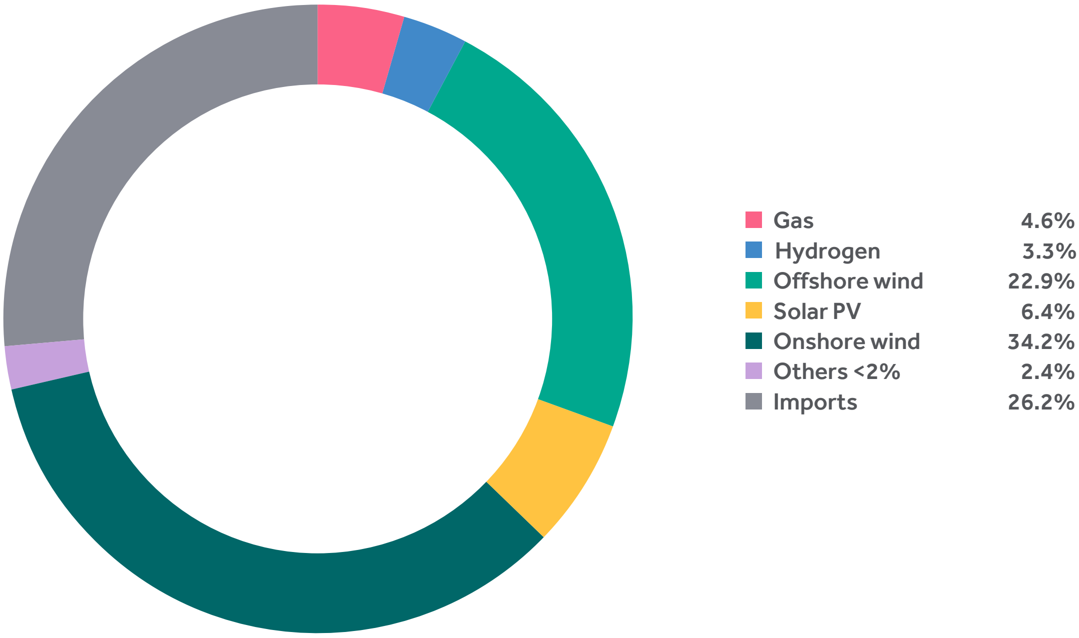


Figure 7.37: Self-Sustaining, annual generation mix in 2040 (NI)

A week in summer with high wind

The balance of supply and demand across a weekly period is shown in Figure 7.38. 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.

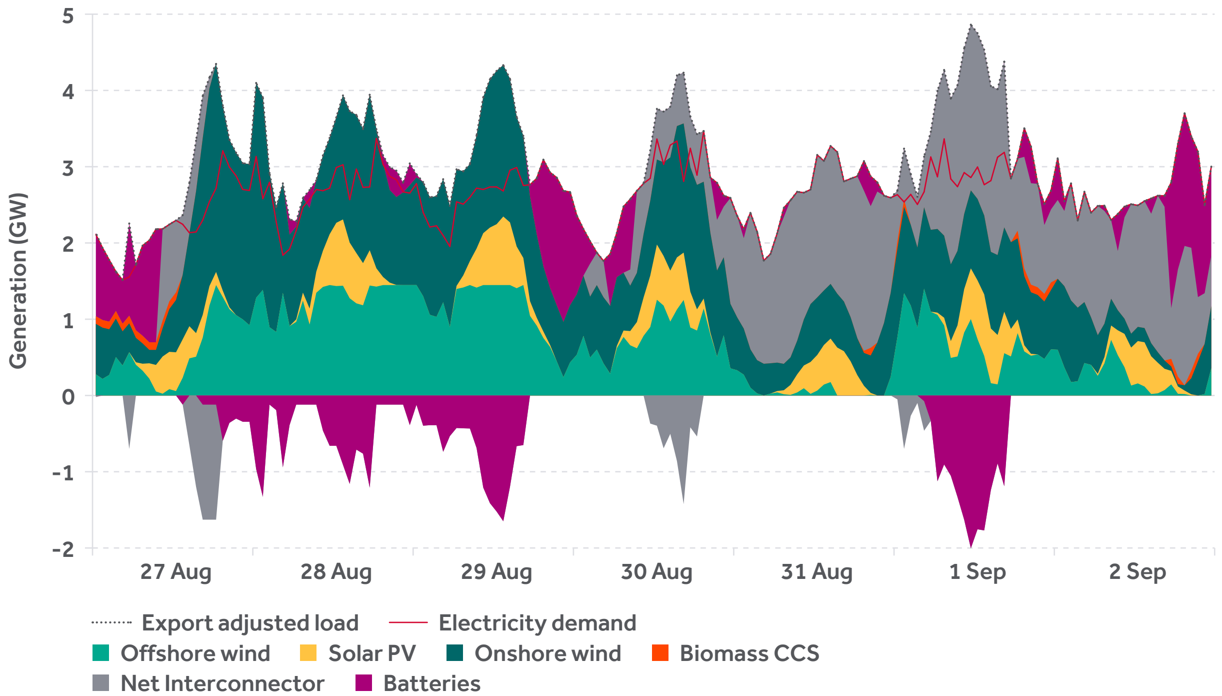


Figure 7.38: Self-Sustaining, weekly timeseries in 2040 – high wind in summer (NI)

A week in winter with low renewable generation

Figure 7.39 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 and hydrogen 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.

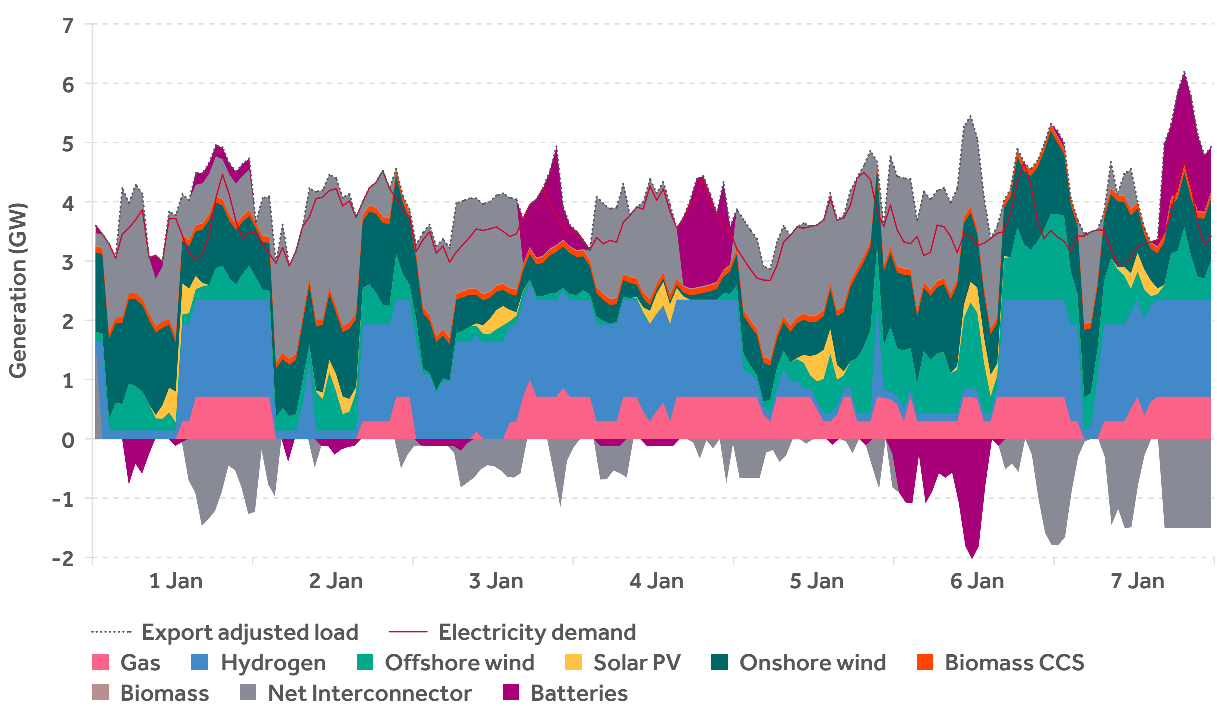


Figure 7.39: Self-Sustaining, weekly timeseries in 2040 – low renewables in winter (NI)

7.7.2 Offshore Opportunity 2040

From 2040, the Offshore Opportunity scenario achieves a net zero power system. Figure 7.40 shows the annual generation mix. This includes:

- Over 71% 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.

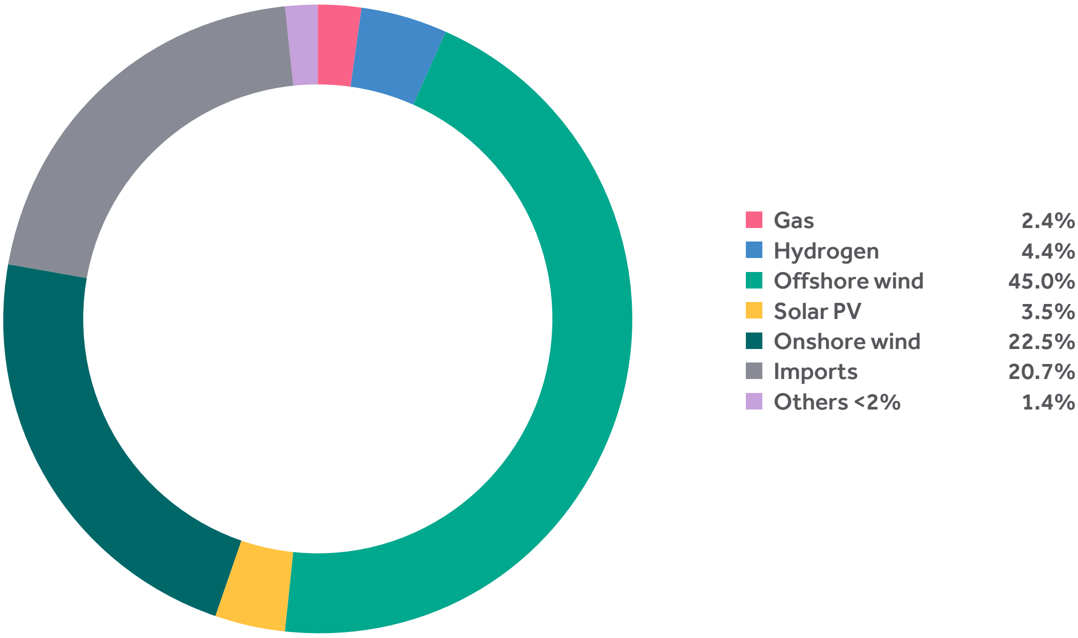


Figure 7.40: Offshore Opportunity, annual generation mix in 2040 (NI)

A week in summer with high wind

The balance of supply and demand across a weekly period is shown in Figure 7.41. 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.

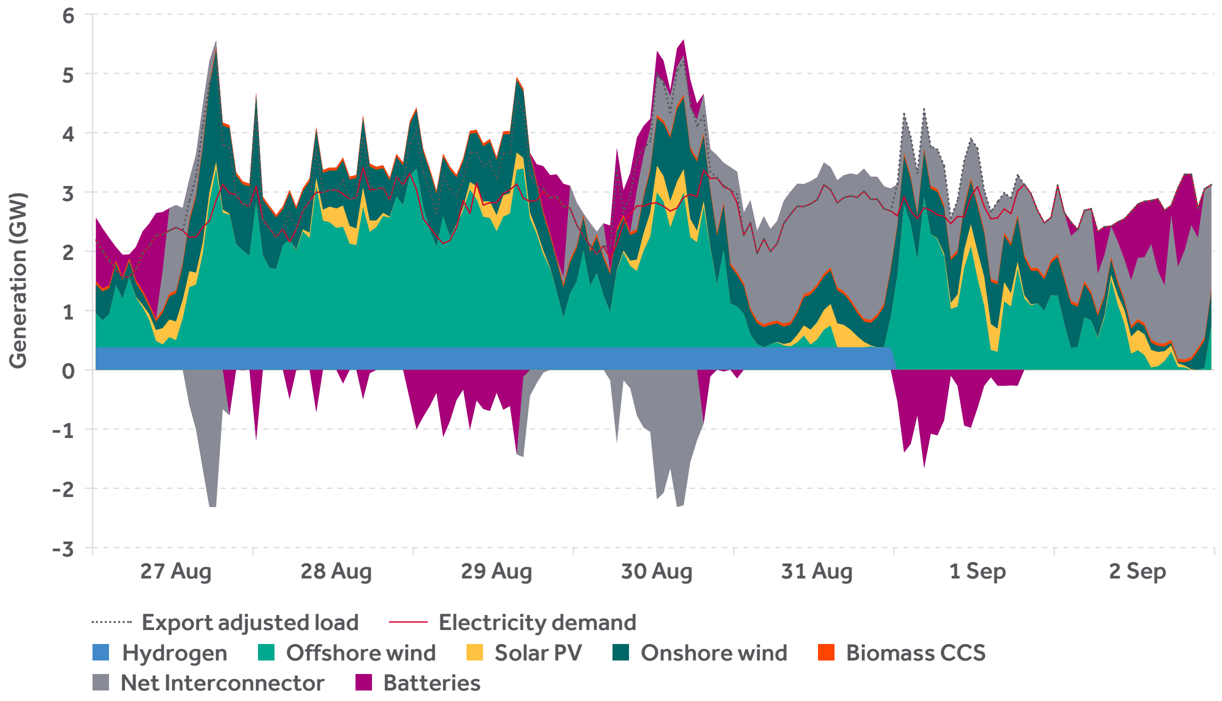


Figure 7.41: Offshore Opportunity, weekly timeseries in 2040 – high wind in summer (NI)

A week in winter with low renewable generation

Figure 7.42 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.

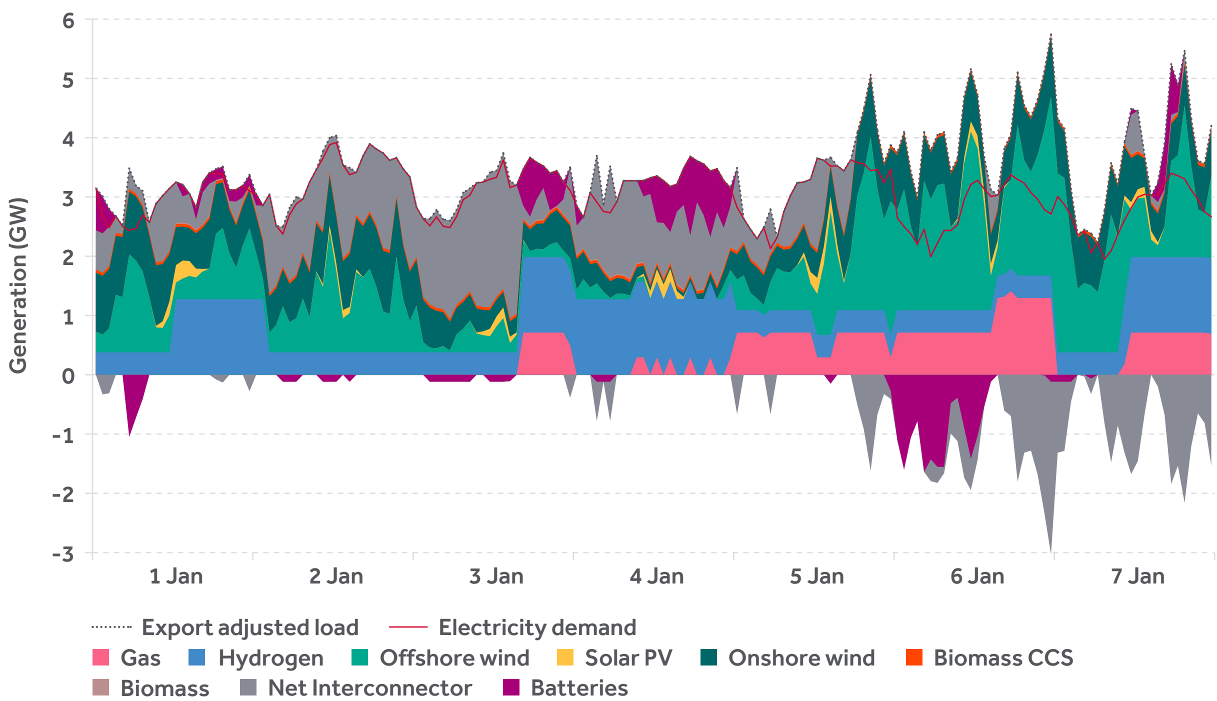


Figure 7.42: Offshore Opportunity, weekly timeseries in 2040 – low renewables in winter (NI)

7.7.3 Constrained Growth 2050

From 2050, the Constrained Growth scenario achieves a net zero power system. Figure 7.43 shows the annual generation mix. This includes:

- Over 80% 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.

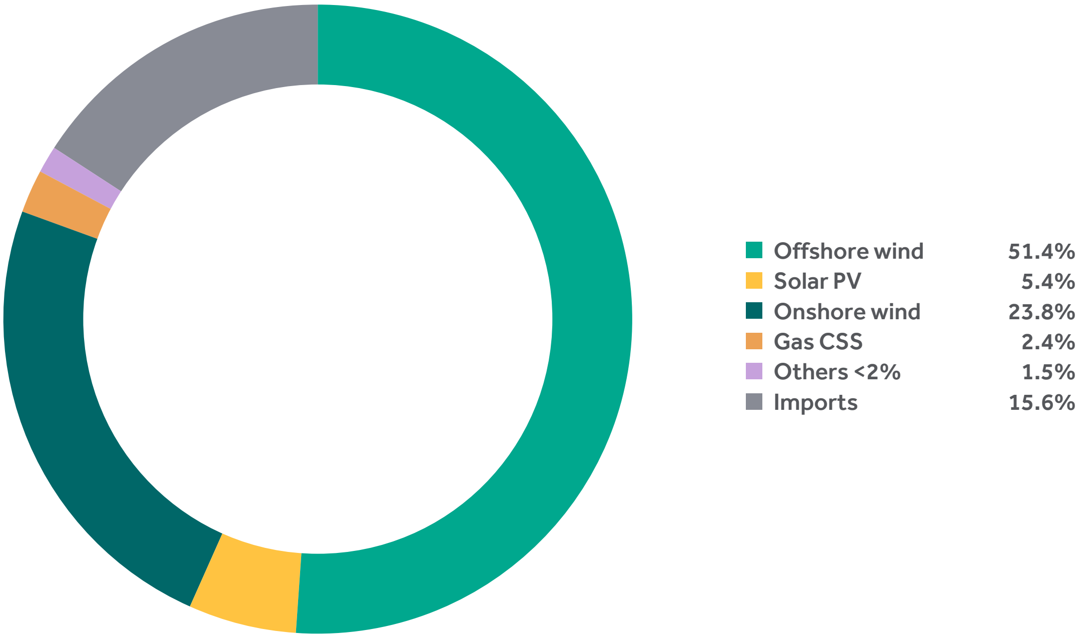


Figure 7.43: Constrained Growth, annual generation mix in 2050 (NI)

A week in summer with high wind

The balance of supply and demand across a weekly period is shown in Figure 7.44. 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.

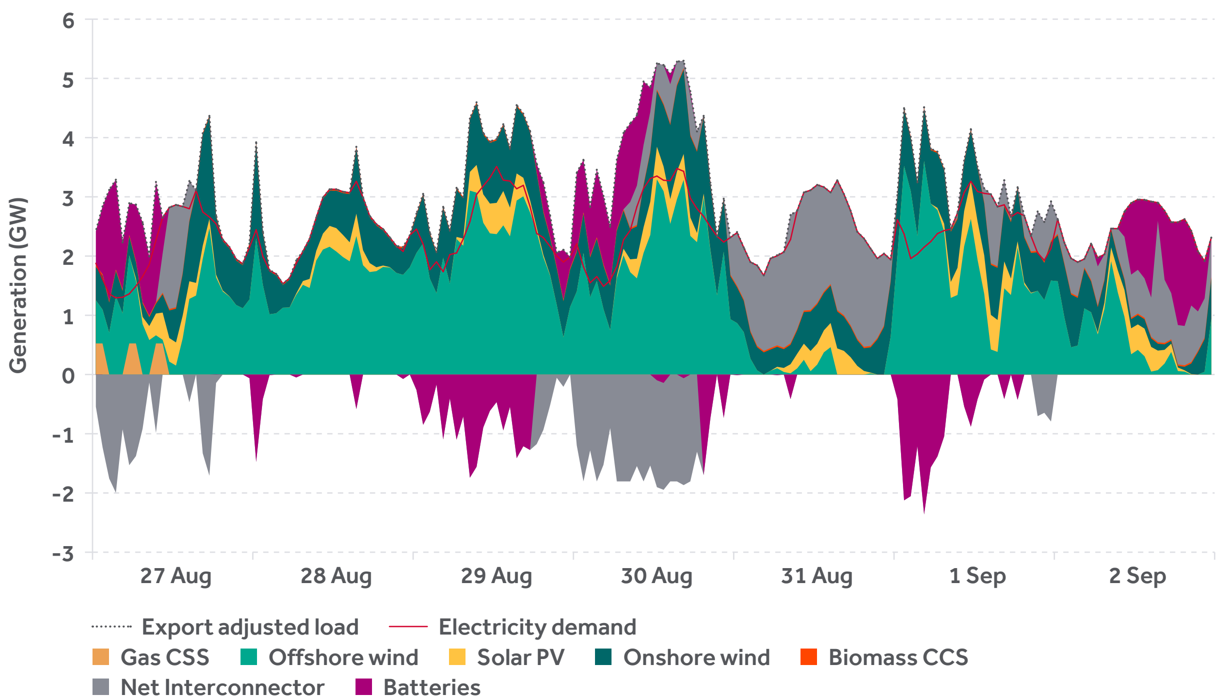


Figure 7.44: Constrained Growth, weekly timeseries in 2050 – high wind in summer (NI)

A week in winter with low renewable generation

Figure 7.45 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.

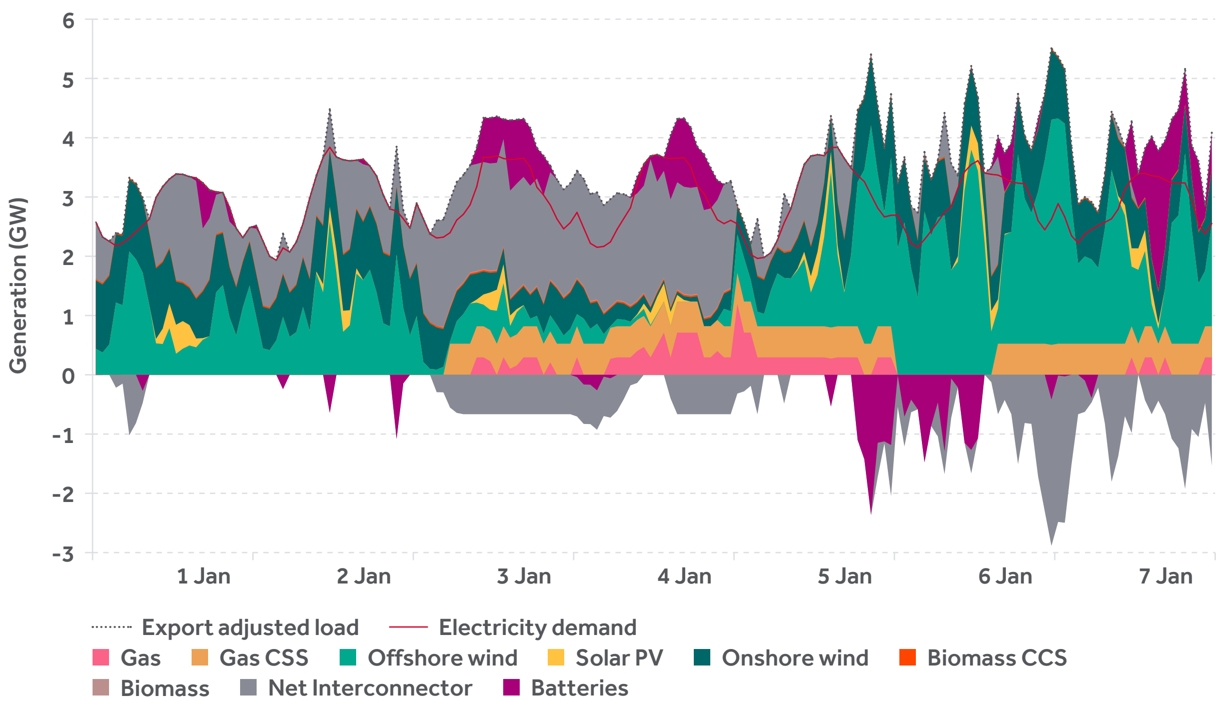


Figure 7.45: Constrained Growth, weekly timeseries in 2050 – low renewables in winter (NI)

7.7.4 Gas Evolution 2045

From 2045, the Gas Evolution scenario achieves a net zero power system. Figure 7.46 shows the annual generation mix. This includes:

- Over 68% 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.

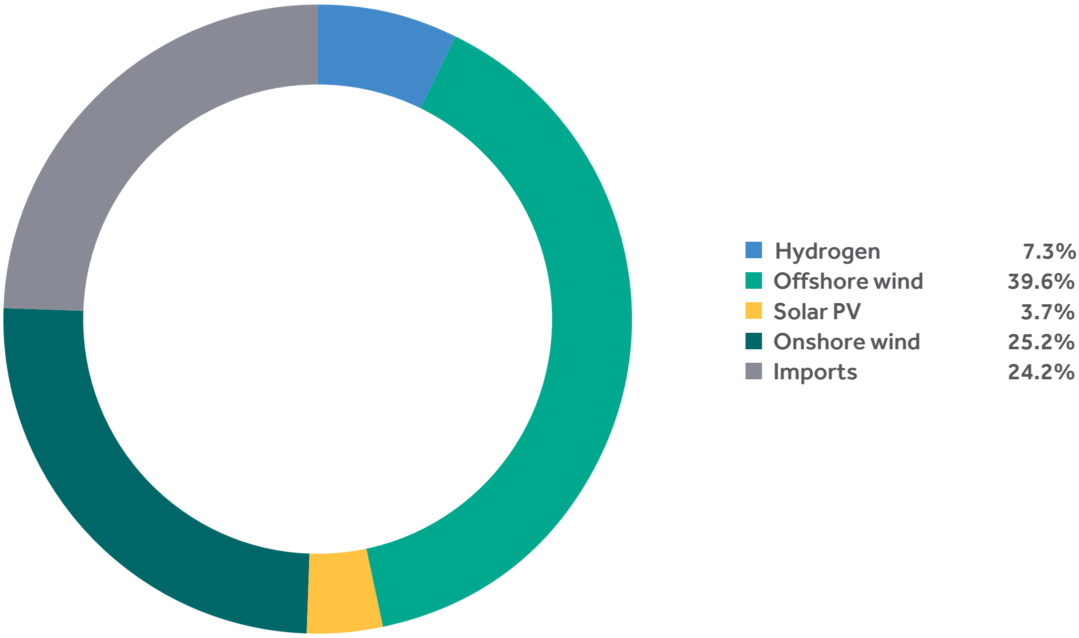


Figure 7.46: Gas Evolution, weekly timeseries in 2045– low renewables in winter (NI)

A week in summer with high wind

The balance of supply and demand across a weekly period is shown in Figure 7.47. 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.

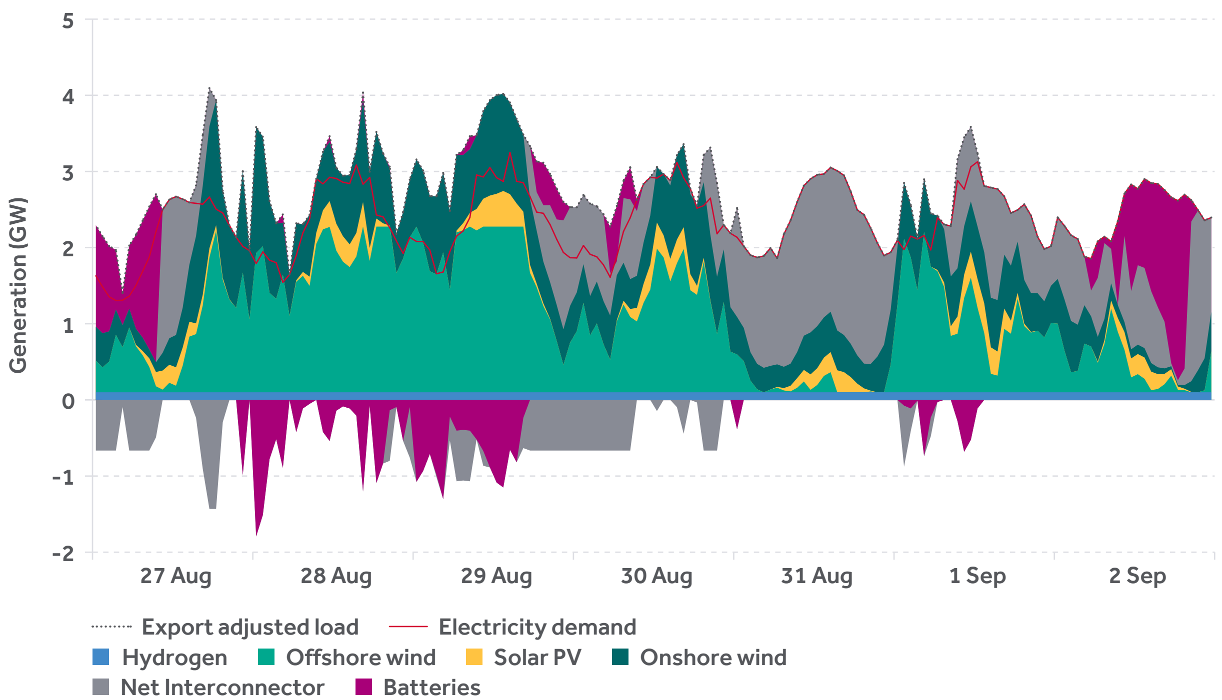


Figure 7.47: Gas Evolution, weekly timeseries in 2045 – high wind in summer (NI)

A week in winter with low renewable generation

Figure 7.48 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.

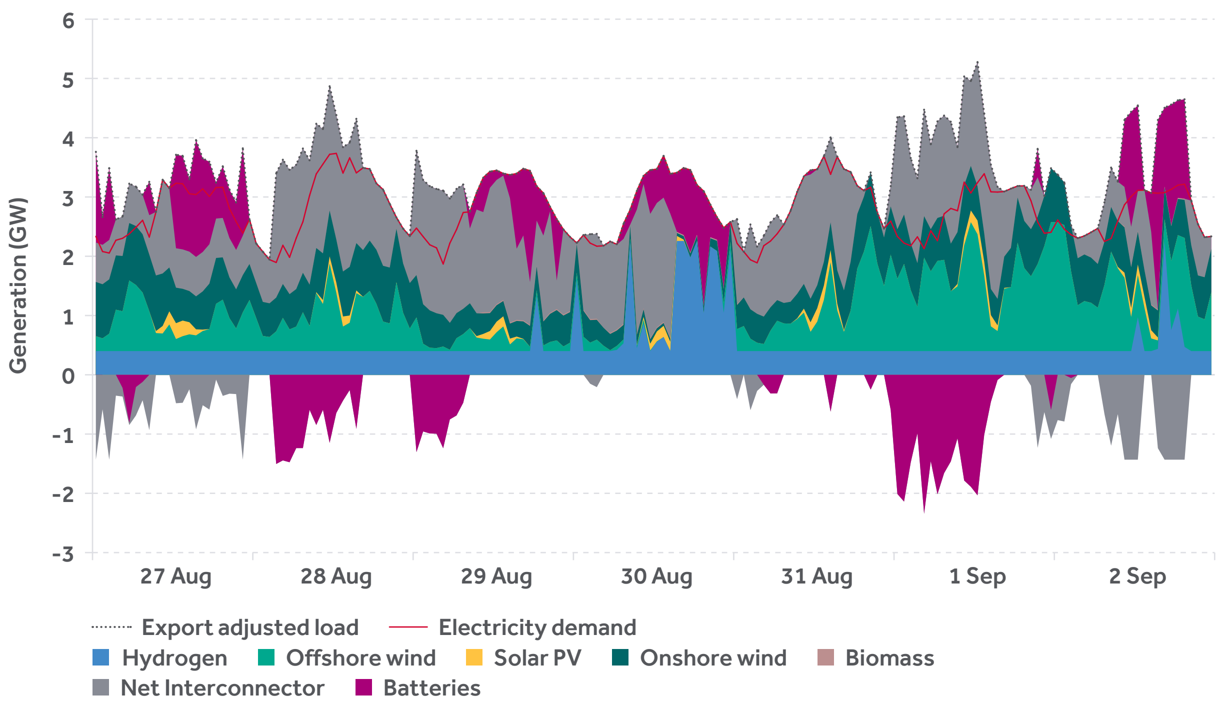


Figure 7.48: Gas Evolution, weekly timeseries in 2045 – low renewables in winter (NI)

7.8 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 7.11 and 7.12 below.

Table 7.11: CO_2 emissions for Ireland (MT)

	2035	2040	2045	2050
Self-Sustaining	0.98	-0.70	-0.74	-1.24
Offshore Opportunity	0.78	-0.83	-0.88	-0.92
Gas Evolution	1.13	0.50	0.00	0.00
Constrained Growth	2.49	1.63	0.97	-0.40

Table 7.12: CO_2 emissions for Northern Ireland (MT)

	2035	2040	2045	2050
Self-Sustaining	0.15	-0.33	-0.39	-0.59
Offshore Opportunity	0.16	-0.26	-0.28	-0.26
Gas Evolution	0.23	0.10	0.00	0.00
Constrained Growth	0.48	0.28	0.13	-0.17

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.

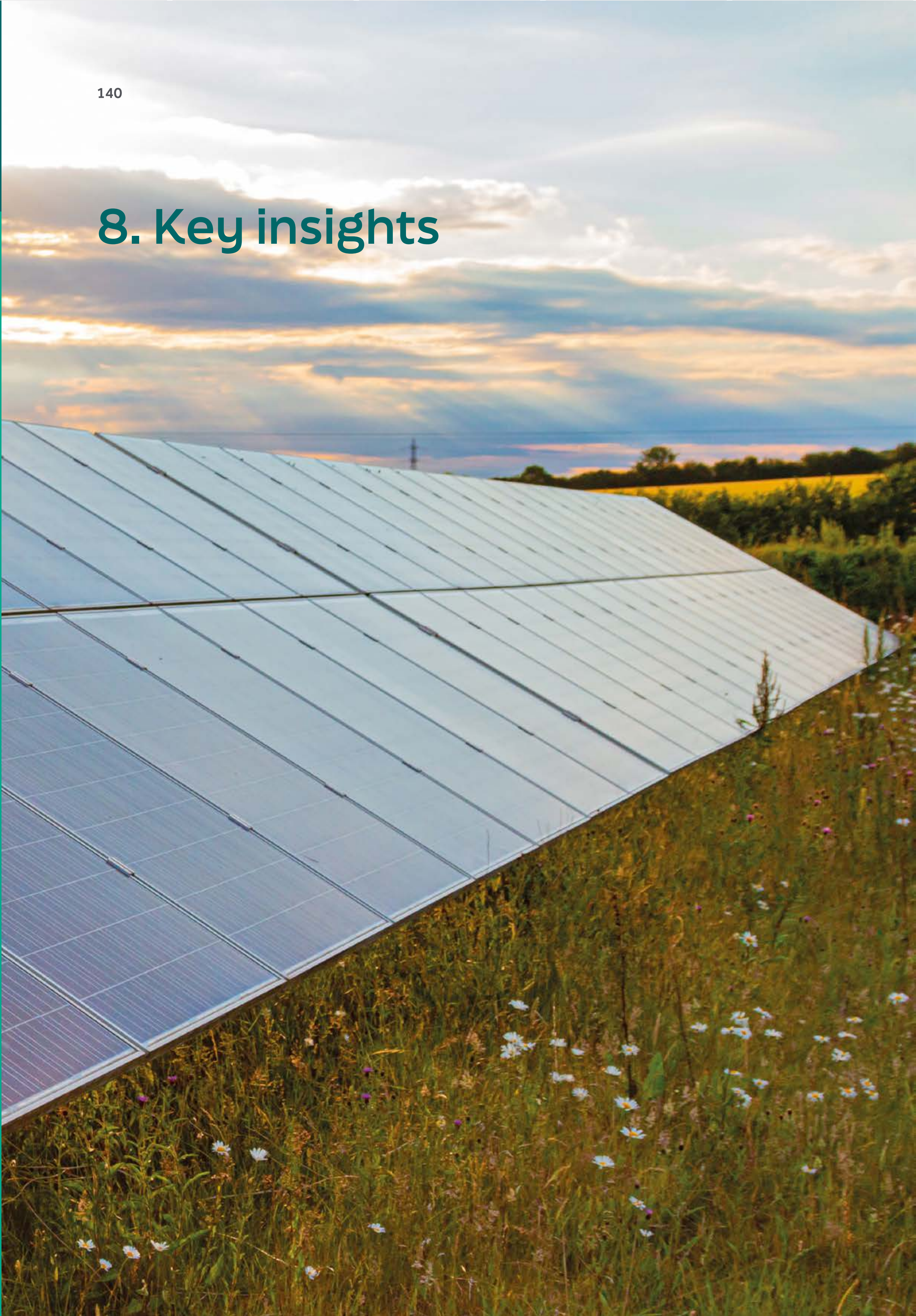
Gas Evolution

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.

8. Key insights



This report presents the final results of Tomorrow's Energy Scenarios 2023. Building on the consultation feedback, our analysis provides strategic insights into the decarbonisation of the power system out to 2050. The energy transition will affect every community and business and it is central to the sustainable development of Ireland and Northern Ireland. We want this long-term study to help inform an ongoing dialogue into the changing role of electricity in coming decades

Our scenarios consider how electricity demand and generation might evolve from 2035 to 2050. This report explains the approach we have taken to developing our scenarios and the results of our analysis. Below we have highlighted some key insights from the study, what they tell us about the energy transition and the future role for electricity, power generation, storage and interconnection supported by different technologies.

8.1 Key insights

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 analysis shows 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. This is as per Ireland's Climate Action Plan 2023 targets and the Climate Change Act in Northern Ireland. With electricity increasingly being supplied from renewable sources, this will lead to a reduction in demand for fossil fuels. We also expect to see an overall increase in energy efficiency. However, meeting the increased demand for electricity, will mean we need to significantly develop our power system.

2. There will be an increasing need for efficiency and demand flexibility

In a renewables-dominated power system, demand will need to be sufficiently flexible to account for fluctuations in renewable generation. This means, when there is less energy available from natural sources such as wind or sun, we need ways of managing this, particularly during times of peak demand. Measures to improve energy efficiency and demand flexibility will be vital to help manage peak loads on the power system.

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

Achieving a net zero power system requires significant development of the entire electricity sector. This is because we will need to shift from a grid based around large fossil-fuel powered generators to a system led by renewables located across our island and our seas. Due to the complexities involved for the whole energy system, we expect this transformation to be achieved no earlier than 2040.

4. We will need a balanced portfolio of generation technologies, led by renewables and 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 increases in **electricity interconnection** to continental Europe and Great Britain.
- A massive growth of **energy storage capacity**, including short, medium and long duration forms of storage.
- 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 plants.

5. Renewable fuels, such as green hydrogen, offer an opportunity to reduce dependence on fossil fuel imports and support increasing energy security

As we move away from fossil fuels, green hydrogen has the potential to play an important future role in the power system, especially when supplies from wind and solar are not sufficient to meet electricity demand. Our green hydrogen dispatch modelling shows how we might incorporate green hydrogen – which is relatively new to the power system – via renewable generators, electrolysers (to extract hydrogen from water) and green hydrogen storage.

This is important because our analysis shows that the grid will need renewables to be supported by firm dispatchable low-carbon power generation. This is energy that can help balance electricity supply and demand and can be turned off when it is not required, for example, when there is sufficient wind or sun to meet our energy needs.

6. A whole energy system transition

SONI and EirGrid's team, who have led the development of TES 2023, have benefited from significant contributions from a number of key stakeholders in Northern Ireland and Ireland. Their support has been essential to the quality of the TES 2023 analysis and the insights we are able to draw. Consultation feedback emphasised the need for further strategic planning to consider critical interdependencies across the whole energy system. Future studies provide an opportunity for energy system stakeholders to collaborate in strategic planning for our energy transition.

Summary

Going forward, Tomorrow's Energy Scenarios 2023 provides a solid foundation to inform our planning for the energy transition in Ireland. We hope you find this report useful, and that our valuable insights can support decision makers in the development of current and future energy policy.

For EirGrid, the next stage is our System Needs Assessment (TESNA) which will follow in 2024. We will be using the results from TES 2023 and TESNA to shape our thinking about more detailed planning for the electricity system and what this means across our networks.

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.

9. Appendices

9.1 Summary of TES 2023 feedback and SONI/EirGrid responses

Theme	Feedback	SONI/EirGrid response
Purpose of scenario planning	Consultation respondents recognised the importance of scenario planning and the reason that EirGrid and SONI use it to support strategic long-term planning of the power system.	SONI and EirGrid will continue to include scenario analysis in future studies for strategic planning of the power and wider energy system.
Scenario framework	Respondents requested more information about how scenarios were developed and why these were selected compared to alternatives.	The inception, rationale, and critical discussion of the four storylines presented in TES may be found in Section 5 of the final TES report, Scenario Framework. Scenarios were developed to help SONI and EirGrid best understand how the electricity system may need to change in future and so we can understand what this means for development of the transmission grid. The goal was to investigate up to four feasible and distinct options and then investigate their behaviour under a variety of informed assumptions. This purpose of exploring these options is to provide a first-step towards the needs assessment of the transmission grid in the future, and how the grid needs to evolve. As presented in the final TES report, key principles underlying the development of the scenarios used in TES included: • Key drivers: The selected scenarios typically represent the most significant and plausible variations in critical factors like energy policies, technology development, or market dynamics. Energy and climate legislation, strategies and plans in Ireland and Northern Ireland since the last edition of TES in 2019. In Ireland this included the Climate Action Plan 2023 and sectoral emissions ceilings for the first and second carbon budgets agreed by the Irish government in July 2022. • Government policy is driving the shift to renewable power generation, led by wind and solar technologies. Decarbonisation of generation and the electrification of energy demand will have significant implications for the electricity transmission system – how it operates and how we develop it to meet future demand. Changes in electricity demand that may be seen in each sector of the economy of Ireland and Northern Ireland as a result of electrification, for example, in electrification of private transport and residential heating. To provide a useful comparison, scenarios were developed to provide different perspectives on the energy transition and what this may mean for development of the Ireland and Northern Ireland's electricity system. The choice to consider a limited number of scenarios, in this case four scenarios, in a modelling study such as Tomorrow Energy Scenarios or similar analyses, is often made for practical reasons to strike a balance between complexity and usefulness: • Resource constraints: Creating and running scenarios can be resource-intensive in terms of computational power, time, and data collection. Limiting the number of scenarios helps manage these constraints. • Interpretability: Having a manageable number of scenarios makes it easier for stakeholders and decision-makers to understand and compare results, facilitating informed discussion and decision-making. The chosen scenarios were developed to capture a wide range of potential futures that are relevant to the study's objectives without becoming overly complex or overwhelming.

Theme	Feedback	SONI/EirGrid response
Grid development process	Some responses requested clarity regarding the Grid Development Process and how the outcomes of TES will be used to inform the subsequent System Needs Analysis. For example, how EirGrid's analysis will prioritise between investments in onshore transmission infrastructure or other technologies such as interconnection or energy storage.	The Grid Development Process followed by EirGrid and SONI includes the following stages: • Identifying the optimum solutions to address future needs of the electricity transmission system and what areas of the grid may be affected. Future needs may be driven by changes in electricity demand, generation, energy storage, interconnection. • Identifying where projects delivering the optimum solutions should be developed and built. • Project development and collaboration with other delivery stakeholders (e.g., ESB Network and NIE Networks). Identifying the optimum solutions to address our future needs is the first stage of this process and includes scenario planning (TES) and System Needs Analysis (TESNA) to assess the needs of the grid to deal with the additional generation and demands. By modelling the scenarios on the grid, seeing where needs arise, we can identify additional capacity or reinforcement needs in the transmission system. These needs will inform the grid development processes in Ireland and Northern Ireland. For TESNA, we take outputs from the scenarios, and consider where system capability or connection may be added – for example, the capacity of new onshore renewables that may be developed in areas of the grid. Our process recognises that the analysis of each scenario provides results that differ. Where similar requirements arise in multiple scenarios, we can be more certain it will be required and can start the development process for it. A need only arising in one scenario would be less of a priority and may need to be held off for a few years until there is more certainty on changes to the generation and demand portfolio, i.e., does the future start to trend towards that one particular scenario, if so, we can look at investigating solutions for the identified need.
Suite of EirGrid publications	Some consultation respondents requested clarity in the suite of publications provided by SONI and EirGrid and how these relate to each other. Other respondents considered that there are too many planning publications.	The development of the transmission network involves forecasting future needs. Solutions to address these needs must strike a balance between network reliability, costs, and environmental impacts. The process is flexible to enable the long-term development of the network. Section 4.3 discusses the framework of key planning documents currently developed by EirGrid, SONI and ENTSO-E and how these are linked together. In summary: • Tomorrow's Energy Scenarios addresses long-term scenario planning. This explores the future to 2035, 2040, 2045 and 2050 based on changes to the electricity portfolio, such as electricity generation, demand, interconnection and storage. • TES System Needs Assessment sets out an assessment of the needs of the transmission system in response to the final TES report results. • Strategic vision publications such as Shaping Our Electricity Future (SOEF) provides an outline of the key developments required in future management of the transmission system. SOEF, considers the power system from networks, engagement, operations and markets perspectives needed to support a secure transition up to 80% RES-E on the electricity grid by 2030. In the medium-term, potential projects are brought through the grid development process and any projects identified will be included in future Transmission Development Plans (TDPs). The TDPs are important inputs to the Generation Capacity Statement (GCS) and Ten Year Transmission Forecast Statement (TYTFS).

Theme	Feedback	SONI/EirGrid response
Scenario framework	Consultation respondents provided a range of feedback including requests to evaluate scenarios showing: 1. More ambitious transition to renewables led generation with a net zero power system by 2035 or earlier. 2. Removal of all fossil fuel generation (unabated and abated) and greater diversity in scenarios. 3. Scenarios consistent with previous TES publications. 4. Stress testing offshore wind targets. 5. Potential for divergence in scenarios in Ireland and Northern Ireland. 6. Concern that the timeline to achieve a net zero power system for Gas Evolution and Constrained Growth was too slow.	SONI/EirGrid welcome the feedback to the scenarios proposed. While it is not possible to provide scenario analysis that addresses all the suggested variations the following seeks to explain how the suggestions have been considered: 1. **A net zero power system by 2035 or earlier** The TES analytical results presented in the consultation report show a net zero power system operating between 2040–2050 depending on the scenario. This timeline is informed by our initial estimates for build rates and deployment of renewable generation, energy storage, interconnection and negative emissions technology (BECCS). If the deployment rates of these technologies and transmission grid development was accelerated it may be possible to deliver a net zero power system by 2035. To support this, additional sensitivity analysis showing a net zero power system by 2035 has been developed. The results of this analysis are provided in Appendix 9.2 of the final TES 2023 report. 2. **Removal of all fossil fuel generation (unabated and abated) and greater diversity in scenarios** Gas Evolution includes the replacement of natural gas generation by green hydrogen and the scenario shows this being complete by 2045. In this scenario hydrogen generators are primarily responsible for providing dispatchable capacity. By 2040, Offshore Opportunity and Self-Sustaining include significant additions of hydrogen capacity to the existing gas capacity. All scenarios also include various levels of biomethane use. 3. **Scenarios consistent with previous TES publications** In development of TES 2023, we considered retaining and updating the scenarios included in the previous edition of TES published in 2019–2020. Having reviewed changes in the landscape of the energy sector, such as the updated Climate Action Plans, the significant offshore ambition, and potential Hydrogen economy, it was deemed appropriate to develop new scenarios for our analysis in TES 2023. 4. **Stress testing offshore wind targets** The nature of the TES modelling approach – supported by PLEXOS to assess least-cost optimisation of power generation – enables technical review of deployment of generation and storage technologies. Results from our analysis are provided in a Databook accompanying the final TES 2023 report. 5. **Potential for divergence in scenarios in Ireland and Northern Ireland** Due to the constraints of the scenario modelling software SONI/EirGrid did not consider divergence of scenarios between Ireland and Northern Ireland. 6. **Timeline to achieve a net zero power system for Gas Evolution and Constrained Growth** We recognise the ambition to achieve a net zero power system as quickly as possible. We developed Gas Evolution and Constrained Growth to suit the technologies they employ and their underlying scenario narrative.

Theme	Feedback	SONI/EirGrid response
Scenario framework	Respondents generally supported the period of study as being 2035–2050. Some respondents requested analysis to commence from 2025 or results to be provided from 2030.	As a starting point, when developing TES 2023 it was considered important to build on and not seek to duplicate detailed analysis already published in summer 2023 as part of Shaping Our Electricity Future v1.1. With that in mind TES analysis commenced from 2030 with specific model results presented from 2035. Across the scenarios, where appropriate, we adjusted the installed generation capacity that was assumed to be operational by 2030. This is noted in Section 7 of the final report with detailed results provided in the attached data workbook.
Carbon budgets	Consultation respondents were supportive and positive about decarbonisation of the power sector. Some respondents sought clarity if the resulting scenarios for Ireland align with the emissions ceiling for the electricity sector associated with Climate Action and Low Carbon Development (Amendment) Act 2021.	The TES analytical results show a net zero power system operating between 2040–2050 depending on the scenario. This timeline is informed by our initial estimates for build rates and deployment of renewable generation, energy storage, interconnection and negative emissions technology (BECCS). If the deployment rates of these technologies and transmission grid development was accelerated it may be possible to deliver a net zero power system before 2040. To support this, additional sensitivity analysis showing two potential routes to a net zero power system by 2035 is provided in Appendix 9.2 of the final TES report. In Ireland, electricity sectoral carbon emissions budgets for the first two budget periods up to 2030 were agreed by the government in 2021. Self-Sustaining and Offshore Opportunity scenarios align with delivery of generation capacity and reinforcement projects planned for 2030 in SOEF v1.1. SOEF v1.1 set out how this portfolio supports alignment with the electricity sectoral emission ceiling and VRES targets. In addition, as a key input to our PLEXOS model, our demand assessment included assumptions for decarbonisation of energy demand in each sector. In Ireland, this analysis was informed by Climate Action Plan 2023, for example relating to the take up of heat pumps and electric vehicles. SONI and EirGrid will continue to work collaboratively with the governments of Ireland and Northern Ireland and other energy sector stakeholders to help agree further decarbonisation targets including the sectoral carbon budgets from 2031 onwards.

Theme	Feedback	SONI/EirGrid response
Electricity demand assumptions	Respondents requested further information regarding the demand assumptions used as inputs to our TES modelling relating to: 1. Total Electricity Requirement (TER). 2. Peak electricity demand. 3. Energy efficiency. 4. Residential and tertiary sectors. 5. Transport sector. 6. Industrial and New Technology Loads.	1. **Total Electricity Requirement** To model generation profiles for Ireland and Northern Ireland up to 2050, assumptions had to be made on how energy demand will change over this period for each scenario. To do this, demand inputs were developed for five key sectors: residential, tertiary (commercial), industrial, transport, and data centres & New Tech Loads. The growth rates of these key sectors are a function of population growth, economic growth, and scenario narratives. On a high level, all these elements combine to form the Total Electricity Requirement (TER). National Grid's Future Energy Scenarios (FES) and ENTSO-E's TYNDP were also studied to validate our methodology and sector-based assumptions. 2. **Peak electricity demand** Peak electricity demand is important because it represents the moment when the grid experiences the highest demand for power. To seek to manage peak demand in our scenario modelling, flexible technologies such as Demand Side Units, Smart Electric Vehicle charging, Vehicle to Grid and demand side storage were included. Various energy efficiency considerations were included that also contribute to reduce the overall peak (see below). 3. **Energy efficiency** In consideration of the EU Energy Efficiency Directive, TES 2023 outlines changes in electricity demand significantly driven by the transition away from fossil fuels to electrification. While we have not modelled the whole energy system, we anticipate that our assumptions for increasing electrification of demand will result in overall reductions in energy demand – electricity is generally more efficient than conventional fossil fuels. As a result, while the TER increases in our scenarios, we anticipate that total energy demand would reduce because of modelled efficiency improvements in each sector that electrifies away from fossil fuels. For residential, tertiary, and industrial sectors, improvements in heating efficiency, fuel type and processes are modelled including for higher rates of electrification. Efficiency savings are also applied to New Technology Loads to consider technology improvements over the years. Electric Vehicle charging profiles are modelled to reflect increasing availability of smarter charging in later years.

Theme	Feedback	SONI/EirGrid response
Electricity demand assumptions (continued)		4. **Residential and tertiary sectors** **Residential** a. Average household size and population projections were derived from 2019 Eurostat data among other sources. These contributed to projecting the total number of households. b. The total residential electricity demand was split into: Heating (both space and water), Cooking, Lighting, and electrical appliance use based on SEAI statistics for 2017. Heating demand per household was split into technology and fuel type. c. The technology splits were guided by literature reviews on related models such as National Grid's Future Energy Scenarios (FES) and the Energy Transition Model (ETM) and adapted to fit the specifics of the TES 2023 scenario storylines. d. These splits were thus modelled based on decarbonisation targets, installation costs, investment appetite and predicted economic growth. **Tertiary** a. Initial demand composition breakdowns are assumed to be relatively unchanged from TES 2019, while technology trajectories follow similar pathways to Residential progress. b. From TYNDP 2022, tertiary electrical demand is projected to rise from 2015 levels in Ireland, with overall tertiary energy demand decreasing due to efficiency of electric heat pumps. 5. **Transport sector** a. Data on vehicles was collated from various sources including the CSO Transport Omnibus 2019 and Department of Transport (DoT). b. Scenarios for the uptake of electric vehicles and, to a lesser extent, hydrogen powered vehicles, were developed as a function of population growth and literature review (FES 2022, NIE networks RP7 projections and ETM) to encompass a range of plausible futures corresponding to the scenario storyline. c. Sources such as, EVDB (electric vehicle database), Viriciti E-bus performance report 2020, Volvo truck literature on heavy duty electric trucks were used to identify specific consumption of electricity for each EV. d. Road and rail freight were electrified based on the economic growth levers used for the industrial demand, i.e., with more heavy industry the need for heavy freight is more. Hydrogen fueled vehicles were made available only to large vehicles, e.g., buses and road freight.

Theme	Feedback	SONI/EirGrid response
Electricity demand assumptions (continued)		6. **Industrial and new technology loads** **Industrial** a. Industrial electrical demand is modelled to grow in all scenarios. The scenarios project heavy industry decarbonising through electrification and the use of hydrogen and biofuels to decarbonise those processes that cannot be electrified. b. All TES scenarios have left room for growth in this sector to reflect the positive electrical demand through industries, that could locate in Ireland to access a large amount of green energy from RES-E. c. TES also aligns with FES 2022 projections with decreasing total industrial energy consumption due to decreasing uptake of Natural gas, Oil and Bioenergy with faster electrification and switch to hydrogen. d. Efficiencies for various fuel types are taken from National Heat Study Low Carbon Heating and Cooling report. e. Growth rate is higher in scenarios where the assumption is that green energy and stronger economy lead to more heavy industry locating and developing in Ireland. f. The Northern Ireland-specific TESNI 2020 developed a proxy-Eurostat dataset for industrial demand in Northern Ireland. A higher proportion of electrification has been assumed in Self Sustaining and Offshore Opportunity. **New technology loads and data centres** a. The total energy forecast is based on a rate of build out towards the connection contracts. It is assumed that these customers have a gradual build out towards their contract, and that the energy consumed day-to-day is constant. b. Data centre growth post-2030 is based on scenario narrative, stronger economy narratives with more green energy have more data centre growth projected. c. It is assumed that the Atlantic Hub data centre connects as planned. Space was allowed for growth in the pipeline connections of NI LEU, and trajectories used were set as a ratio of equivalent projections in Ireland.
Weather year	Some stakeholders raised queries regarding the use of a single climate year to inform the scenario analysis.	For the TES analysis, an average weather year was selected, in this case 2009. This particular year is recommended by ENTSO-E in the TYNDP as a sensible representative weather year for the European climate as a whole. Clearly, the weather experienced changes every year so in practice we may see, for example, prolonged periods of cold temperatures or prolonged periods of low or high wind speeds. Changes in weather will be experienced differently across Ireland, Northern Ireland and other countries. This weather year includes multi-day periods of strong renewable generation and periods with limited renewable generation from wind and solar. Some stakeholders noted that assessing scenarios based on an average weather year may mean that future system requirements may not be fully considered – for example in weather years (or multiple years) with prolonged periods of low renewable generation. We recognise this concern and will address these issues in future assessments to consider the resilience and adequacy of the power system to low wind or cold weather years.

Theme	Feedback	SONI/EirGrid response
Costs	Some respondents requested information about cost assumptions used in TES modelling.	As noted in the consultation report, cost input assumptions were principally based on ENTSO-E's TYNDP data. These costs were supported by other sources including AEMO Integrated System Plan 2022 AEMO | 2022 ISP inputs, assumptions and scenarios and European Commission reports on energy sector technology costs (Technology Pathways in Decarbonisation Scenarios Technology pathways in decarbonisation scenarios – Publications Office of the EU (europa.eu)). Our analysis includes estimates of fixed and operational costs of the different technology types to support expansion modelling.
Dispatch down	Some respondents raised concern that the level of dispatch down may be underestimated as constraints and curtailment information was not provided. Respondents also queries the level to which energy storage could support the reduction of dispatch down.	PLEXOS operates by minimising overall system cost. There are times in the model when the available renewable energy is greater than the demand meaning some amount of dispatch down of renewable energy must occur. In our modelling, this is done on a technology neutral basis within Ireland and Northern Ireland separately. As noted in Section 7 of the final report, other forms of dispatch down currently exist, namely constraints and curtailment. Constraints do not feature in our models as they are single node with no network representation. Curtailment does not exist in our models as they do not consider any operational requirements such as SNSP limits. It is worth noting that these operational requirements may be less strict in the future than present-day requirements. As a result of not considering constraints and curtailment our estimations of dispatch down represent a minimum level of dispatch down that would likely be higher if these additional forms of dispatch down were considered. This could have some impact on the relative economics of capacity buildout of generators, storage and interconnection.
Coal, oil and peat	Some respondents highlighted that the report should make clear that coal, oil and peat generation should be removed by 2035.	In the TES 2023 Consultation Report, we said that coal, oil and peat generators were assumed not to be in operation by 2035. For clarity, we have not included these generators in the TES 2023 analysis so we have assumed that coal, oil and peat generators will not to be in operation for the period of the study.

Theme	Feedback	SONI/EirGrid response
Modelling capacity expansion in Great Britain and continental Europe	Some respondents sought clarity about how TES modelling considered the development of the power system in Great Britain and continental Europe concurrently with the modelling for Ireland and Northern Ireland in each scenario.	In our modelling, installed generator capacities in Great Britain and France are taken from the TYNDP22 scenario that best matches the TES scenario. For conventional units (gas, nuclear etc.) the exact trajectory in the TYNDP scenario from 2030-2050 is followed. For onshore wind, offshore wind, solar, batteries and gas/hydrogen candidate expansion available from 2030–2050 in both Great Britain and France. This means that the model optimises the growth of capacities in these markets. The expansion costs are the same on a per megawatt basis between Ireland, Northern Ireland, Great Britain and France but different capacity factors in different regions affect the economics of each technology in each market. A breakdown of the installed generator capacities in Great Britain and France is included in the Databook accompanying the final report.
Hydrogen	Some respondents highlighted electrolysis plant for production of hydrogen should be grid-connected. Respondents generally supported the inclusion of hydrogen in the TES scenarios. Some respondents requested additional information regarding production and storage requirements in relation to power generation. For example, hydrogen storage may support seasonal storage of renewable energy.	In the consultation report, it was assumed all production of green hydrogen came from offshore wind. In practice this may come from a variety of different sources including dedicated renewable generation and surplus energy from the grid. Hydrogen supply may also be supported by imports through repurposed gas interconnectors. For our final report we have included results from modelling for green hydrogen production (electrolysis), storage and demand. The results are provided on an all-island basis in Section 7 and the accompanying Databook.

Theme	Feedback	SONI/EirGrid response
Energy storage	Some respondents raised queries regarding the approach to forecasting energy storage requirements including: • Demand side storage and Vehicle 2 Grid (V2G). Performance characteristics of energy storage technologies (e.g., round-trip efficiencies). • Technologies considered as 'Long-Duration'. • Other energy storage technologies.	We recognise that energy storage technology is developing and we have sought to reflect this with our TES analysis. For each scenario, some amount of battery storage is available as a candidate within PLEXOS. Battery storage is useful from a system perspective (and therefore from PLEXOS' cost-minimisation perspective) because it allows stored energy to cover shortfalls in a much cheaper and faster way than otherwise possible (if a thermal generator had to run, or more generation capacity be built, for example). In addition, the capabilities of batteries to conduct arbitrage between high and low-priced periods of time smooths market fluctuations and reduces costs. For these reasons, the presence of batteries is beneficial to the overall system. Some batteries in the PLEXOS model are pre-existing or planned for installation by 2030. Others have been added as candidates. Lithium-Ion batteries of durations between 2-8 hours have been added. In addition, in the Self-Sustaining scenario, a 100-hour long duration storage option has been added, intended to replicate an iron-air battery. The duration value of a battery measures its storage divided by its power (e.g., a two hour battery can discharge at full power for two hours before it is spent). Lower-duration batteries are less useful, but also typically cheaper. Within reasonable constraints based on likely manufacturing abilities and technology development, we have allowed PLEXOS freedom to optimise these battery options in different scenarios. We recognise that hydrogen, natural gas and other technologies may provide dispatchable power in periods of higher electricity demand or when other sources of generation are not available – for example during prolonged periods of low wind. The requirements for 'seasonal energy storage' and how these requirements may best be met will be considered by SONI/EirGrid in a future study. TES 2023 analysis does not explicitly include thermal storage, distributed energy, district heating, boilers, or the full range of distributed energy resources, as its primary focus is on the electricity system dynamics from 2035 to 2050. However, it acknowledges the significant benefits of technologies like Power2Heat, Thermal Energy Storage, and electrification of the heat sector in decarbonising energy systems and promoting energy efficiency. These topics are likely to be very important in future energy system planning. It is recommended that they are considered as part of future studies of the whole energy system in Ireland and Northern Ireland.

Theme	Feedback	SONI/EirGrid response
Carbon Capture & Storage	Some stakeholders sought further information regarding the deployment of CCS technology and suggested this should be explored in future iterations of TES as the technology develops. Queries were also raised regarding the Ireland's policy position regarding CCS and the potential carbon capture rates that could be reasonably be assumed. A small number of respondents suggested that negative emissions technology should not be included in a net zero power system.	The potential role of CCS in abating conventional thermal generators and biogenic generators (BECCS) was considered in the TES analysis. Recognising that CCS is a developing technology, we included scenarios with and without CCS to show different potential pathways for power generation. Addressing consultation feedback, our final analysis includes reduced carbon capture rates of 90% from the flue. For all scenarios, with the proportion of electricity from renewable generators increasing, the capacity factor of thermal generators will decline to much lower levels and there will be increasing periods in which demand can be almost or entirely met by renewables, storage and interconnection. Ireland's policy position regarding CCS technology has been explored previously by Ervia (see CCS-Ireland-Initial-Assessment.pdf (ervia.ie). Noting the potentially future role for CCS in abating emissions from conventional thermal or biogenic generators this is anticipated to be an area of further research and policy development in Ireland and Northern Ireland. The accompanying Databook provides further detail regarding deployment of CCS technology in each scenario.
Nuclear power generation	Some respondents suggested that Nuclear power should be considered as a generation technology in TES 2023.	TES 2023 was developed on the basis that government policy is not supportive of nuclear power – it is not permitted in Ireland under the Electricity Regulation Act, 1999 (Section 18 (6)). A change in government policy would be required to enable its use in the context of the future power system. In Northern Ireland, while energy policy is generally devolved, nuclear power is an exception – it remains a matter of national importance and falls under the category of excepted matters. Therefore, decisions related to nuclear energy are not within the legislative competence of the Northern Ireland Assembly https://www.gov.uk/guidance/devolution-settlement-northern-ireland TES 2023 has been developed on the basis that the policy unlikely change in the short to medium term. We understand that some countries are considering development of nuclear power generators – this includes jurisdictions both with and without existing nuclear plant. Should policy develop that is supportive of a nuclear power a future review may consider the potential for nuclear generation.

Theme	Feedback	SONI/EirGrid response
Biomass	One respondent queried SONI/EirGrid's assumption that biomass-fired generation plant would not be operating post 2031.	We note that Bord na Móna plan to renew and continue the planning approval for operation of Edenderry Power Station. Notwithstanding this, SONI/EirGrid's latest Generation Capacity Statement does not include this generator in its assessment. For consistency this approach was followed for TES 2023. Furthermore, TES23 considers scenarios that include capacities of BECCS of between 75-300MW in Ireland and we note that the existing biomass plant in Edenderry could be capable of meeting some or all of this requirement if it is equipped with the necessary capability to capture and store CO_2.
VRES capacities	Some respondents raised concern that onshore capacities for solar and wind were too low. Other respondents suggested that targets for offshore wind capacity in Ireland should be higher than the current non-binding targets of 37GW. Some respondents were concerned that the targets for offshore wind capacity in Northern Ireland were too high at 4GW, others felt that this was too low.	We note consultation respondents shared a range of opinions relating to the potential development for onshore and offshore VRES generation capacity. In developing the scenarios we sought to strike a balanced position that reflected different future development pathways. The scenarios were designed to provide different results for development of VRES. For example, Self-Sustaining allowed optimised development of solar and wind generators (up to reasonable spatial limits onshore) while Offshore Opportunity included the forced development of 37GW offshore wind generators. As further information becomes available, for example, regarding the potential for repowering of existing onshore wind sites or confirmation of offshore capacity in Northern Ireland's marine area, we will review this and update our assessments in future publications.

Theme	Feedback	SONI/EirGrid response
Inter-connection	Consultation feedback regarding interconnection and its role in the TES scenarios included: 1. How will electricity prices develop in electricity in coupled markets? 2. How does the inclusion of increasing interconnection affect the generation portfolios of Great Britain and France? 3. Does increasing interconnection raise concerns regarding adequacy of energy and security of supply? 4. Findings do not appear to include or consider the role of Hybrid Interconnectors. 5. Offshore Opportunity includes for a large addition to interconnection capacity – is this feasible, noting supply chain constraints?	Experience and research into electricity interconnection has highlighted a number of benefits. These include: 1. Increasing electricity interconnection between countries can help to reduce the total system costs of electricity networks. The overall outcome may be seen to be an increased level of net welfare with benefits seen by consumers as electricity prices tend to converge across connected markets. For Ireland and Northern Ireland, this should mean a reduction in the prices of electricity through increased coupling of the SEM to Great Britain and continental Europe. 2. Increasing electricity interconnection should also benefit Great Britain and France. Our accompanying Databook provides information for how the generation portfolios in each modelled region develops through our scenarios. It should be noted that both Great Britain and France are also exploring further interconnection to other countries. ENTSO-E recently published the Offshore Network Development Plan 2024 European offshore network transmission infrastructure needs Offshore Network Development Plans (entsoe.eu) which includes more information. 3. System adequacy and Security of Supply are important considerations for planning the transmission network in every region. SONI and EirGrid will continue to review the appropriate level of interconnection and electricity imports to meet Ireland's and Northern Ireland's requirements for adequacy and security of supply. It should be noted that at this time energy imports dominate the energy mix for Ireland and Northern Ireland in the form of fossil fuels (coal, gas, oil). Increasing electrification and developing domestic generation capacity from VRES should reduce the overall proportion of imported energy over time. 4. Hybrid interconnectors were not included as a candidate in this level of analysis. Hybrid interconnectors will be considered in future studies. 5. Offshore Opportunity does include a large addition of interconnection capacity. The development of this capacity is a consequence of this scenario which includes a high level of offshore wind development by 2050 in line with government targets. To deliver this level of additional capital infrastructure will require overcoming a number of challenging hurdles, one of which is the level of capacity and capability in the whole value chain across the asset lifecycle. TES is a strategic long term study and with complementary measures from the key stakeholders it is reasonable to assume that the challenges may be overcome over the period to 2050.
Whole energy system	Some respondents requested that the scenarios consider the future development of the whole energy system.	The energy transition poses challenges that effect supply, transmission and demand across the whole energy system. As TSOs, SONI and EirGrid are keen to collaborate with stakeholders to consider scenarios that assess concurrent development and interdependencies across the whole energy system and each sector.

9.2 Sensitivities assessing net zero power system from 2035

Some consultation responses requested analysis of scenarios that would lead to a net zero power system from 2035. To address this feedback two sensitivities were developed to understand the results of a faster pace of transition.

To address this and provide meaningful results we adapted our two scenarios which supported the fastest transition to net zero: Self Sustaining (SS NZ35) and Offshore Opportunity (OO NZ35). Many features of the core scenarios remained unchanged in our sensitivity analysis. These included:

- Sensitivities start from the same generation capacities assumed in the core scenarios for Self Sustaining and Offshore Opportunity (2030).
- Demand profiles in each sensitivity remained the same as the core scenarios for 2035.

Key changes introduced to the sensitivities included:

- CCS technology remained available as a candidate in the SS NZ35. To provide an alternative perspective, CCS technology was removed as a candidate from OO NZ35.
- Carbon emission constraints were amended in the modelling to force emissions from power generators to reduce to zero from 2035.

9.2.1 Sensitivity Results

The results from our sensitivity analysis are provided in the accompanying Databook. This includes tables of generation capacity, dispatch results and resulting carbon emissions for each scenario in 2035.

When compared to the core scenarios, the sensitivities are very ambitious. They include changes in generation capacity build and dispatch in Ireland and Northern Ireland. In summary, the tighter emissions constraints drive a more ambitious build-out of zero carbon generators. Both sensitivities show a faster roll-out of variable renewables; complemented by dispatchable low-carbon technologies.

For SS NZ35 accelerated decarbonisation is supported by faster development of negative emissions technologies (BECCS) and abatement of gas generators.

For OO NZ35 accelerated decarbonisation does not have CCS available as a candidate. As a consequence, this relies upon faster development of variable renewables, decommissioning of methane generators and their replacement with hydrogen generators. The accompanying Databook highlights that this would need to be complemented by accelerated roll out of further dedicated renewables powering electrolysers and hydrogen storage infrastructure.

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