Northern Ireland Constraints Report 2016

May 2016

SONI

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Document Structure

This document contains an Executive Summary, a Glossary of Terms section, and five main sections.

The **Executive Summary** gives an overview of the main highlights of the document and presents the regional results for each study year.

The **Glossary of Terms** explains some technical terms used in the document.

Section 1 is an introduction to the purpose of the report, definitions of curtailment and constraint with reference to the relevant SEM committee papers.

Section 2 provides an overview of the Northern Ireland transmission system and how constraint and curtailment are defined from a TSO prespective.

Section 3 provides detail on how the power system model is built, so that future possible levels of constraint and curtailment can be estimated.

Section 4 describes how to interpret the nodal results tables found in **section 5.**

Section 5 provides the reader with results for curtailment and constraint at each transmission node where new renewable generation is located.

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Executive Summary

The purpose of this report is to provide new generation connection applicants with information on the possible levels of generation output reduction for the period 2016-2024. It updates the previous SONI report "Generator Output Reductions: Calculation methodology, assumptions applied and Northern Ireland results for 2014 to 2020 including intervening years" published in March 2014.

SONI is responsible for planning the Northern Ireland transmission system to facilitate the connection of new generation and demand. In planning a network for generation there may be differences in timing when network and generation projects are completed. When generation is built before network reinforcements are completed generators could be required by the transmission system operator to reduce their output to prevent the network becoming overloaded. This is referred to as constraint.

The All-Island Ten Year Transmission Forecast Statement 2015 is a document that provides detailed information on the generation and network development over the next 10 years. This study uses the All-Island Ten Year Forecast statement 2015 as a reference for network developments over the study horizon 2016 to 2024.

As well as providing new generators with constraint information, this report also provides information on curtailment. Curtailment refers to situations where the output of generators may be reduced to keep the overall power system secure e.g. there are limits on the amount of non-synchronous generation that can generate at any point in time. Curtailment results are presented in this report as an all-island percentage value.

This report aims to provide new generation connection applicants with detailed information on the possible levels of generation output reduction:

- Results are presented for each relevant 110kV node where generation is connecting between 2016 until 2024.

- The level of generation curtailment and constraint for each node to which new connections are being offered.

Table 1 shows a regional summary of the constraints and curtailments across the time horizon.

Table 1 Curtailment & Constraints Results Summary

Summary of Northern Ireland Curtailment and Constraints									
Year	2016	2017	2018	2019	2020	2021	2022	2023	2024
Curtailment (%)	2-5	3-5	2-4	4-6	3-5	4-7	4-7	4-7	4-7
Constraint (%)	1	~0	~0	1	1	1	1	~0	~0
Curtailment and Constraint (%)	3-6	3-5	2-4	5-7	4-6	5-8	5-8	4-7	4-7

The results were generated from power system modelling software. The model uses information that was provided from a number of sources: SONI, NIE, and consultation with industry stakeholders. The results provide an indication of the possible levels of constraint and curtailment that a generator may experience over the time horizon.

Glossary of Terms

Capacity Factor

$$Capacity\ Factor = \frac{Energy\ Output}{Hours\ per\ year * Installed\ Capacity}$$

Combined Cycle Gas Turbine (CCGT)

A type of thermal generator that typically uses natural gas as a fuel source. It is a collection of gas turbines and steam units; where waste heat from the gas turbines(s) is passed through a heat recovery boiler to generate steam for the steam turbines.

Constraint

The reduction in output of a generator due to network limits.

Curtailment

Curtailment is when the transmission system operators EirGrid and SONI ask generation to reduce their output to ensure system security is maintained.

Contingency

A network planning term used to describe a possible power system event such as the loss of part of the network or a generator.

Demand

The amount of electrical power that is consumed by a customer and is measured in megawatts (MW). In a general sense, the amount of power that must be transported from transmission network connected generation stations to meet all customers' electricity requirements.

Forced Outage Probability (FOP)

This is the statistical probability that a generation unit will be unable to produce electricity for non-scheduled reasons due to the failure of either the generation plant or supporting systems. Periods when the unit is on scheduled outage are not included in the determination of forced outage probability.

Gigawatt Hour (GWH)

Unit of energy

1 gigawatt hour = 1,000,000 kilowatt hours = 3.6×10^{12} joules

Interconnector

The electrical link, facilities and equipment that connect the transmission network of one EU member state to another.

Maximum Export Capacity (MEC)

The maximum export value (MW) provided in accordance with a generator’s connection agreement. The MEC is a contract value which the generator chooses as its maximum output.

Megawatt (MW)

Unit of power

1 megawatt = 1,000 kilowatts = 10^6 joules / second

Short run marginal cost (SRMC)

The instantaneous variable cost for a power plant to provide an additional unit of electricity, i.e. the cost of each extra MW it could produce excluding its fixed costs. The SRMC reflects the opportunity cost of the electricity produced, which is the economic activity that the generator forgoes to produce electricity. For example, in the case of a generator fuelled by gas, the opportunity cost includes the price of gas on the day that it is bidding in, because if the generator was not producing electricity it could sell its gas in the open market.

Total Electricity Requirement (TER)

TER is the total amount of electricity required by a country. It includes all electricity exported by generating units, as well as that consumed on-site by self-consuming electricity producers, e.g. CHP.

Transmission Losses

A small proportion of energy is lost as heat or light while transporting electricity on the transmission network. These losses are known as transmission losses.

Transmission Peak

The peak demand that is transported on the transmission network. The transmission peak includes an estimate of transmission losses.

Transmission System Operator

In the electrical power business, a transmission system operator is the licensed entity that is responsible for transmitting electrical power from generation plants to regional or local electricity distribution operators.

1 Introduction

In March 2014 System Operator for Northern Ireland (SONI) published a paper called "Generator Output Reductions: Calculation methodology, assumptions applied and Northern Ireland results for 2014 to 2020 including intervening years". This report gave new generation customers an indication of possible constraint and curtailment for the years from 2014 until 2020.

Since March 2014 there have been a significant number of new connection requests to SONI. The connecting parties include transmission renewable cluster connections, large scale solar PV and individual windfarms. Since the previous report it is worth noting that the large scale renewable offshore projects are less likely to develop in the short to medium term. Given the scale of changes since the last report SONI have decided to update the report with the latest assumptions. It only makes sense to re-run constraints models whenever there are significant changes.

The report output is complimentary to the generation connection process release of Firm Access Quantity (FAQ) allocations given with each new connection offer. This report will aim to provide updated levels of network constraint and system curtailment that generators are likely to be subject to. The information will be annual figures, provided for each 110 kV bulk supply point. The time horizon for the report will be from 2016 until 2024.

SONI presented the proposed the modelling assumptions and scenarios to Northern Ireland Renewable Integration Group (NIRIG) and the Renewables Grid Liaison Group (RGLG) in November 2015. Following this consultation the modelling assumptions and scenarios were frozen in December 2015.

1.1 Relevant Single Electricity Market Committee (SEMC) Publications

Since the initial consultation, the SEMC have consulted on and published key decisions relating to curtailment and constraint both in dispatch and in the Single Electricity Market. Specific SEMC papers include:

• SEM-11-105: "Principles of Dispatch and the Design of the Market Schedule in the Trading and Settlement Code"

• SEM-13-012: "Constraint Groups arising from SEM-11-105"

• SEM-13-010: "Treatment of Curtailment in Tie-Break Situations"

A summary of the decisions affecting modelling and analysis of curtailment and constraint in the SEM are presented below:

Constraints: Generation which best alleviates a specific constraint is reduced as a priority.

Constraints in a Tie-Break Situation: Outside of constraint groups, generation is reduced on a pro-rata basis. Within a constraint group, generation is reduced on a grand-fathered basis in the following order – non-firm, partially firm and firm generation.

Constraint Groups: Two constraint groups have been identified on an All-Island basis, the first in Donegal and the second in the South-West of Ireland. The constraint group in

Donegal exists today, with the constraint group in the South-West of Ireland coming into effect when the new 220 kV stations are built in the region. No constraint group has been identified in Northern Ireland.

Curtailment: Pro-rata allocation of energy to be curtailed.

2 Northern Ireland Constraints 2016-2024

2.1 The Northern Ireland Transmission Network

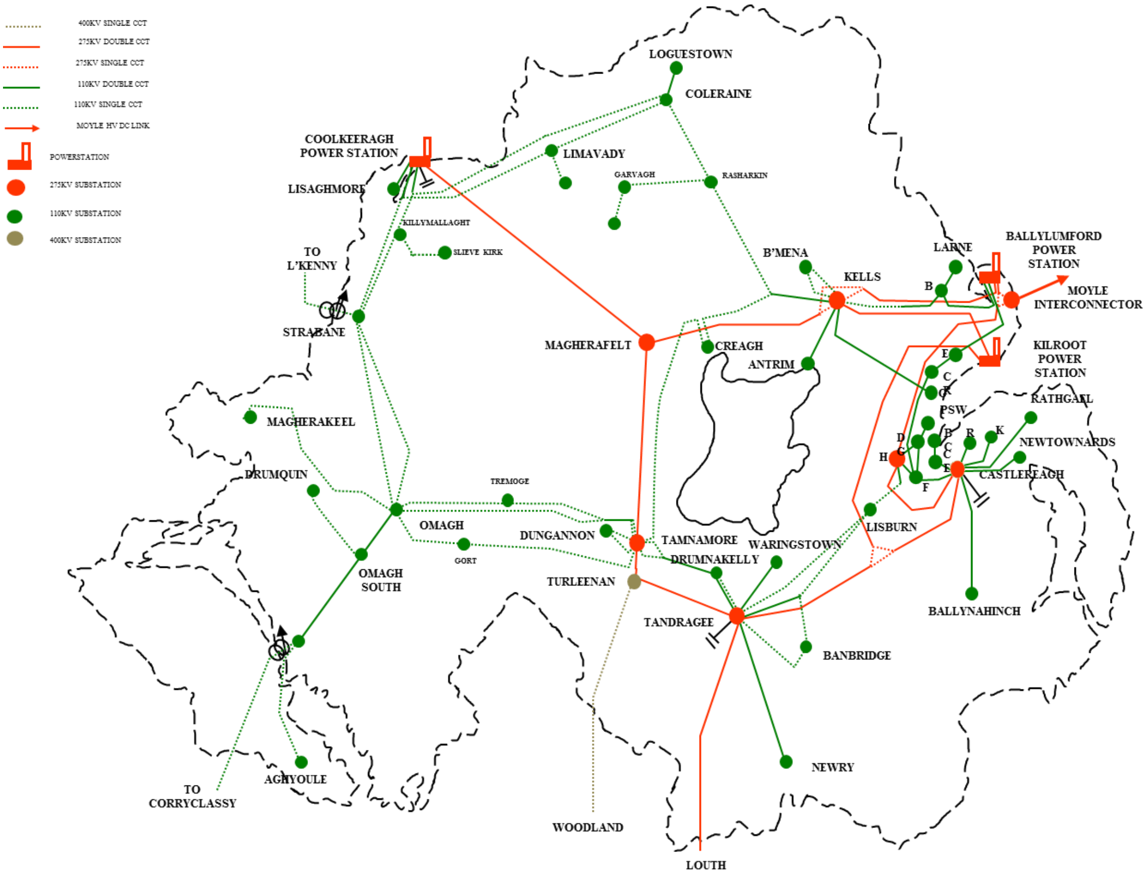


Figure 1 the Northern Ireland transmission network (2020)

The Northern Ireland transmission network is needed to allow bulk electrical power flows of electricity from power stations and renewable generation sites to the towns and cities in Northern Ireland. The transmission system is operated by SONI in a safe, secure, economic, efficient and reliable operation. SONI are responsible for planning the network of the future. Currently new renewable generation connections are being planned to enable the output from windfarms to supply the power to our homes and businesses. This is in keeping with the 40% target as set out in DETI's Strategic Energy Framework 2010.

The purpose of this technical study is to provide the possible levels of transmission network constraint across the study period 2016-2024. The network constraint levels can be due to a number of reasons:

- The expected build and location of new generation connections;
- The climatic year, i.e. how sunny or how windy the year is;
- The expected network development;

- The network contingencies that cause other lines to overload in the event of the fault of another piece of network.

At this stage it is worth discussing the terms that we will need to refer to through the document.

2.2 Constraint

A technical definition of constraint can be found in SEMC papers:

• SEM-11-105: "Principles of Dispatch and the Design of the Market Schedule in the Trading and Settlement Code"

• SEM-13-012: "Constraint Groups arising from SEM-11-105"

• SEM-13-010: "Treatment of Curtailment in Tie-Break Situations"

In layman's terms network constraint can be expressed by the pipe analogy. The illustration shows that if we have a bottleneck in a pipe, the flow on the output is reduced compared to the flow that is available at the input.

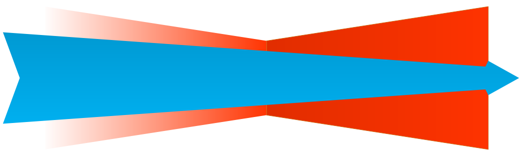


Figure 2 A bottleneck pipe

In comparison if we have a pipe that has no bottleneck, the flow at the input is exactly the same as the output flow.

Figure 3 The straight pipe

In the management of the transmission network there are very similar issues. We have generators which are the source of electrical energy trying to push power (electrical flow) through overhead lines and underground cables (the pipes) to where the electricity customers are located. The network is planned and operated by SONI to ensure that the cheapest forms of electrical energy can be delivered to where it is needed thereby keeping the lights on.

Where there are network bottlenecks, low cost forms of generation may be asked the system operators to reduce their output at times when there is too much power trying to push through the bottleneck. This reduction in generator output has a number of costs associated with it, primarily because the energy from the generator that has been constrained must be supplied by another generating unit, this will generally cost the electricity customer additional money per unit of electricity.

Figure 4 illustrates the generation build out for Northern Ireland to 2020. The map shows that the assumed location of the renewable generation is mainly in the West. The main bulk of the electricity customers in Northern Ireland are located in and around the Belfast area, which is shown by a high concentration of green 110 kV bulk supply points.

There are two key network bottlenecks in the Northern Ireland transmission grid, the Kells and Tamnamore bulk supply points. This represents the areas of the network in which the power is being transferred from the 110 kV transmission lines up onto the 275 kV transmission lines, for efficient transfer of power to the towns and cities in the east of Northern Ireland.

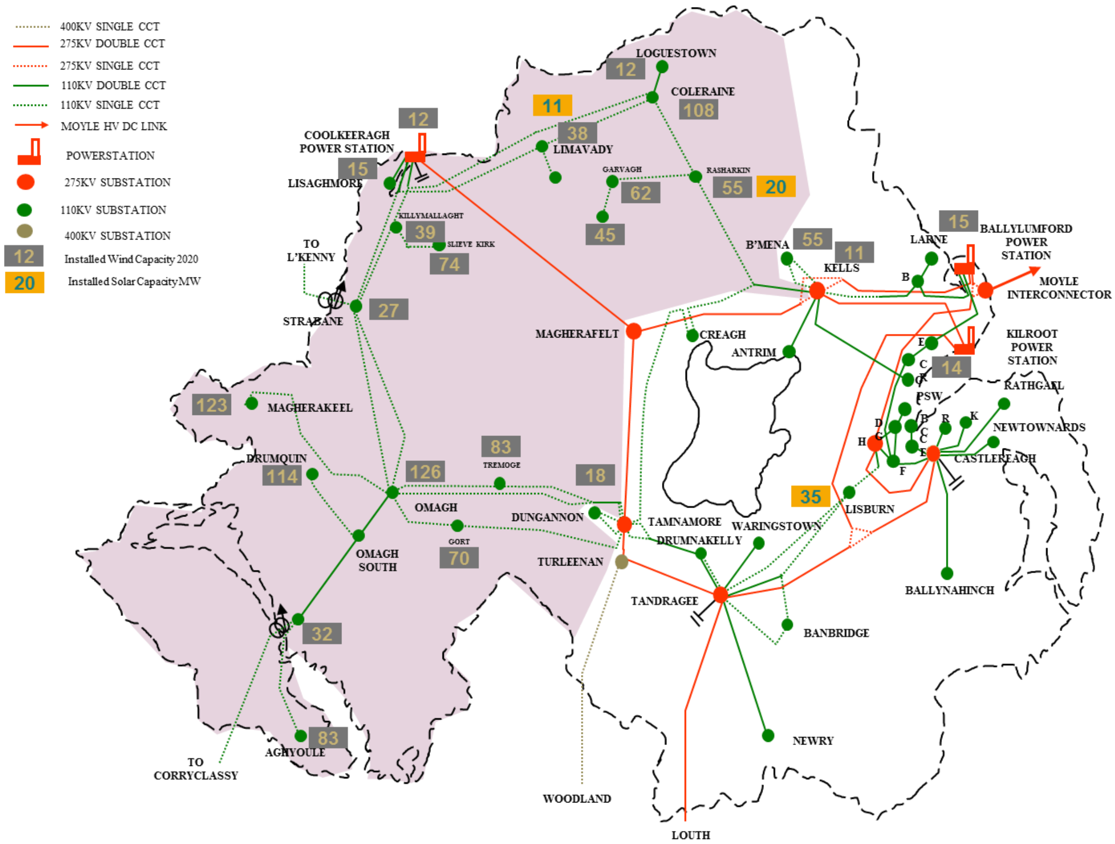


Figure 4 the Northern Ireland generation location and network (2020)

The SONI network planners will propose schemes that can help to remove the network bottlenecks. This will help to improve the efficiency of the network in delivering the lowest cost forms of electrical energy from generators to the electricity customers. The Northern Ireland constraints report will include the proposed network build out to enable generators to understand the amount of network constraint that they could possibly be subject to during the study period.

Figure 5, gives an overview of the network developments that are presented in the All-Island Ten Year Transmission Forecast Statement 2015. The main network project proposals are located in the west of Northern Ireland. The west of Northern Ireland is the location of the greatest number of requests for new generation connection offers.

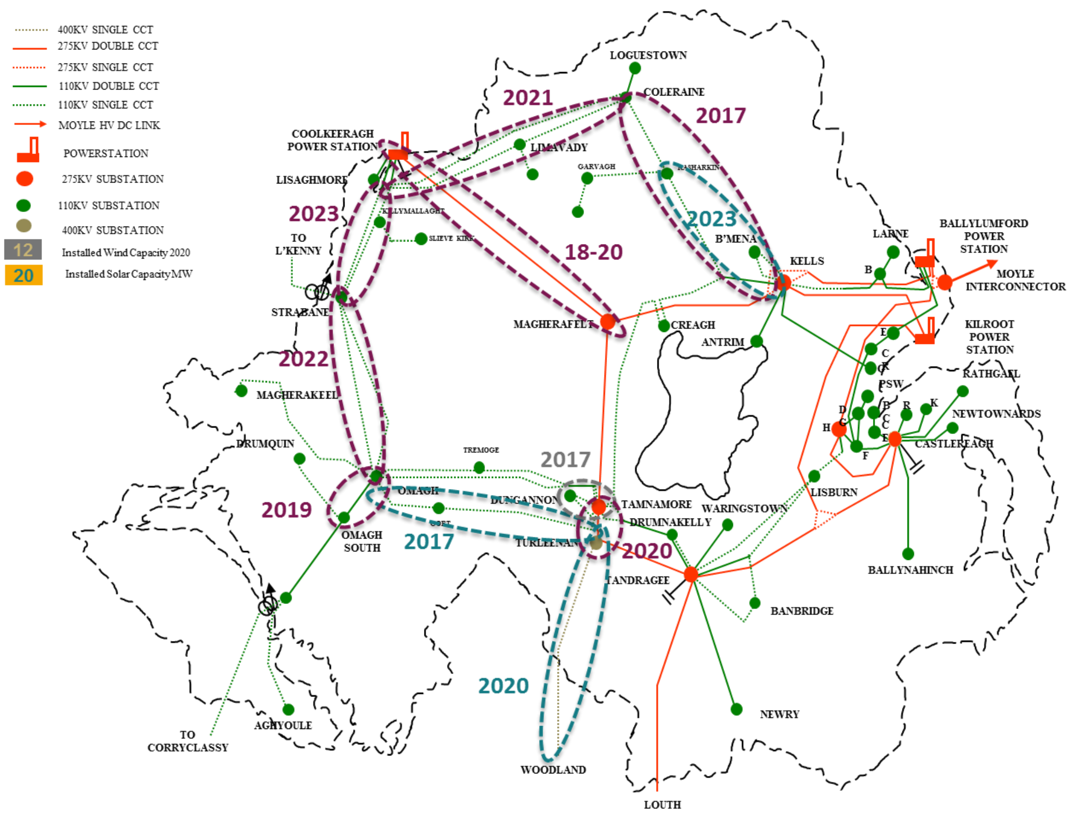


Figure 5 the Northern Ireland transmission network build out 2016 -2024.

2.3 Generation and Network Build out

The study horizon provides information on a likely generation build out with a relevant network roll out. For the purposes of simplicity of constraint modelling, generation and network build out dates will be handled as follows:

1) The generation connections planned to energise before the 31 June are included from the beginning of a study year. The generation connections that are planned after 31 June in a given study year are included at the start of the next year.

2) The network changes that are planned for energisation before the 31 June are included from the beginning of a study year. The network changes that are planned for energization after 31 June in a given study year are included at the start of the next year.

The study years are therefore considered to be a horizon overview of the levels of constraint that could be expected. The study horizon does not represent the actual network delivery, but provides the reader with an insight into the average network constraints that could be expected before network reinforcements are built out.

2.4 Contingency

At this stage it is appropriate to define another network term, **'contingency'**. This is commonly referred to as the 'N-1 criterion'. Transmission network planning takes into account the failure of a piece of network or plant that could have an impact on other transmission lines or generation. Essentially the transmission network is designed to be able to withstand the loss of one transmission line or other piece of equipment. Under normal operating conditions transmission lines or transformers share the power, so that if another piece of network equipment fails there is spare capacity available.

The Plexos power system modelling tool is able to account for contingencies. The Plexos model will reduce generation output to prevent transmission lines and transformers 'overloading' should a contingency occur.

2.5 Curtailment

Curtailment is when the transmission system operators ask generation to reduce their output to ensure system security is maintained. The reasons for this reduction in generation output may be due to one or a combination of:

- Too much non-synchronous generation compared to all-island demand.
- There is a requirement to run a minimum number of large power stations.
- All-island demand is lower than the output of renewable energy.
- The HVDC interconnectors between the all-island system and Great Britain are at their maximum export capacity.

These factors tend to cause curtailment to occur generally during windy night time periods. Curtailment is an all-island system issue. The level of curtailment will be the same across all nodes across both Ireland and Northern Ireland.

Figure 6 shows a path for all-island curtailment based on assumptions specifically for this study. The study assumptions were arrived at through SONI and external stakeholder engagement. It is worth noting the following:

- Relaxing of system operational rules are modelled for the DS3 programme up to 2020. After 2020 there are no changes to operation rules. (Further information on the DS3 programme can be found at: *http://www.eirgridgroup.com/how-the-grid-works/ds3-programme/*)
- The level of Ireland's wind generation changes incrementally towards 2030 based on the outstanding Gate 3 generators.
- There are no measures modelled to manage renewable energy figures greater than 40% in the years after 2020. Therefore additional storage, interconnection or

generation enhancements that could help in reducing the prospective curtailment levels post 2020, are not included.

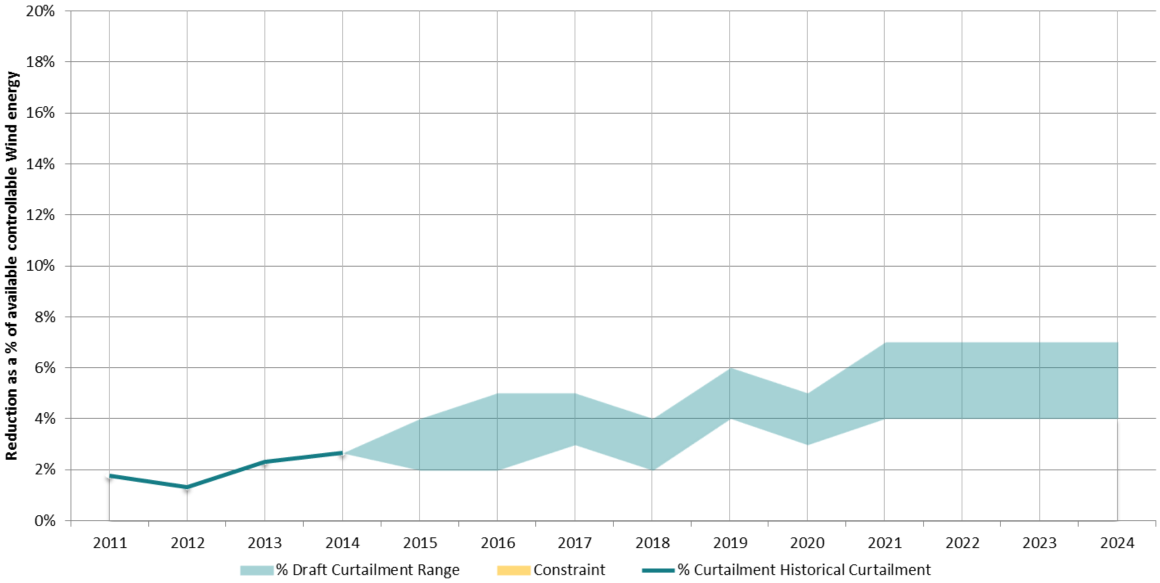


Figure 6 All-Island curtailment (*based on assumptions specific to the Northern Ireland Constraints Study 2016 -2024*)

3 Power System Economic Modelling

3.1 Power market dispatches

Plexos is a tool that is used within the power industry to model the economics of power markets, together with the technical characteristics of the power system. There are similar tools used in the real-time operation of the power system for daily scheduling of generation to meet demand. The Plexos software can model various types of power system, so that the electrical demand is met by different types of generation, such as coal, gas, oil, wind, solar etc.

The output from Plexos will provide a unit commitment and dispatch schedule for each hour of the year. The plexos output will tell us the following:

- What generator we need online (*the commitment*).
- How much power we need (*the dispatch*) to meet the hourly electrical demand.

There are generally three types of dispatch models that are used in the investigation of generation curtailment and constraint. There is the unconstrained, the system constrained and the system constrained with transmission networks.

3.2 The unconstrained dispatch

In the unconstrained simulation, both system constraints and transmission network constraints are ignored. This means that only constraints impacting on generator commitment and dispatch related to generator characteristics such as minimum up/down times, ramp rates, heat states, minimum stable load, etc. are considered. This is indicative of a market dispatch run, and doesn't take into account system and grid constraints.

3.3 The system constrained dispatch

In the system constrained simulation, the system constraints (e.g.: operating reserve requirement; minimum conventional generation requirement; North-South Interconnector flow limitation; and limits on the instantaneous system non-synchronous penetration (SNSP)) are respected, but the transmission network constraints are ignored.

The system constrained model can be used to estimate the level of curtailment that could be possible over the time horizon.

3.4 The system and transmission constrained dispatch

Finally, in the system and transmission constrained simulation the transmission system network is added to the model, so that the simulation takes into account technical and economic generator characteristics, and also system and transmission network constraints.

The system and transmission constrained dispatch will provide average levels of constraint when there is reduction of generation to prevent the overload of a network asset, such as an overhead line or a transformer.

3.5 The Software: Plexos Integrated Energy Model

Plexos is an economic modelling tool which allows users to simulate the operation of a power system. This software is used by the all island energy regulators to model the all island power market (*further information is available on the joint regulator website: www.semcommittee.com*). The model must be built using various data sources, allowing the user to represent the power market, for example we need:

- Generation
    - The size of the unit, and the amount of power it can deliver.
    - The fuel type (coal, gas wind, solar etc).
    - The efficiency of the conventional power station.
    - Intermittent generation are modelled by a historical profile.
- Electricity Demand
    - The energy required by industry, commerce & residential customers.
- Fuel and Carbon Prices
    - The cost of gas, coal & oil in future years.
    - The price of carbon is a charge applied to each tonne of carbon dioxide produced by the power station.
- Interconnection
    - The ability to trade with other markets, in this case Great Britain.
- Operational Rules
    - These are rules that have to be obeyed by the transmission system operator to ensure that the supply and demand is securely balanced.

3.6 Generation

Generation can be labelled as either conventional or renewable generation.

- **Conventional generation:** typically uses a fuel such as coal, gas or oil to generate heat, which in turn is used to produce electrical energy. The most efficient generators such as CCGT are able to convert fuel to electrical energy at close to 60% efficiency.
- **Renewable generation:** can include technologies such as hydro, solar or wind. Renewable generation is typically climate dependent. The energy conversion is usually dependent on weather conditions to generate electrical energy. The output from renewable technologies is generally referred to in terms of capacity factor rather than efficiency.

3.6.1 Renewable Generation

Building an economic power market model will always make simplifying assumptions. One such simplification is that the climatic year will use historical data. The use of historical data means that the power market model will create generation commitment and dispatch decisions based on a known wind and solar profile, this is known as 'perfect foresight'. In real-time operation of the power system this is not the case as there will sometimes be an error between the forecasted wind and the wind that it available within the hour. This can mean that the model may show lower levels of curtailment since with perfect foresight it may choose to de-commit units based on what it knows will happen in. In reality differences in wind or demand forecasts mean that a different schedule of generators may be required at times than that modelled with perfect foresight.

The amount of electrical energy output from renewable generation is generally described in terms of capacity factor. The capacity factor relates to the amount of energy that could be achieved from a renewable technology over the period of one calendar year. Table 2 shows that the annual energy yield is significantly different when comparing renewable technologies types. One factor in the energy yield difference is that solar PV doesn't produce electrical energy at night, but the wind can blow at any time of the day or night.

Table 2 Example: Annual renewable energy yield for a 100MW installation

	Size of installation (MW)	Capacity Factor (%)	Annual Energy (MWh)
Solar PV	100	10%	87,600
Wind Farm	100	30%	262,800

3.6.1.1 Climatic Profiles

For the purposes of these studies, two climate years have been chosen to help account for some elements of weather uncertainties. The chosen climate years are shown in Table 3. Sections 3.6.1.2 and 3.6.1.3 illustrate the solar and wind patterns across the climate years. Initial model testing showed that although there are small differences in capacity factors the wind profiles were seasonally different. The seasonal variation was observed to be a useful in evaluating the network constraints as it presented a range of values.

Table 3 Annual Capacity Factors for historical Northern Ireland climate profiles

Climate Year	Northern Ireland Solar Capacity Factor	Northern Ireland Wind Capacity Factor
2009	10.4%	30.3%
2013	9.8%	29.1%

*Note: The **all-island wind capacity factors** for the climate years 2009 and 2013 are 31.0% and 30.0% rounded to the nearest percentage point (Source All-island Generation Capacity Statement 2016-2024)*

It is important that the solar and the wind profiles are for the same year, so that the two profiles are correlated in terms of weather patterns. The input profile to the Plexos model is an hourly pattern for the solar and the wind profiles.

- Solar profiles were also available for each region (Ireland, Northern Ireland & GB).
- Wind profiles were available for each of the wind areas, as previously used in the Gate 3 constraints reports.

3.6.1.2 Solar

Solar profiles tend to have a fairly predictable shape. Figure 7 and Figure 8 shows the average hourly energy output from solar PV over a one year period. The capacity factor for solar PV is largely dependent on latitude - the closer to the equator the higher the annual capacity factor. The solar capacity factor for a country like Spain will have a value of around 20%, i.e. double the output of Northern Ireland.

The surface plot of Figure 7 highlights the Northern Ireland solar profile characteristic. The lowest intensity of solar electrical output is in the 4 winter months November through to February with hourly values on average not exceeding 20%. As expected the solar electrical energy output is highest in the summer months with average hourly solar electrical output peaking in the 50-60% range.

The main point is that the solar electrical energy output is fairly predictable, and is typically there during times of increasing electrical demand i.e. the morning rise. Solar energy output may be reduced if it is located on a part of the network that has constraint issues.

The comparison of the solar years shows that the energy outputs have a very similar pattern, in fact they are 81% correlated.

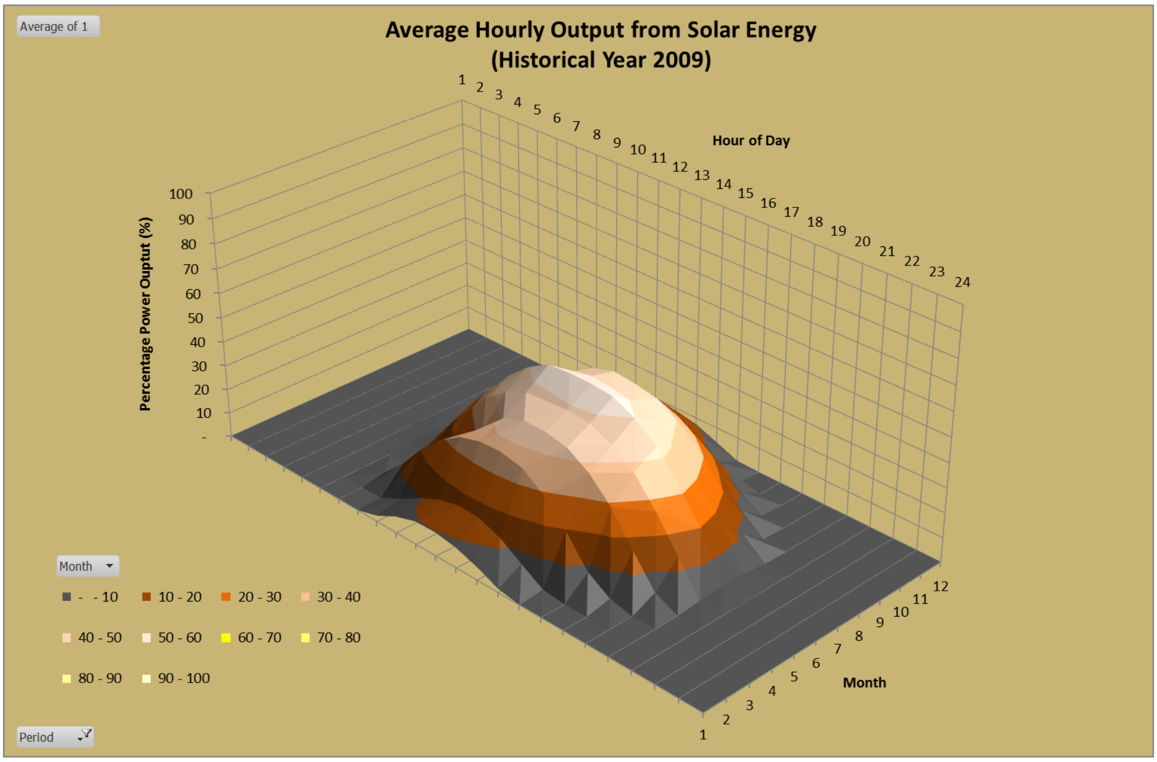


Figure 7 Average Solar Energy Profile for 2009

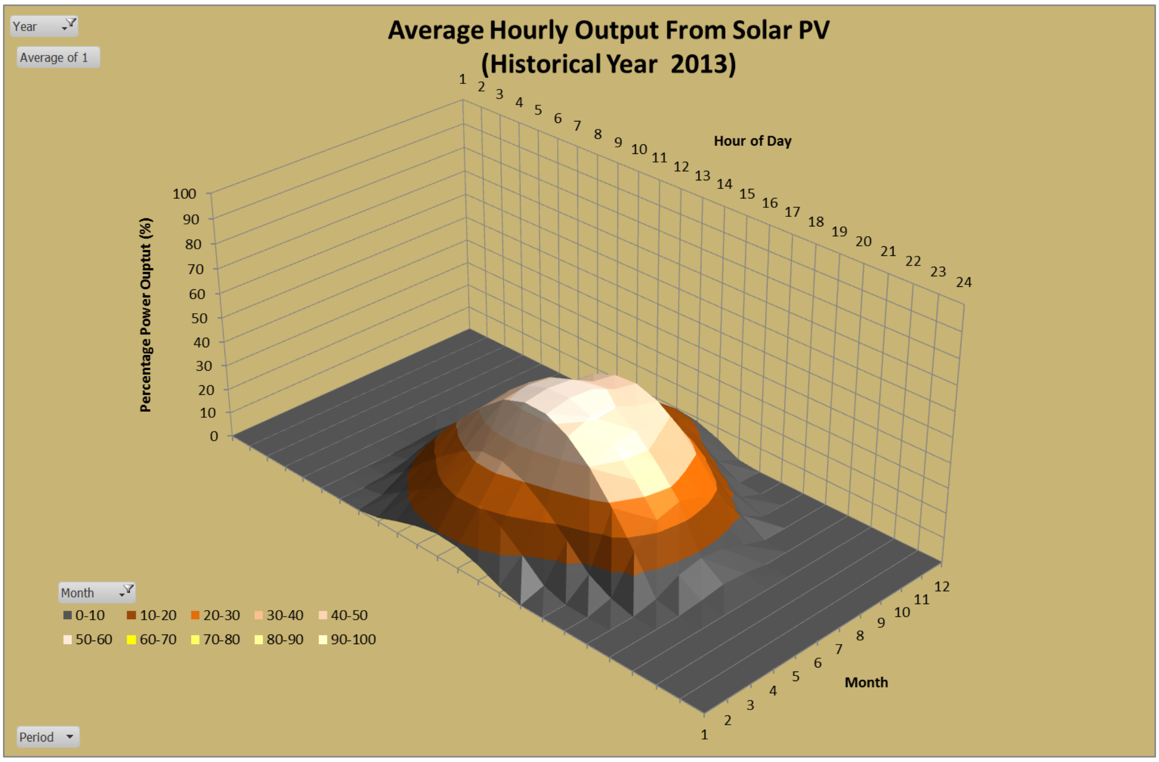


Figure 8 Average Solar Energy Profile for 2013

3.6.1.3 Wind Profiles

Figure 9 and Figure 10 show that for two comparable wind capacity years seasonal wind patterns can be very different. The correlation between the 2009 and 2013 wind profiles is about 2%. The correlation between wind years is extremely low. For the purposes of modelling such variation should allow us to test the impact of different wind patterns on network constraints.

Given that the chosen climate year capacity factors are very close to the five year average, it is believed that these are suitable 'wind years' to reflect what has been historically observed.

It is assumed that on balance, it is reasonable to use the historical wind data as a basis for future wind profiles for the purposes of this study. The regional wind profiles are created from historical metered data.

Wind generation on the island was modelled in the analysis using an hourly wind power series at every transmission node where wind generation is connected. The wind at each node will be categorised based on Firm Access Quantity and controllability. In Ireland, wind generation was also categorised based on Gate and connection status (i.e. temporary or permanent).

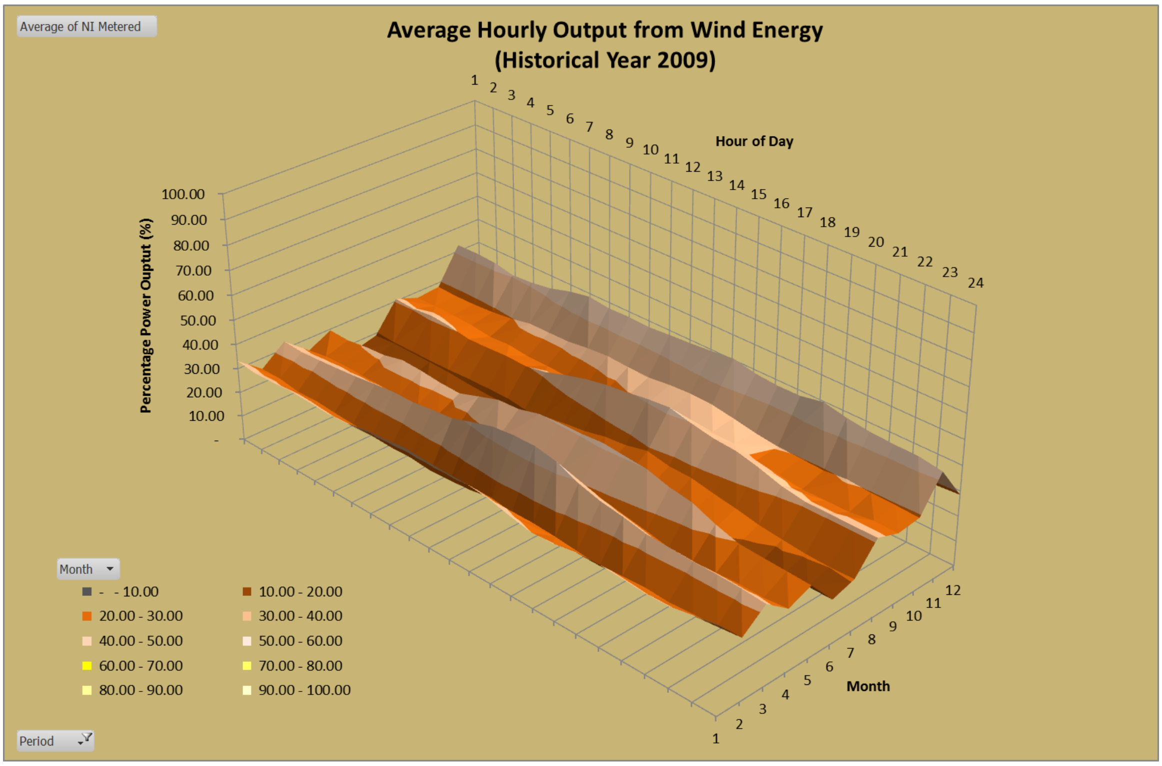


Figure 9 Average Wind Energy Profile for 2009

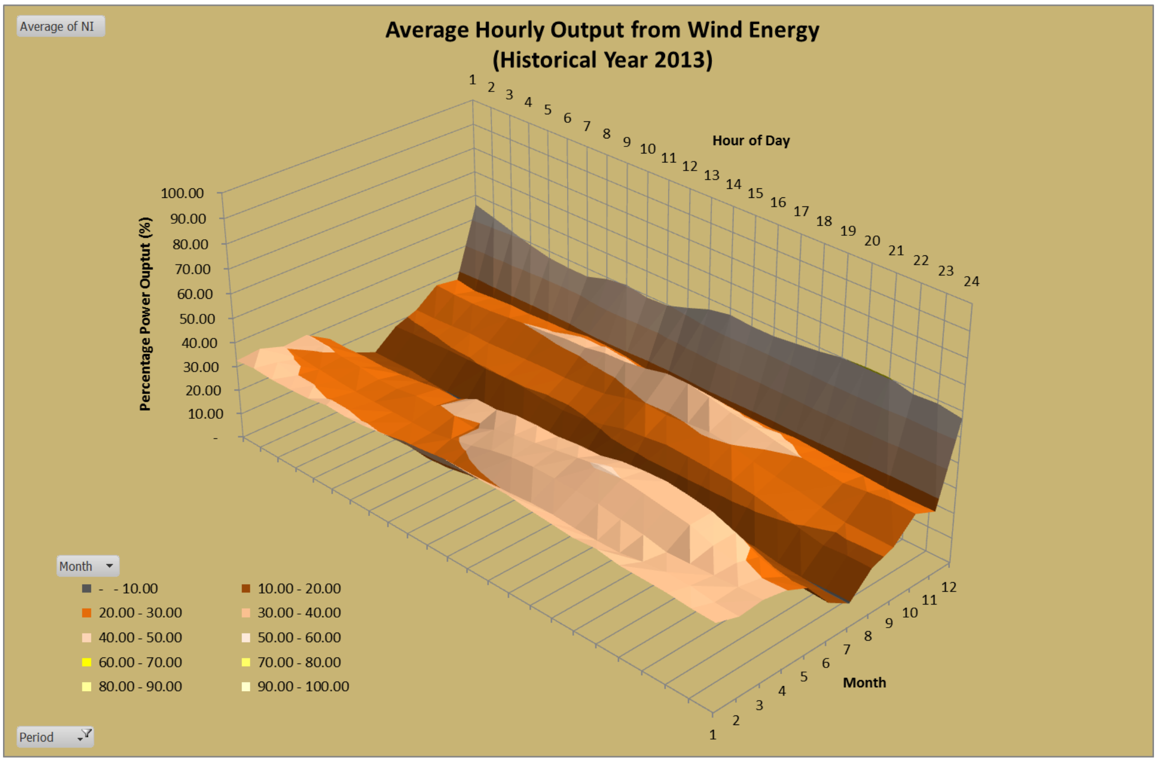


Figure 10 Average Wind Energy Profile for 2013

3.6.1.4 Wind Regions

To provide a more representative wind series the regional historical wind profiles are used. The region capacity factors are shown in Table 4.

By using regional wind power profiles in the studies it is possible to account for the geographical variation of wind power across the island. Evidently, this assumption does not take into account possible variations in wind power within each region and it is fair to say that some wind farm sites may have above average wind conditions while others may have below average conditions.

Since this study is mainly focused on the impacts that constraints and curtailment have on the transmission system, it is considered reasonable to assume regional profiles will capture the average behaviour of wind in an area.

Table 4 Regional wind profile capacity factors

Wind Regions		2009 Capacity Factor	2013 Capacity Factor
Northern Ireland	NI	30.3%	29.1%
Ireland	A	34.5%	29.7%
	B	29.7%	29.6%
	C	32.8%	32.1%
	D	25.9%	23.5%
	E	32.0%	29.4%
	F	31.9%	29.5%
	G	29.5%	28.4%
	H1	32.8%	30.9%
	H2	30.6%	28.5%
	I	32.0%	32.6%
	J	29.5%	28.4%
	K	30.6%	35.9%
	Offshore Ireland	35.2%	35.2%

3.6.1.5 Generation Controllability

It was assumed that there is full compliance with wind farm controllability requirements on the island. It was assumed that all generators with an MEC greater than 5 MW were controllable except those wind farms known to have grid code derogations, including those connected before 1 April 2005. The study methodology takes into account all uncontrollable wind generation and does not include these generators in any output reductions calculations.

3.6.1.6 Renewable Generation Build out

The purpose for this report is to provide a range of possible constraint and curtailment levels for new generation connecting to the power transmission system. A major input to the power market model is the amount of generation that will connect over the period from 2016 until 2024. For the purpose of this report the build out of new generation in Northern Ireland will be based on:

- The generators that are connecting and contracted for connection.
- The latest connection information was received from NIE *(November 2015).*

The technologies that will be studied include large scale solar PV (greater than 5MW), and large scale wind farms (greater than 5MW). Small scale generation technologies (less than 5MW) are included in the studies, but their outputs are not assessed as part of this study.

It is worthy of note that there is about 800MW of new generation connection requests (post 13 August 2015), these projects are not included in this study, (*this was consulted on with industry and the Renewable Grid Liaison Group*).

3.6.1.7 Large scale solar and wind farms build out

There is only one generation build out scenario, so generators are included with reference to the estimated connection date. Connection date is based on the latest available information from NIE. The renewable generation build out is likely to help provide Northern Ireland customers with 40% of their electrical energy from renewable sources by the year 2020.

Table 5 Northern Ireland Constraints 2016 Installed Wind Capacity

Installed Wind Capacity									
Year/Scenario	**2016**	**2017**	**2018**	**2019**	**2020**	**2021**	**2022**	**2023**	**2024**
Northern Ireland Wind Capacity									
Total NI Wind(MW)	671	843	997	1216	1216	1228	1228	1228	1228
Ireland Wind Capacity									
Total Wind (MW)	2695	3061	3305	3613	3945	4146	4339	4482	4651
All Island Wind Capacity									
Total Wind (NI + IE) (MW)	3366	3904	4302	4829	5161	5374	5567	5710	5849

Figure 11 shows the build out for large scale renewable generation across the study horizon. The build out accounts for the 'Northern Ireland Renewable Obligation closure grace period', which was requested by industry as a best estimate for the roll-out of renewable generation.

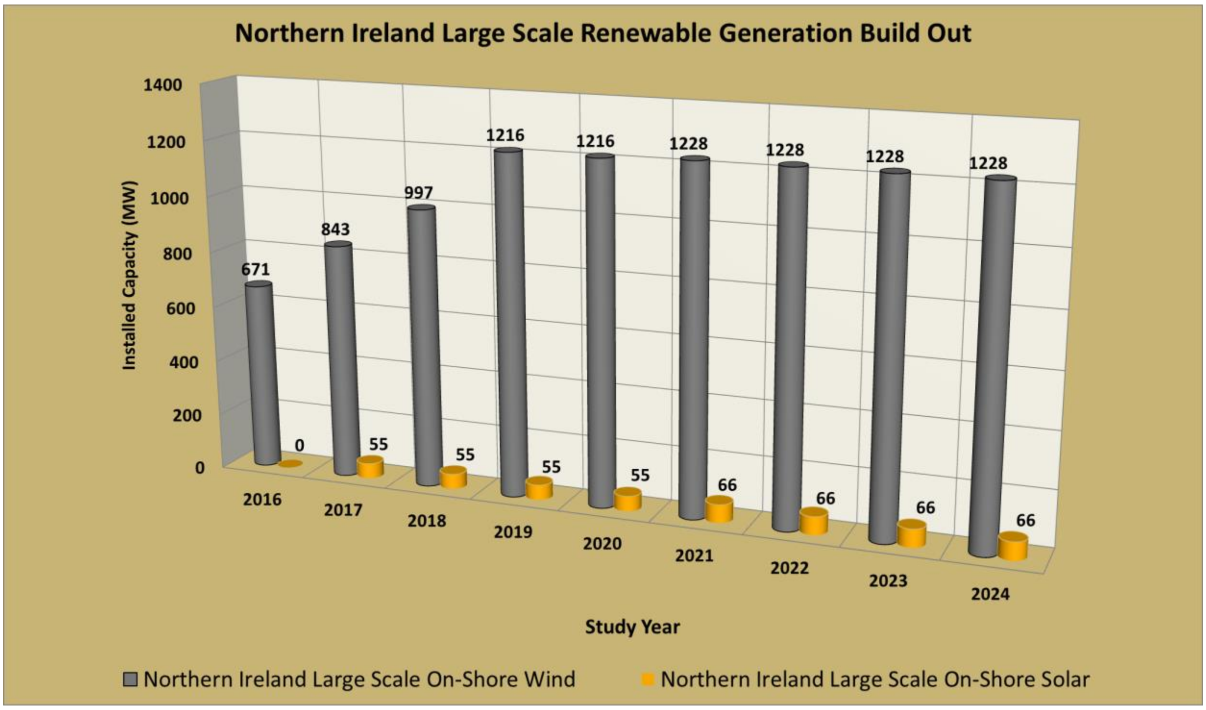


Figure 11 Northern Ireland wind and solar build out across the study horizon

The amount of installed wind farms on an all island basis is shown in Figure 12, it was agreed with industry to include increases to wind in Ireland across the entire study horizon.

The Ireland wind build out was based on:

1) The volume of Gate 3 wind still available for connection.
2) A rate of wind connection to achieve the 40% 2020 renewables target.
3) A reduced generation connection rate post 2020, but increasing towards an Ireland renewable energy mix of 55% by 2030, corresponding to European power systems scenarios (ENTSO-E TYNDP16).

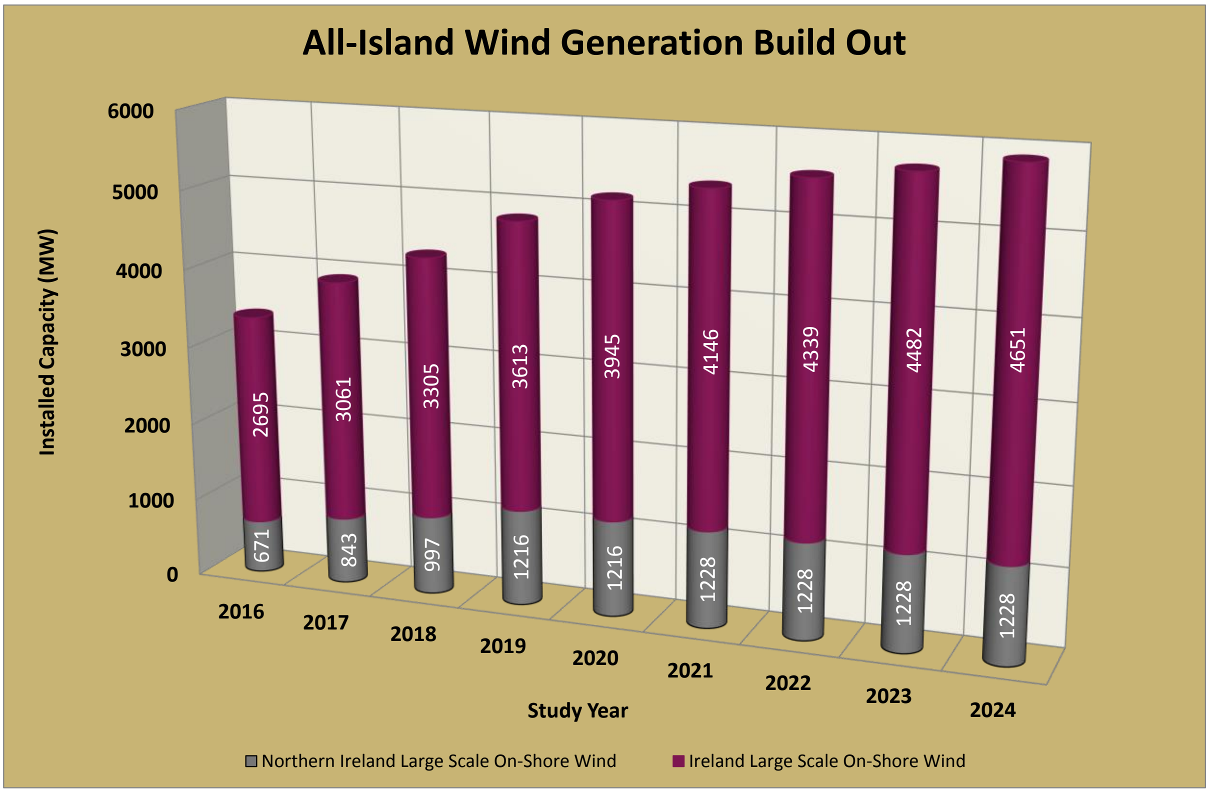


Figure 12 Ireland and Northern Ireland wind generation build out across the study horizon

3.6.1.8 Offshore Generation Projects

There are no offshore windfarms or large scale tidal generation projects included. This doesn't suggest that there will not be any projects in these areas, but at the data freeze date there were no contracted offshore projects.

3.6.2 Conventional Generation Projects

The conventional generation portfolio that is used for the study period is based on the All-Island Generation Capacity Statement 2016-2025. The technical data that is required for the purposes of the Plexos power market model is based on the all-island project dataset 2013-14 published by the regulatory authorities. (For further information: *https://www.semcommittee.com/market-modelling*)

The technical data set includes the following information:

- Fuel type (e.g. gas, wind, coal etc.)
- Maximum and minimum operating output (MW)
- Capacity state and heat rates (used to determine how much fuel is burnt to produce 1MW of output power)
- Ramp rates (important to determine how quickly a machine can change its power output)
- Minimum up/down time (i.e. how long a machine must be on for or off for before it can be started again)

This technical data will allow the Plexos software to work out the cost of making a megawatt of electrical energy for each type of technology. Each technology will have a different cost.

The price of each technology is stacked in order of lowest to highest prices in what is termed a merit order, Figure 13. The zero cost generation are typically renewable generation sources, with the most expensive units representing those conventional generators with the lowest efficiency, highest fuel costs or a combination of both.

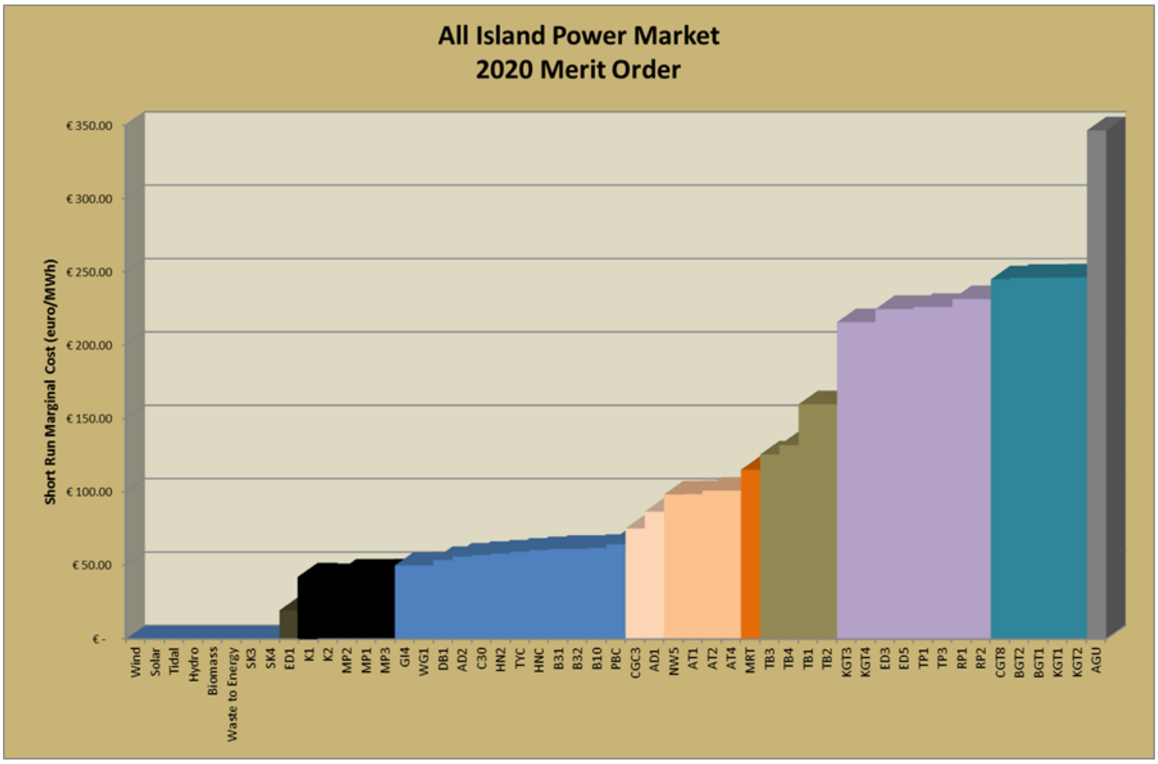


Figure 13 all-island power market merit order (2020)

Other factors that influence the generation dispatch over an extended study horizon are:

1) Generation Commissioning & Decommissioning
2) Generation Outages
3) Generation Emissions restrictions

The following sections will cover the various conventional and technologies changes that may occur over the study horizon. It is worth pointing out that since we are considering only connecting and contracted generation, not all generation in the following section will be included in the study model.

3.6.2.1 Conventional Generation Commissioning

For Northern Ireland and Ireland it is assumed that there are no new conventional units to be commissioned during the study period.

3.6.2.2 Storage Projects

Currently there is a compressed air energy storage (CAES) project that has a pre-construction offer however, it has no firm connection date. For the purposes of this study the CAES project will not be included in the study period.

There is one transmission scale storage project in Northern Ireland, a 10MW battery used for ancillary service provision. Since this is not part of the energy market the battery has not been included in the model.

Table 6 Large scale energy projects in Northern Ireland

Generating Unit	Maximum Export Capacity (MW)
Compressed Air Energy Storage	268
AES Battery	10

In the all-island market there is currently one storage technology used in the energy market. Turlough hill pump storage is included from the first year of the study.

Table 7 Large scale energy projects in Ireland

Generating Unit	Minimum Capacity (MW)	Maximum Export Capacity (MW)	Round Trip Efficiency
Turlough Hill	5	292	70%

3.6.2.3 Small Scale Generation

The Northern Ireland Renewable Obligation (NIRO) is a government levy scheme that supports growth in small and large scale generation projects. For the purposes of the modelling it is assumed that the NIRO allows enough small scale generation to connect to the Northern Ireland distribution system to reach a 40% renewable goal.

Small scale generation in constraints modelling refers to small uncontrollable, generation typically less than 5MW such as:

- Wind turbines, e.g. a 250kW wind turbine supplying a farm or factory
- Solar PV e.g. a 4kW PV system installed on a home
- Hydro e.g. a 100kW run of river hydro scheme
- Tidal generator e.g. a 1.2MW Turbine
- Combined Heat and Power Generation, e.g. a 1MW natural gas CHP supplying a leisure centre
- A anaerobic digester for example a 500kW AD plant converting electricity from waste food
- A diesel generator, for example standby generation for a factory or commercial building.

There has been significant investment in small scale renewable over the last number of years in Northern Ireland. Small scale generation investments are expected to continue until at least March 2017. SONI received the expected small scale generation build out for each year of the study from NIE Networks at each transmission bulk supply point.

The generation build out reflects the NIRO support of small scale projects up until 2017, see Table 8. No further growth is assumed after 2017, this is to be consistent with the connecting and contracted methodology applied to the large scale generation projects.

The small scale generation profiles are built from historical climate data scaled to the NIE bulk supply point data. It is assumed that these profiles are connected to the distribution system and hence are subtracted from the total demand. Hence in modelling these profiles are fixed and cannot be modified by Plexos.

Table 8 Small scale generation build out for years 2016-2024

Small Scale Generation	Capacity (MW)								
	2016	2017	2018	2019	2020	2021	2022	2023	2024
CHP, Biomass & Anaerobic Digestion	63	65	65	65	65	65	65	65	65
Solar	80	98	98	98	98	98	98	98	98
Hydro	12	21	21	21	21	21	21	21	21
Tidal	1	1	1	1	1	1	1	1	1
Wind	128	181	181	181	181	181	181	181	181

The Small Scale Generation (SSG) generation in Ireland are based on the all-island generation capacity statement 2016-2025 assumed capacities.

3.6.2.4 Biomass Generation

There are three new biomass plants included in the model, see Table 9. These are priority dispatch plant that can be dispatched down to minimum generation levels during curtailment or constraint. The Belfast biomass generator is predominantly, but not exclusively biomass.

Table 9 Biomass generation build out for years 2016-2024

Generating Unit	Minimum Capacity (MW)	Maximum Export Capacity (MW)	Commissioning Date
Lisahally Biomass	12.75	18	In at beginning of Study
Belfast Biomass	6.0	17.6	1/1/2018
Mayo Biomass CHP	17	43	01/01/2017

3.6.2.5 Waste to Energy Generation

There are two new waste to energy plants included in the model, see Table 10. They are classified as priority dispatch plant as some of the waste has a renewable source. During constraint or curtailment that maybe dispatched down to minimum generation levels.

Table 10 Waste to energy generation build out for years 2016-2024

Generating Unit	Minimum Capacity (MW)	Maximum Export Capacity (MW)	Commissioning Date
Indaver	5	15	In at beginning of Study
Dublin Waste To Energy	18	62	In at beginning of Study

3.6.2.6 Conventional Generation Retirements

Over the study period there are a number of potential generation retirements. The assumptions are in line with the All-Island Generation Capacity Statement 2016-2025. The major driver for these retirements is the Industrial Emissions Directive (IED). The IED directive is a piece of legislation that sets limits on the amount of emissions that can be emitted from large industrial sites.

Table 11 Conventional generation retirements for years 2016-2024

Generating Unit	Maximum Export Capacity (MW)	Decommissioning Date
Ballylumford 4, 5	250	31st Dec 2019
Kilroot ST1, ST2	514	31st Dec 2023
Aghada AD1, AT1	348	31st Dec 2023
Marina CC	95	31st Dec 2023
North Wall 5	104	31st Dec 2023
Tarbert 1, 2, 3, 4	592	31st Dec 2022

3.6.2.7 Conventional Generation Outage

Generation outages can be categorised as two types the expected and the unexpected. Therefore scheduled generation maintenance outages (expected) and generation trips (the unexpected) are modelled in Plexos. A single generator maintenance programme is modelled for each year of the study horizon. The outage pattern is that for an average year.

The generation trips are modelled as forced outage probabilities. This information is available on the SEM committee website. Plexos will generate forced outage patterns from the FOP and mean time to repair data, which will provide a deterministic outage pattern against which the model will dispatch generation against demand.

3.6.2.8 Conventional Generation Emissions Limits

For the purposes of this study, it has been assumed that from mid 2020, the coal units at Kilroot (K1 and K2) will have to comply with Industrial Emissions Directive (IED) from the European Commission. This affects the annual NOX emission limits for these units and has been modelled as a cap on their annual energy output to an estimated value agreed with AES Kilroot. The restriction is modelled as a 1500hr stack hour running limit. The K1 and K2 units are de-commissioned from the model at the end of the year 2023.

3.7 All-Island Demand

The role of the electricity power market is to enable efficient supply of power from all types of generation to meet the demand from electricity consumers. The supply demand balance helps ensure that the lights are kept on for each and every hour of the year.

The demand for electricity is a key input into the Plexos power market model. The information for the peak demand (i.e. the maximum amount of hourly electricity needed in an hour) and the total energy requirement (GWh) for the all-island system is found in Table 12. The demand figures are aligned with the median forecasts from the All-Island Generation Capacity Statement 2016-2025.

The Plexos power market model uses a historical demand profile. A load forecasting tool within Plexos was used to build future energy demand profiles based on the demand shape for the year 2014. Holiday periods were preserved during the Plexos future year profile build process.

The total energy requirement figure includes all network losses, at distribution and transmission levels. The total requirement also includes the amount of energy that is produced at small scale generation levels, sometimes referred to as self-consumption.

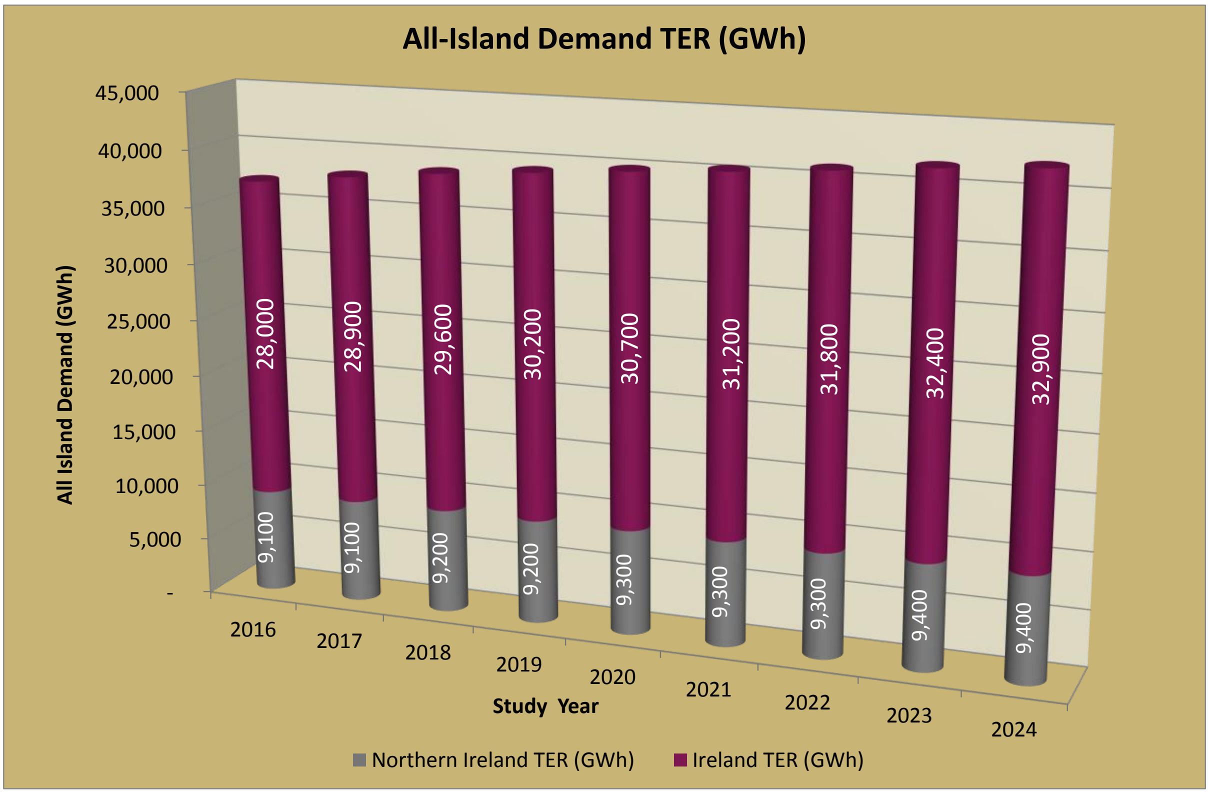


Figure 14 All-Island TER(GWh) demand for each study year 2016-2024

Table 12 Total energy requirement demand (GWh) and peak (MW) for years 2016-2024

Year	TER (GWh)			TER Peak (MW)		
	Ireland	Northern Ireland	All-island	Ireland	Northern Ireland	All-island
2016	28,000	9,100	37,100	5,092	1,761	6,805
2017	28,900	9,100	38,000	5,167	1,769	6,888
2018	29,600	9,200	38,800	5,209	1,777	6,938
2019	30,200	9,200	39,400	5,243	1,785	6,980
2020	30,700	9,300	40,000	5,294	1,792	7,038
2021	31,200	9,300	40,500	5,338	1,799	7,089
2022	31,800	9,300	41,100	5,416	1,807	7,174
2023	32,400	9,400	41,800	5,498	1,815	7,264
2024	32,900	9,400	42,300	5,578	1,823	7,354

3.7.1 The Northern Ireland Demand

The all-island market balances supply and demand for the whole island. This report is only focussed on network constraints in Northern Ireland, so a split region model is required, for modelling purposes only the updated Northern Ireland network is included.
Generally there are Northern Ireland network issues when demand is low and wind is high. This is due to the location of the newly connection renewable generation in comparison to where the electricity demand is located. Table 13 presents the proportions of demand and large renewable generation in each area.

Table 13 Distribution of Northern Ireland demand

Northern Ireland Region	2020 Proportion of Demand in Area (%)	2020 Proportion of Large Scale Wind Capacity in an Area	2020 Proportion of Large Scale Solar Capacity in an Area
West	22%	91%	55%
East	38%	8%	45%
Belfast	40%	1%	0%

The demand distribution at a nodal level is illustrated in Figure 15. The load distribution was kept in line with the All-Island Ten Year Transmission Forecast statement 2015.

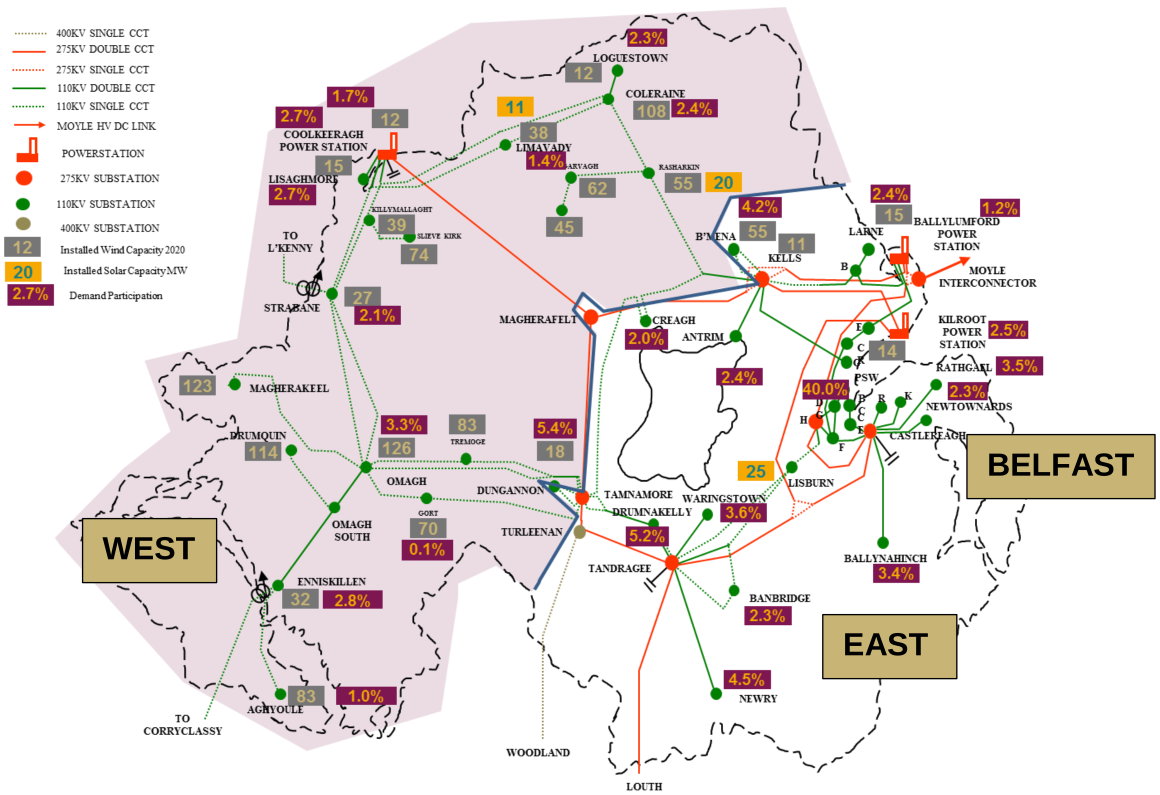


Figure 15 Northern Ireland Demand Distribution (2020)

In Ireland, without the expection of the North South Interconnections, the network is not modelled and therefore the load is not modelled at nodal level.

3.7.2 Demand Characteristics

The Plexos power market model runs on an hourly basis, this means that there are demand quantities for every hour of the year. Demand tends to be fairly predictable in that during the nighttime periods demand is low, as the day light hours appear there is a steady increase until tea time (5-6pm) when the demand peaks. There tends to be less demand during the weekend days compared to the working week days. There are summer and winter variations with demand typically being lower in summer than in winter. Figure 16 shows a typical daily demand profile for the all-island power system.

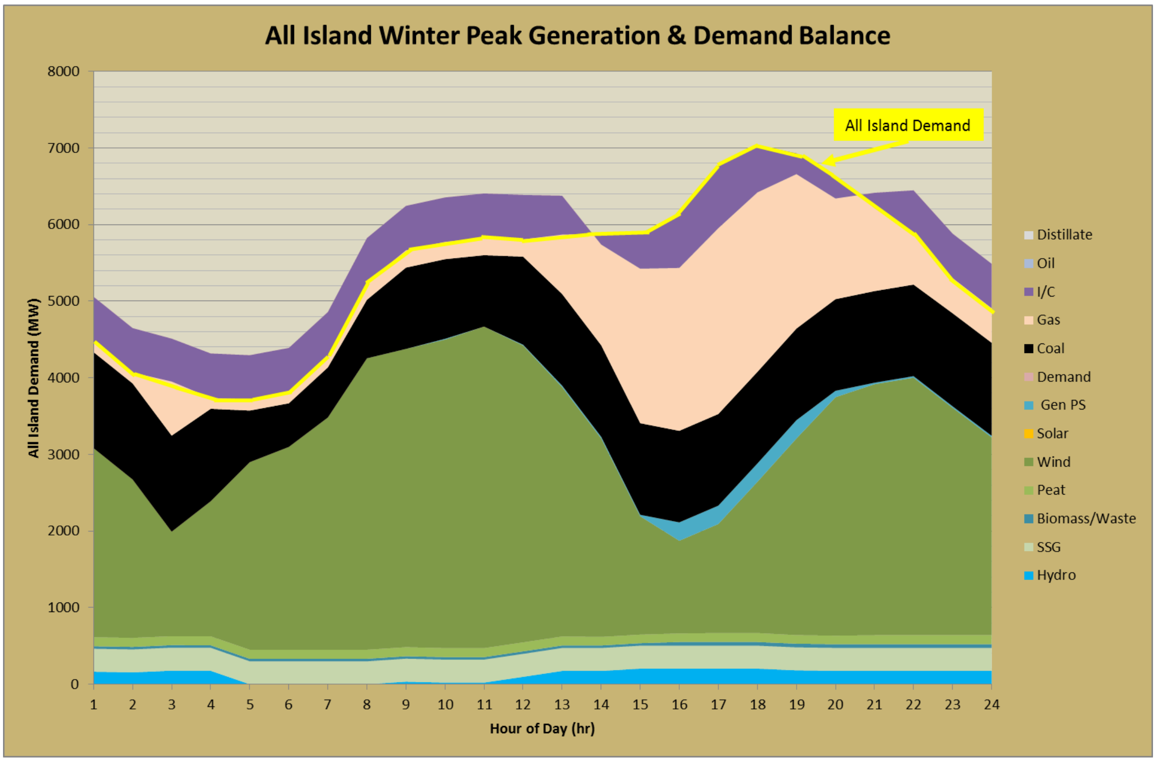


Figure 16 All-Island winter peak generation and demand balance

3.8 Fuel and Carbon Prices

The price of fuel is an important input to the model and will have an impact on the levels of both curtailment and constraint experienced by the generators. The coal, gas, and carbon prices are based on the International energy agencies (IEA) World Energy Outlook 2014 fuel forecast for 2020. The prices used in the model are presented in Table 14.

Table 14 Fuel prices used in the study

Fuel Type	New Policies WEO 2014 (Real Terms 2013) 2020 Prices
Gas	€ 8.91
Coal	€ 2.98
LSFO	€ 11.81
DO	€ 20.69
PEAT	€ 3.75
CO2 €/tCO2	€ 15.60

The fuel prices were kept constant through the study period. The monthly differences in gas and oil prices are accounted for by using historical fuel profiles, but ensuring that the annual average was equal to the WEO 2014 value.

The cost of carbon is included in the commitment and dispatch decisions for each generating unit that emits carbon.

It is assumed that Peat power plants operate on an economic basis.

Dublin bay power has a long term fuel contract and is allowed to bid lower costs to the market on the basis of this. For the purposes of this constraints modelling exercise, it is assumed that Dublin bay power's gas price is 65% of gas compare to other gas units. The units will use the same gas price from 2018 onwards.

3.9 Interconnection Assumptions

High Capacity Interconnection on the all-island system consists of a number of circuits:

- 1 double circuit 275 kV AC interconnection between Ireland and Northern Ireland.
    - An additional 400 kV Circuit between Northern Ireland and Ireland (*referred to as the second North South Interconnector*) is assumed to connect at the beginning of 2020.
- 2 High Voltage Direct Current (HVDC) interconnectors to GB.
    - Moyle Interconnector.
    - East West InterConnector (EWIC).

This section describes the assumptions and modelling methodology employed in the studies.

Table 15 details the modelling assumptions employed with respect to North South Interconnection power flows for the constraints model.

Table 15: North-South tie-line power flow assumptions

North-South Tie-Line Power Flow Assumptions
Prior to the second North-South Interconnector being built, the Louth-Tandragee Interconnector is assumed to be limited to flows of 300MW from South to North and 300MW from North to South. When the second North-South Interconnector is in place, this limitation is removed and flows increase to +/- 1,100 MW It is assumed that the Letterkenny-Strabane and Corraclassy-Enniskillen 110 kV connections are not used to transfer power between the two control areas for the purposes of this constraints modelling exercise.

3.9.1 Moyle

The Moyle Interconnector, started commercial operation in 2002. The Moyle Interconnector links the electricity grids of Northern Ireland at Ballylumford with the GB grid at Auchencrosh in Scotland. It has a capacity of 500MW, but at the data freeze point is currently limited to 250MW flow in either direction due to one of the cables being unavailable. It is assumed that the export capacity of Moyle stays at 250MW up until 2016.

In 2017 the export capacity from Northern Ireland to Scotland is reduced to 80MW for the duration of the study due to network limitations in GB. The import capacity remains at 450MW.

3.9.2 EWIC

It is assumed that EWIC is modelled for all study years with a maximum import capacity of 500MW. The export capacity varies over the study period to reflect the operational rule changes.

3.9.3 Interconnector Modelling

For modelling purposes it is assumed that the export capacity of each interconnector is de-rated by 10% to account for wind forecast error, trading imperfections etc. In other words the maximum export possible for the purposes of this modelling is 450MW on EWIC and 225/72MW on Moyle.

For all scenarios, Moyle and EWIC were allowed to export wind that would otherwise have been curtailed. There is an underlying assumption that GB does not have transmission limitations at the same time, and that it is capable of accepting the excess wind generation. Also note that for this study, the focus is on the generation output of wind farms and not on the production costs or market modelling. The GB Market was modelled by using the National Grid Future Energy Scenario (FES) 2014 Document. The FES 2014 Gone Green Scenario was chosen since this is most aligned with the EU studies that SONI use for ENTSO-E (European Network of Transmission System Operators for Electricity) market analysis.

The FES 2014 gone green scenario is a scenario which tends to favour interconnection flows from SEM to GB due to a number of factors, such as the decommissioning of a significant proportion the GB coal generation portfolio, this is consistent with the IED directive that will mean many coal power plants are unsustainable without significant investment.

Interconnection losses are not modelled, however, a small interconnection wheeling charge is applied. A wheeling charge is a charge applied to each megawatt of energy that flows on the interconnector

For the purposes of this study there are no new interconnection projects, or changes to existing GB capacities considered post 2020.

Table 16 Summary of interconnection capacities and SEM to GB Market Flows

Summary SEM to GB Market Flows									
Year	**2016**	**2017**	**2018**	**2019**	**2020**	**2021**	**2022**	**2023**	**2024**
Interconnection Capacities									
Moyle Import	250	450	450	450	450	450	450	450	450
Moyle Export	180	72	72	72	72	72	72	72	72
EWIC Import	500	500	500	500	500	500	500	500	500
EWIC Export	270	360	450	450	450	450	450	450	450
Annual SEM Imports & Exports (GWh)									
SEM to GB (Exports)	2,000	2,400	2,400	2,600	2,600	2,700	2,700	2,700	2,800
GB to SEM (Imports)	400	700	800	700	700	700	700	700	800

Note: Interconnection exports are de-rated to 90% of physical capacity for purposes of modelling uncertainties such as wind forecast error, trading inefficiencies etc. Annual import and export quantities are subject to rounding.

3.10 Operational Rules

The purpose of this section is to define the set of 'operational constraints', and how these constraints may evolve over the proposed study period. Operation constraints are important since they will help to define system issues that may lead to low cost generation output being reduced. The constraint studies will assess the levels of curtailment that generators may experience in the period from 2016-2024.

Curtailment is an all–island issue. This report will present the generation curtailment on a jurisdictional and nodal basis. The way in which operational constraint rules change over time are a very important factor when trying to model expected levels of generation curtailment. Operational constraint rules which are said to be 'binding' will tend to turn down renewable generators which is then reported as curtailment.

For the purposes of these studies the 'EirGrid and SONI operational constraints update 28 August 2015' document was used for the base 2016 study year. The changes in the rules across the study horizon were based on the DS3 programme roll-out, major infrastructure project developments etc. Further information on 'Delivering a Secure Sustainable Electricity System (DS3)' can be found on the EirGrid group website (*http://www.eirgridgroup.com/how-the-grid-works/ds3-programme/*)

This section will present the all-island operational constraints, used to develop the 'constraint rules' for the Plexos economic dispatch tool. As with previous studies, such as the Gate 3 constraints reports and the Northern Ireland Generator Output Reduction reports, it was assumed that the operational constraints would evolve and reduce in size with network and system reinforcement. Relaxing of operational constraint rules will help lessen or reduce the increases that could be expected in all island curtailment.

3.10.1 Operational Constraint Rules Post 2020

The current DS3 programme has been established to enable the connection of enough renewable generation to meet government 2020 targets. The horizon for these studies extends past the year 2020. There are no additional operational constraints modifications assumed, since there are no specific studies that can be used to support any additional rule changes.

3.10.2 System Wide Operational Constraint

There are a number of operational constraints that are associated with the DS3 programme. These operational rules make sure that the system operators can run the system within frequency stability limits. Changes to system rules require capital investment to be made, both at TSO and a generator levels. The studies assume that the required TSO capital approvals and generator investment decisions happen in a timely manner.

Table 17 Active System Wide Operational Constraints

Active System Wide Constraints		
Limit	Operational Constraint rule	NI Constraint/Curtailment report
Non Synchronous Generation	There is a requirement to limit the instantaneous penetration of asynchronous generation connected to the All-Island system.	The limits vary across the years of the report: 55%(2016), 60%(2017), 65%(2018), 70%(2019), 75%(2020-2024).
Operational Limit For RoCoF	There is a requirement to limit the RoCoF on the All-Island system.	The limits vary across the years of the report: 0.5Hz/Sec(2016-2019), 1Hz/Sec(2020-2024)
Operational Limit For Inertia	There is a requirement to have a minimum level of inertia on the All-Island system.	The limits vary across the years of the report: 20,000MWs(2016-2019), 15,000MWs (2020-2024)

3.10.2.1 System Non-Synchronous Penetration

There is a system need to limit the amount of 'non-synchronous' generation at any point in time. The limit makes sure that the power system is operated within a stable zone.

There is a rule which can be expressed by a maths formula:

$$SNSP\ Limit \geq \frac{All\ Island\ Wind\ Generation + Interconnector\ Imports}{All\ Island\ Demand + Interconnector\ Exports}$$

An increase in the SNSP limit will allow more 'non-synchronous' generation to be accepted onto the system. The DS3 work stream is responsible for determining the SNSP outlook. The timeline for increases in SNSP are shown in Figure 17:

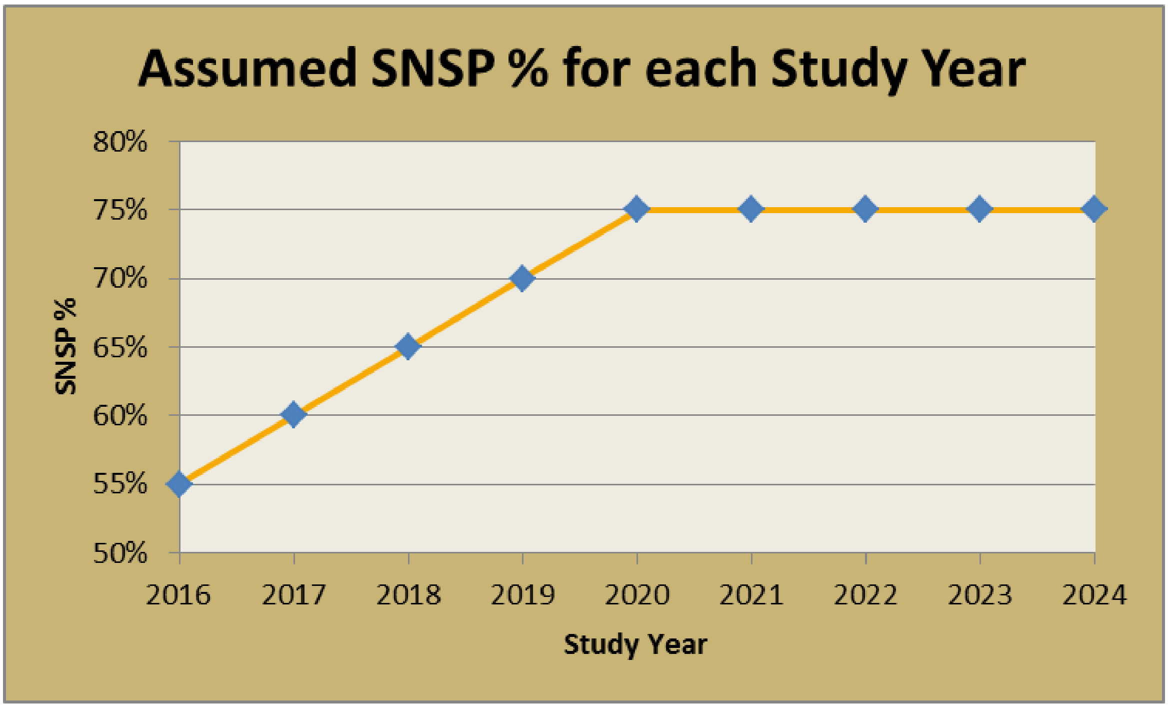


Figure 17 Limits on the non-synchronous generation that is allowed at any moment on the power system

3.10.3 Operational Reserve Needs

The power system is operated, so that if there is a fault or trip of any large piece of generation, there will be enough back-up 'reserve generation' to prevent the lights going off. Generally this service is provided by generation that is operated 'part loaded', so if there is a problem the reserve generator can quickly increase its output to keep the lights on. For the purposes of this study only Primary Operating Reserve and the Negative Reserve services are considered.

Primary Operating Reserve means that the system will be operated, so that ¾ of the largest generator output, or interconnection import at any point in time is covered should that power becomes unavailable, i.e. an interconnection fault or generator trip. For the purposes of modelling the Plexos model tracks the largest generation / interconnector output at each hour and makes sure that there is enough reserve generation available. Only Primary Operating reserve is modelled since this is typically the most testing reserve service to cover.

Plexos has the ability to model the negative reserve service. This reserve service is used to cover a system problem such as an interconnection trip whilst exporting, or demand reducing too quickly. If such an event occurs there is a danger that the system frequency will rise too quickly and too high. The system operator needs to be able to run back the output from generators to prevent the system from speeding up too much. This reserve service typically means generation is operated above its scheduled output to cover the service.

Table 18 Active system wide operational constraints

Operational Reserve Requirements		
Limit	Operational Constraint rule	NI Constraints Report
Primary Reserve All-Island - 75% of the Largest In-Feed A Minimum of 115MW Ireland Min – 110/75 NI Min – 50	All-Island primary reserve must be 75% of the largest infeed with jurisdictional limits of: A minimum of 115MW should be covered by the All-Island rule. **Jurisdictional Requirement** (Up until 2nd North South in Service, 2020) Ireland At night 75MW / Daytime 110MW. Northern Ireland 50MW.	POR all island requirement valid for all years of report Jurisdictional requirements removed in 2020-2024.
Negative Reserve Ireland Min – 100MW NI Min – 50MW	Negative reserve must be held on the system. When a Generators output is above its minimum generation threshold, it is said to carry negative reserve. There will only be a cost associated when lower cost generation is curtailed to allow ramping of generation above its minimum generation level to cover the negative reserve service. Ireland Requirement 100MW. Northern Ireland Requirement 50MW.	Negative reserve requirement valid for all years of the report.

3.10.4 Minimum Number of Synchronous Generators at any time

There are a number of operational rules that are obeyed by the system operator at a regional and local level. The rules are typically there to ensure that there is enough inertia on the system for system frequency stability, or for localised issues, such as, network voltage support. Changes to the rules are guided by operational and / or planning assumptions. Across the study horizon it is assumed that the appropriate capital approvals are granted, especially where voltage support projects that are foreseen.

Table 19 Ireland must run rules

Active Ireland Constraints		
Limit	Operational Constraint Rule	NI Constraints Report
System Stability: AD1, AD2, DB1, HNC, HN2, MP1, MP2, MP3, PBC, TB3, TB4, TYC, WG1	There is a minimum number of high-inertia machines that must be on-load at all times in Ireland. Required for dynamic stability.	The requirement vary across the years of the report: 5 units (2016-2017) 4 units (2018-2024)
Dublin Generation : 2 Units, DB1, HNC, HN2, PBC	There is a minimum number of large generators that must be on-load at all times in the Dublin area. Required for voltage control. This assumes EWIC is operational	The requirement remains the same across all years of the report: 2 units (2016-2024)
Dublin North Gen: 1 Unit, PBC, HNC, HN2 **Dublin South Gen:** 1 Unit, PBC, DB1	Requirement for generation in North/South Dublin (for load flow and voltage control).	The requirement remains the same across all years of the report for both constraints: 1 unit (2016-2024)
Southwest Gen : 2 by night 3 by day	There must be at least 2/3 generators on-load at all times in the South West area. Required for voltage stability. AD1, AD2, AT11, AT12, AT14, SK3, SK4, WG1	2 units 2016 – 2017 Constraint to be removed from 2018
Moneypoint: , MP1, MP2, MP3 1 Unit	There must be at least one Moneypoint unit on load at all times Required to support the 400 kV network.	1 unit (all study years) The requirement remains the same across all years of the report

Table 20 Northern Ireland operational constraint rules

Northern Ireland Constraints		
Limit	Operational Constraint rule	NI Constraint/Curtailment report
System Stability C30, B31, B32, B10, BPS4, BPS5, BPS6, K1, K2	There is a minimum number of high-inertia machines that must be on-load at all times in Northern Ireland. Required for dynamic stability. Relaxes once NS2 in commission.	The requirement vary across the years of the report: 3 units (2016-2019) 2 units (2020-2024)
North West Generation C30	C30 must be on load when the NI system demand exceeds 1,000MW to ensure voltage stability.	The requirement remains the same across all years of the report
Ballylumford Generation B31, B32, B10, BGT1, BGT2, B4, B5, B6	The output from Ballylumford must be limited seasonally due to a circuit rating limitation.	The requirement remains the same across all years of the report. Summer 1174MW Winter 1344MW
Kilroot Emission Limit K1, K2	Emissions limits from K1 and K2 are restricted to 1,500 hours from June 2020. These units retire end 2023.	1,500 hrs (mid 2020, 2021, 2022, 2023) Units retired (2024)

3.11 Network Changes

The purpose of a constraint report is to highlight the effectiveness of network roll out on constraints. The Plexos model can be used to give an indication of where generation is likely to be reduced for before network uprate and new build projects are completed. Table 21 provides the detail of the network investments proposed across the study horizon 2016 – 2020, these are aligned with the All-Island Ten Year Transmission Forecast Statement 2015.

There are a number of network development projects dates that were adjusted from the All-Island Ten Year Transmission Forecast Statement 2015. The Coolkeeragh to Magherfelt double circuit is a major asset replacement project, after discussions with NIE networks and SONI near-time it was decided that many of the 110 kV uprates would be unlikely to happen within the same maintenance period. The timeline for the northwest 110 kV line uprate projects, was pushed out to post 2020 for the purposes of this modelling exercise, these modifications are highlighted in Table 22. Any modifications to the proposed uprate timelines were consulted on with industry through workshops held at SONI offices.

It should be noted that the inclusion of reinforcements projects in this study is not confirmation that they will proceed. These are modelling assumptions and should not be considered as fact. Since the Ireland network is not switched on in the model, the only transmission reinforcement considered for Ireland is that of the second North South interconnector development.

Table 21 Proposed Network Investments: years 2016-2020

Description	Network Project	Included in Study
Transformer Asset Replacement	Belfast, Knock Main	01/01/2017
Substation Reconfiguration	Belfast, North Main	01/01/2017
Uprate of 110 kV Circuit	Castlereagh - Rosebank	01/01/2017
Transformer upgrade	Belfast, Donegal North Main	01/01/2017
New 110 kV Substation	Rasharkin Cluster Station	01/01/2017
110 kV Circuit Uprate	Coleraine- Rasharkin - Kells	01/01/2017
New 110 kV Substation	Gort Cluster Station	01/01/2017
New 110 kV Circuit	Omagh – Gort - Tamnamore	01/01/2017
Substation Reconfiguration	Tamnamore Phase 2	01/01/2017
New 110 kV Substation	Tremoge Cluster Station	01/01/2017
New 110 kV Circuit	Omagh-Tremoge-Tamnamore	01/01/2017
110 kV Circuit Reconfiguration	Dungannon/Omagh/Tamnamore	01/01/2017
New Substation	Omagh South	01/01/2019
110 kV Circuit uprate	Omagh – Omagh South	01/01/2019
New 110 kV Substation	Drumquin Cluster Station	01/01/2019
New 110 kV Substation	Garvagh Cluster Station	01/01/2019
400 kV Circuit	Woodland – Turleenan	01/01/2020
275 kV Circuit Uprate	Turleenan - Tamnamore	01/01/2020
275 kV Double Circuit Uprate	Coolkeeragh-Magherafelt	01/01/2020
New 110 kV Substation	Belfast, Airport Road	01/01/2020

Table 22 Proposed Network Investments: years 2021-2024

Description	Network Project	Included in Study
110 kV Circuit Uprate	Coleraine-Coolkeeragh, Limavady	01/01/2021
110 kV Circuit Uprate	Omagh-Strabane (2022)	01/01/2022
110 kV Circuit Uprate	Coolkeeragh-Killymallaght-Strabane (2023)	01/01/2023
New Build 110 kV Circuit	Kells-Rasharkin (2023)	01/01/2024
New Build 110 kV Double Circuit	Armagh - Tandragee	01/01/2024

3.12 Tranmission Network

The transmission network in Northern Ireland was based on SONI's latest network assumptions. The All-Island Ten Year Transmission Forecast Statement 2015 was used as a reference source for network projects. The transmission network in Ireland was not modelled. This section details modelling assumptions associated with the transmission network.

3.12.1 Derating from MVA to MW

Plexos is a DC load flow simulation tool, therefore it only models active power flows. Transmission plant and line ratings, are generally defined in terms of MVA. For the purposes of modelling the MW ratings for transmission line circuit in Northern assumed a power factor of 0.95 in Northern Ireland.

3.12.2 Overhead Line, Cable and Transformer Overload Ratings

In working out the best generation dispatch Plexos will take into account 'N-1 contingencies on the transmission system'. An N-1 Plexos dispatch will reduce generation output to ensure that if a network problem occurs, there would be no overloads on any other network asset.

When determining if the post-contingency flows are within limits, the program uses the overload rating of the apparatus or plant, where specified, instead of the normal rating. The overload rating is typically higher than the normal rating but is only allowed in emergency conditions and for short periods of time. The overload rating is plant specific.
In the Northern Ireland planning standards, overload ratings are specified for transformers, but not for overhead lines.

3.12.3 Transmission System Outages

The network constraint modelling will not take account of scheduled transmission outages or network up rate outages.

3.12.4 Distribution System Outages

For the purposes of the constraints modelling, a simplified model of the distribution system was used. All load and generation was assumed to be aggregated to the nearest transmission node. It was checked as much was reasonably possible that this did not impact on potential transmission system flows e.g. parallel paths.

3.12.5 Contingency Monitoring

A full list of N-1 contingencies is included in the Plexos model which accounts for the possible loss of transmission lines and transformers. Plexos will solve these contingencies and produce a dispatch that will avoid any post-fault circuit overloads.

In Northern Ireland, all 110/275 kV transformers as well as all 110 kV circuits are considered as N-1 all year round. The 275 kV double circuit contingencies are modelled such that in winter, the contingency is the loss of the double circuit and in summer is the loss of a single circuit. There is one exception, the Coolkeeragh-Magherafelt 275 kV double circuit loss is considered all year round.

3.12.6 Special Protection Schemes

In power system operations, when the Coolkeeragh-Magherafelt 275 kV double circuit trips, a ‘post-contingency’ runback scheme is operated at Coolkeeragh. The special protection scheme is such that the steam unit it tripped so that the CCGT can run at 160MW, 100MW below its minimum recommended operating point. This has been accounted for in post processing of the constraint results.

3.12.7 Network Changes

To reflect the differences in constraints modelling compared to steady-state AC load flow studies. Some minor changes were made to the network data such as switching in transformers that are normally on hot standby and not splitting stations for short circuit reasons.

4 Interpretation of Results

The all Island Plexos models for 2014 to 2024 produce annual hourly conventional and renewable generation dispatches and interconnector export flows from the All-Island system to GB.

The SEM-Committee decision papers SEM-11-105 and SEM-13-010 state that constraint should be handled before curtailment. SEM-13-010(ii) TSO 'Definition of Curtailment and Constraint', provides further information on how in practice curtailment may bind first, therefore masking constraint. Curtailment is shared between Northern Ireland and Ireland on the ratio of available controllable wind during the hour where the curtailment issue exists. Total wind reduction is calculated by comparing the wind availability to the wind dispatch on a system level.

The Plexos model will only apply wind reduction to generation that is deemed to be controllable. The network model aims to reduce wind generation that has the greatest effect in alleviating a transmission constraint as a priority. In Northern Ireland, where a tie-break situation arises in relation to a transmission constraint, wind reduction is applied on a pro-rata basis as per SEMC rules.

There are no constraint groups in Northern Ireland. In the event of a constraint where generation has an equal effect in alleviating the bottleneck, generation output reduction will be on a pro-rata basis.

The wind constraint and curtailment results on a Northern Ireland system level and on a nodal basis are presented. For each node, a table of results shows:

- The total capacity of wind connected at that node.
- The capacity of additional wind connecting during each study year/scenario.
- The capacity of controllable wind generation at that node.
- The annual wind energy available at that node
    - This includes both controllable and uncontrollable annual generation (GWh).
- The amount of curtailed and constrained controllable energy
    - This is presented in terms of energy (GWh) and as a percentage of controllable energy available at that node.

The results from the tables are also presented as a graph to show the impact of curtailment and constraint across the study time horizon.

Wind reduction as a result of curtailment is presented as a range, with a lower value and a higher value. The lower value represents the curtailment figure for the climate year 2013. The higher represents the curtailment figure for the climate year 2009. The combined constraints and curtailment at the node is also presented as a range.

In addition, all figures presented in this report are rounded to the nearest whole number. Where the model produces a result of greater than 0.0% and less than 0.5%, this will be shown as ~0% in the report. 1. Where the model produces a curtailment energy range of between 0.5GWh and less than 1.5GWh, it will be reported as a range 1-1.

Table 23 Summary of Northern Ireland constraints and All-Island curtailment

Summary of Northern Ireland Curtailment and Constraints									
Year	2016	2017	2018	2019	2020	2021	2022	2023	2024
Curtailment (%)	2-5	3-5	2-4	4-6	3-5	4-7	4-7	4-7	4-7
Constraint (%)	1	~0	~0	1	1	1	1	~0	~0
Curtailment and Constraint (%)	3-6	3-5	2-4	5-7	4-6	5-8	5-8	4-7	4-7

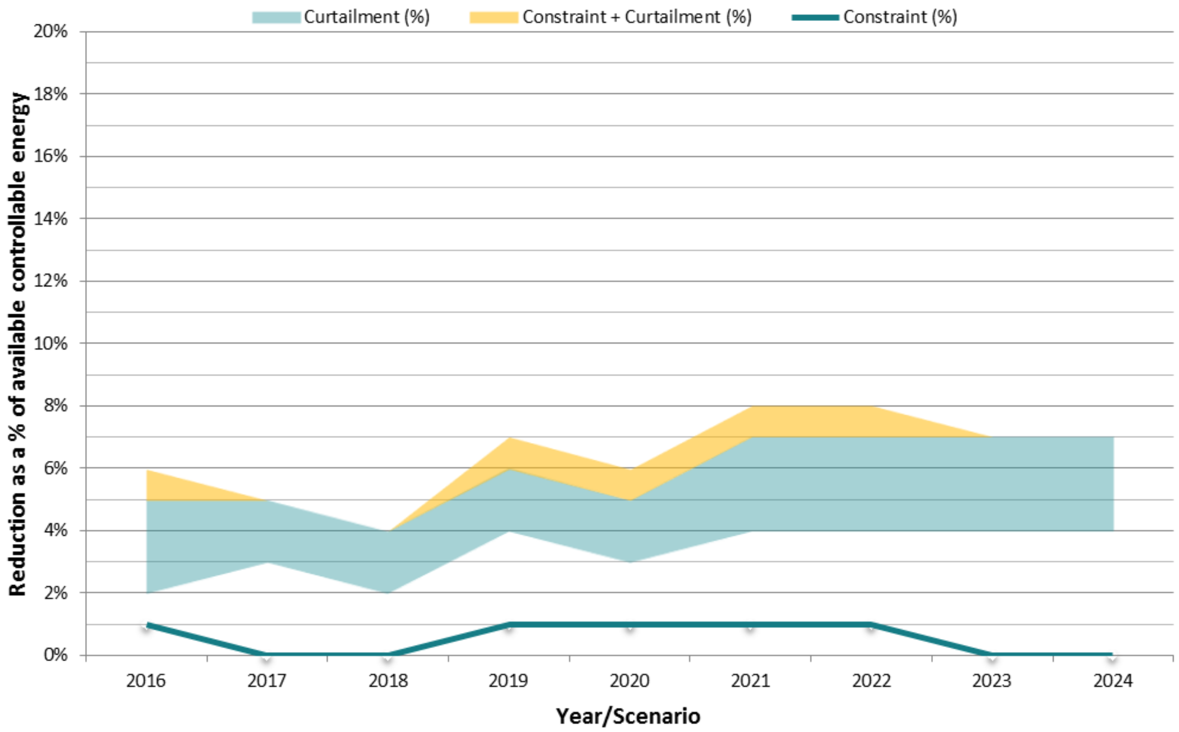
5 Nodal Results

The following section presents the results for various transmission locations where renewable generators are greater than 5 MW. The reporting of curtailment and constraint is on those generation stations that are fully controllable and therefore can be dispatched down for constraint and curtailment.

For the avoidance of doubt the nodal tables provide the complete curtailment and constraint range for each node.

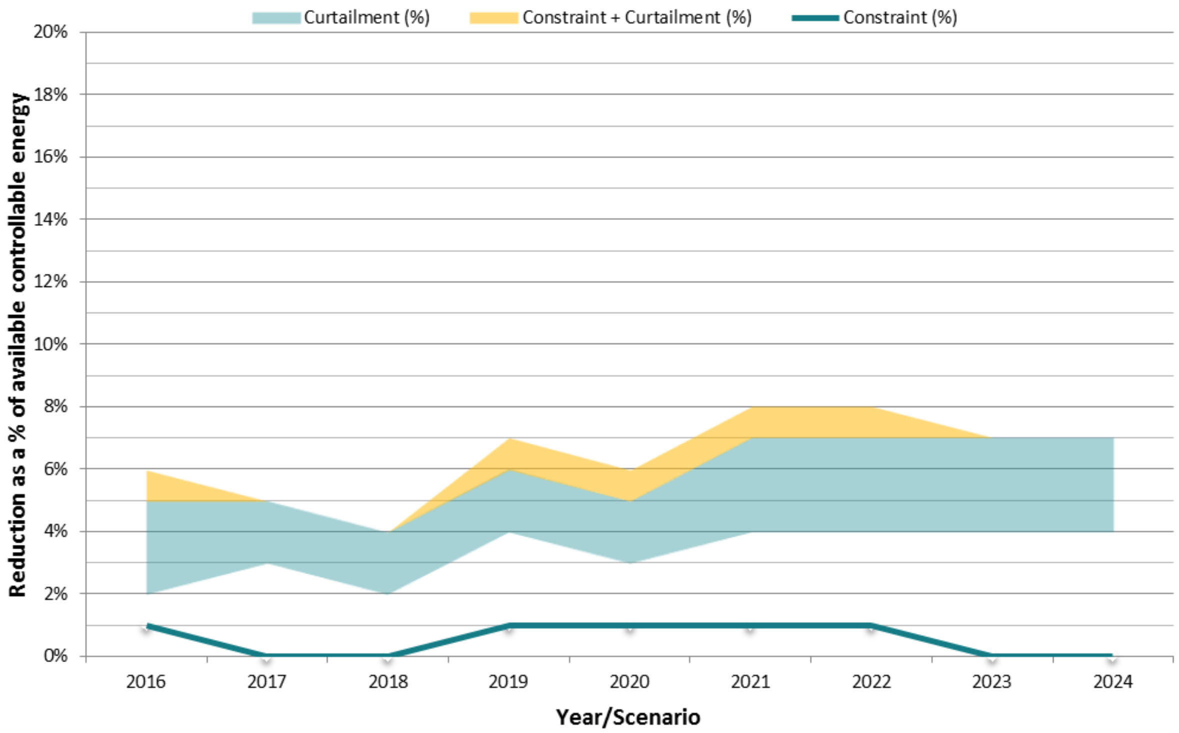
5.1 Northern Ireland Summary

Northern Ireland Summary – Generation Results									
Year/Scenario	2016	2017	2018	2019	2020	2021	2022	2023	2024
Wind & PV Capacity at Node									
Additional Wind or PV(MW)	0	227	149	219	0	22	0	0	0
Existing Wind & PV (MW)	671	671	899	1047	1267	1267	1289	1289	1289
Total Wind & PV(MW)	671	899	1047	1267	1267	1289	1289	1289	1289
Of which is Controllable (MW)	592	820	968	1188	1188	1210	1210	1210	1210
Results									
Available Energy (GWh)	1750	2243	2630	3201	3206	3240	3240	3240	3245
Curtailed Energy (GWh)	34-74	59-110	51-101	107-178	85-152	123-205	127-214	122-217	131-223
Constrained Energy (GWh)	8	~0	3	22	31	23	22	2	2
Curtailed + Constrained Energy (GWh)	42-82	59-110	54-104	129-200	116-183	146-228	149-236	124-219	133-225
Curtailment (%)	2-5	3-5	2-4	4-6	3-5	4-7	4-7	4-7	4-7
Constraint (%)	1	~0	~0	1	1	1	1	~0	~0
Curtailment and Constraint (%)	3-6	3-5	2-4	5-7	4-6	5-8	5-8	4-7	4-7



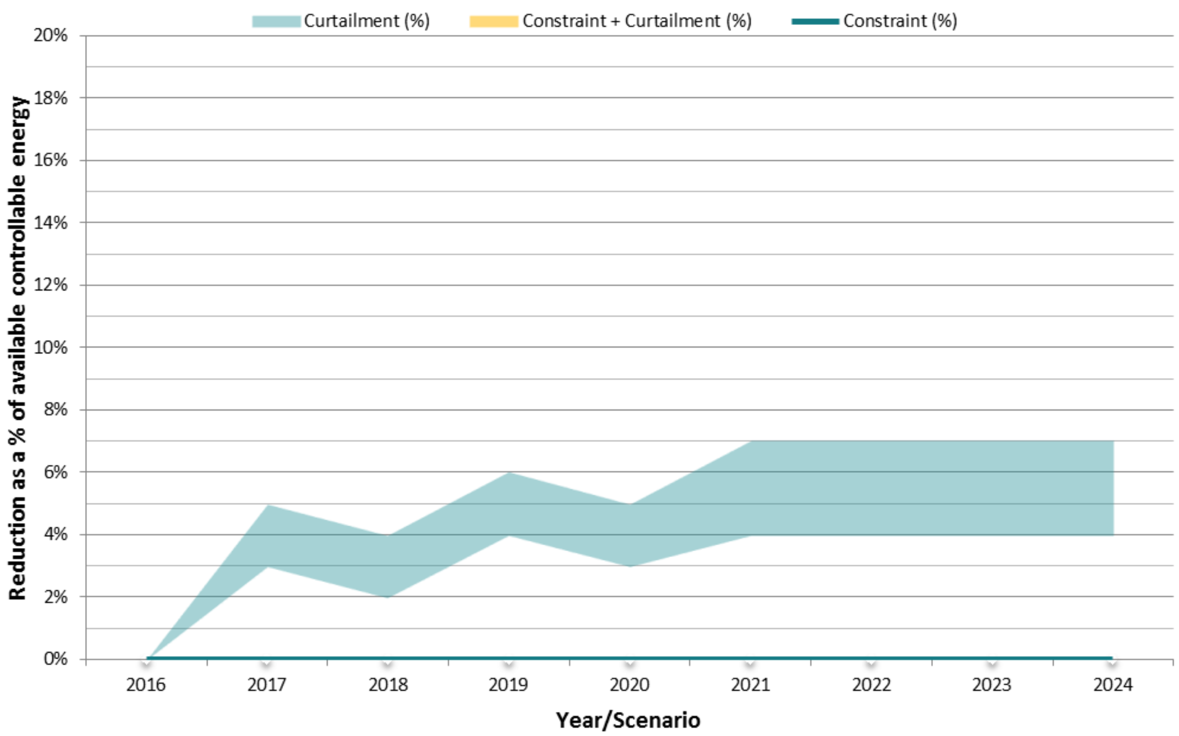
5.2 Aghyoule

Aghyoule – Wind Generation Results									
Year/Scenario	**2016**	**2017**	**2018**	**2019**	**2020**	**2021**	**2022**	**2023**	**2024**
Wind Capacity at Node									
Additional Wind (MW)	0	0	0	0	0	0	0	0	0
Existing Wind (MW)	83	83	83	83	83	83	83	83	83
Total Wind (MW)	83	83	83	83	83	83	83	83	83
Of which is Controllable (MW)	69	69	69	69	69	69	69	69	69
Results									
Available Energy (GWh)	215	215	215	215	215	215	215	215	215
Curtailed Energy (GWh)	4-9	5-10	4-7	6-11	5-9	7-12	7-13	7-13	8-13
Constrained Energy (GWh)	1	~0	~0	2	2	2	2	~0	~0
Curtailed + Constrained Energy (GWh)	5-10	5-10	4-7	8-13	7-11	9-14	9-15	7-13	8-13
Curtailment (%)	2-5	3-5	2-4	4-6	3-5	4-7	4-7	4-7	4-7
Constraint (%)	1	~0	~0	1	1	1	1	~0	~0
Curtailment and Constraint (%)	3-6	3-5	2-4	5-7	4-6	5-8	5-8	4-7	4-7



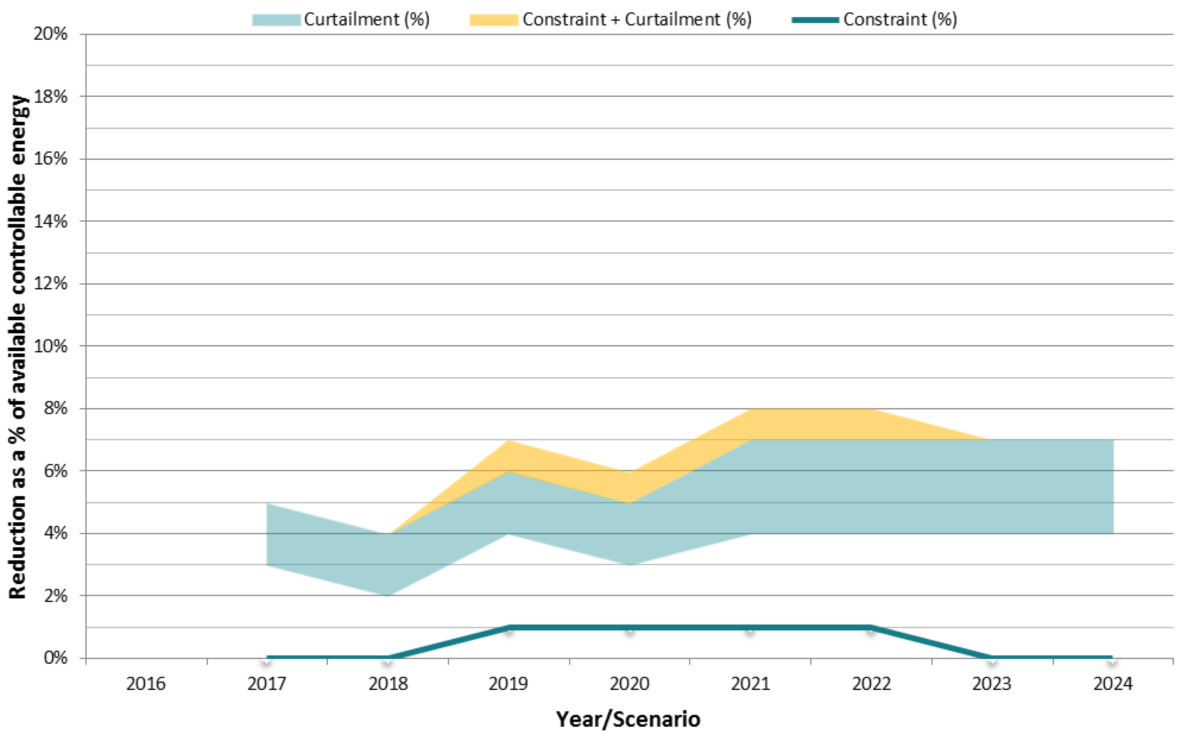
5.3 Ballymena

Ballymena – Wind Generation Results									
Year/Scenario	2016	2017	2018	2019	2020	2021	2022	2023	2024
Wind Capacity at Node									
Additional Wind (MW)	0	6	0	44	0	0	0	0	0
Existing Wind (MW)	5	5	11	11	55	55	55	55	55
Total Wind (MW)	5	11	11	55	55	55	55	55	55
Of which is Controllable (MW)	0	6	6	50	50	50	50	50	50
Results									
Available Energy (GWh)	13	29	29	144	144	144	144	144	144
Curtailed Energy (GWh)	0-0	0-1	0-1	5-8	4-7	5-9	5-9	5-9	6-10
Constrained Energy (GWh)	0	0	0	0	0	0	0	0	0
Curtailed + Constrained Energy (GWh)	0-0	0-1	0-1	5-8	4-7	5-9	5-9	5-9	6-10
Curtailment (%)	0-0	3-5	2-4	4-6	3-5	4-7	4-7	4-7	4-7
Constraint (%)	0	0	0	0	0	0	0	0	0
Curtailment and Constraint (%)	0-0	3-5	2-4	4-6	3-5	4-7	4-7	4-7	4-7



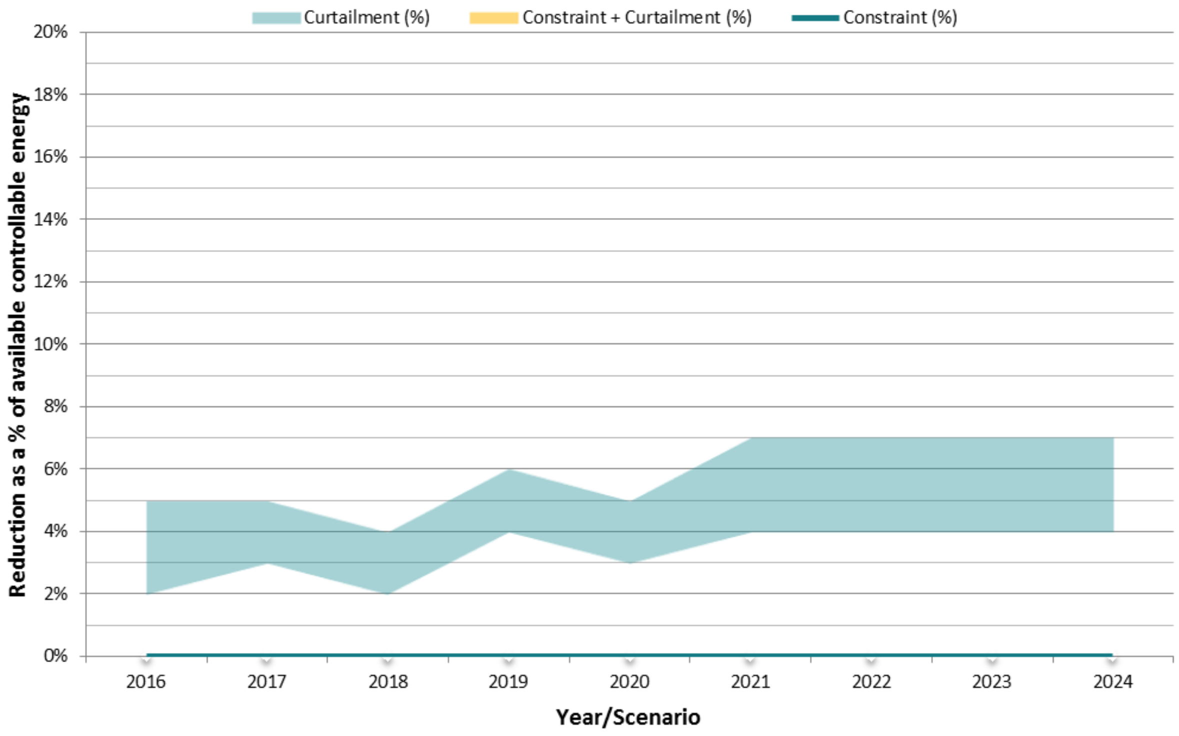
5.4 Brockaghboy

Brockaghboy – Wind Generation Results									
Year/Scenario	2016	2017	2018	2019	2020	2021	2022	2023	2024
Wind Capacity at Node									
Additional Wind (MW)	0	45	0	0	0	0	0	0	0
Existing Wind (MW)	0	0	45	45	45	45	45	45	45
Total Wind (MW)	0	45	45	45	45	45	45	45	45
Of which is Controllable (MW)	0	45	45	45	45	45	45	45	45
Results									
Available Energy (GWh)	0	117	117	117	117	117	117	117	117
Curtailed Energy (GWh)	0-0	3-6	2-5	4-7	3-6	5-8	5-8	5-8	5-9
Constrained Energy (GWh)	0	0	~0	1	1	1	1	0	0
Curtailed + Constrained Energy (GWh)	0-0	3-6	2-5	5-8	4-7	6-9	6-9	5-8	5-9
Curtailment (%)	0-0	3-5	2-4	4-6	3-5	4-7	4-7	4-7	4-7
Constraint (%)	0	0	~0	1	1	1	1	0	0
Curtailment and Constraint (%)	0-0	3-5	2-4	5-7	4-6	5-8	5-8	4-7	4-7



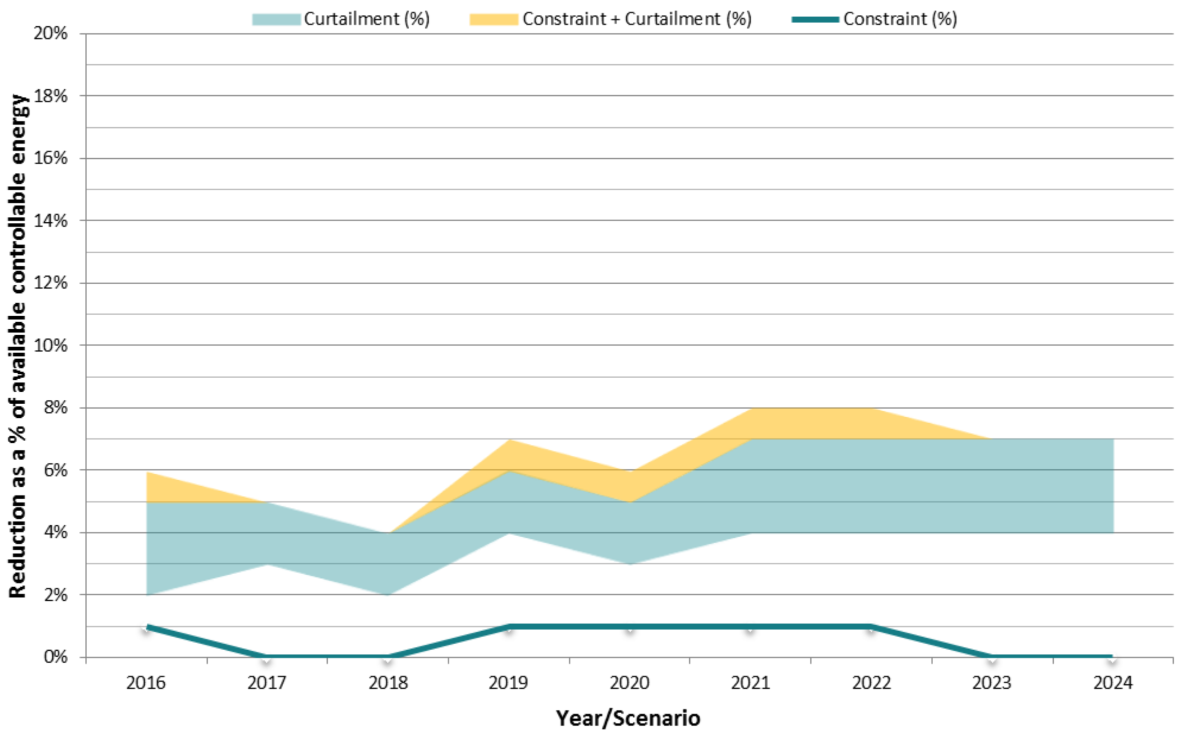
5.5 Carnmoney

Carnmoney – Wind Generation Results									
Year/Scenario	**2016**	**2017**	**2018**	**2019**	**2020**	**2021**	**2022**	**2023**	**2024**
Wind Capacity at Node									
Additional Wind (MW)	0	0	0	0	0	0	0	0	0
Existing Wind (MW)	14	14	14	14	14	14	14	14	14
Total Wind (MW)	14	14	14	14	14	14	14	14	14
Of which is Controllable (MW)	14	14	14	14	14	14	14	14	14
Results									
Available Energy (GWh)	36	36	36	36	36	36	36	36	36
Curtailed Energy (GWh)	1-2	1-2	1-1	1-2	1-2	1-2	1-3	1-3	2-3
Constrained Energy (GWh)	0	0	0	0	0	0	0	0	0
Curtailed + Constrained Energy (GWh)	1-2	1-2	1-1	1-2	1-2	1-2	1-3	1-3	2-3
Curtailment (%)	2-5	3-5	2-4	4-6	3-5	4-7	4-7	4-7	4-7
Constraint (%)	0	0	0	0	0	0	0	0	0
Curtailment and Constraint (%)	2-5	3-5	2-4	4-6	3-5	4-7	4-7	4-7	4-7



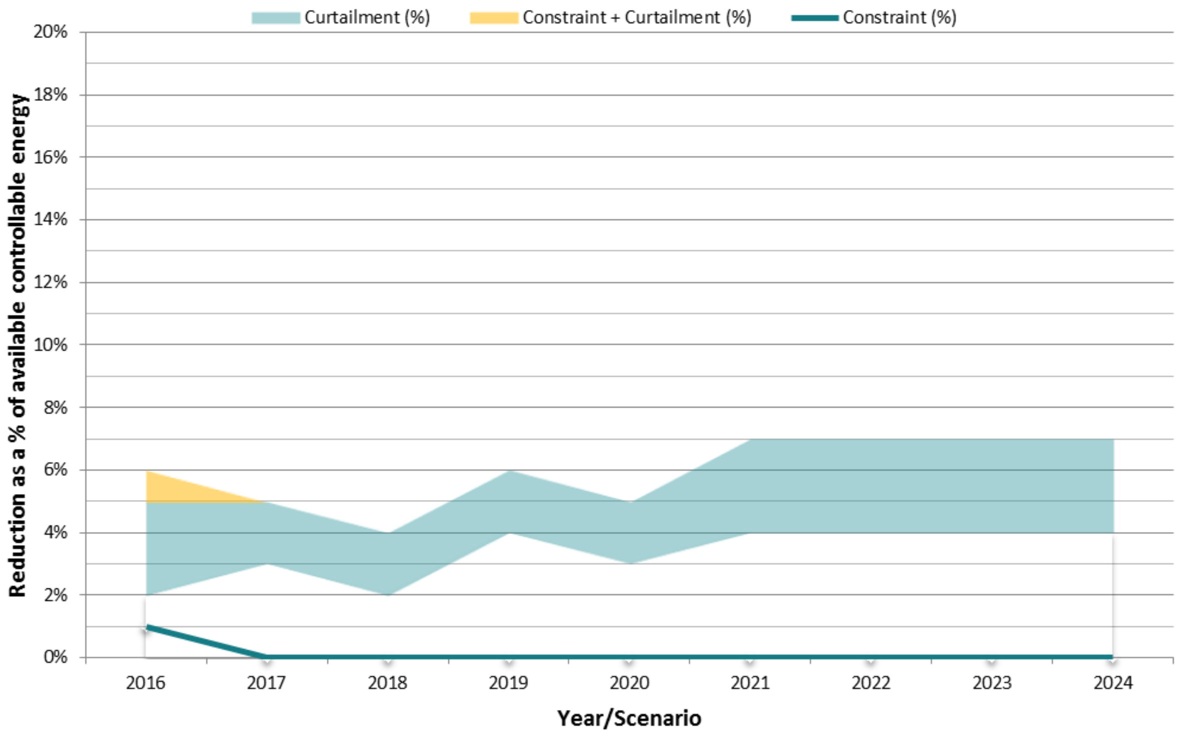
5.6 Coleraine

Coleraine – Wind Generation Results									
Year/Scenario	2016	2017	2018	2019	2020	2021	2022	2023	2024
Wind Capacity at Node									
Additional Wind (MW)	0	0	0	0	0	0	0	0	0
Existing Wind (MW)	108	108	108	108	108	108	108	108	108
Total Wind (MW)	108	108	108	108	108	108	108	108	108
Of which is Controllable (MW)	103	103	103	103	103	103	103	103	103
Results									
Available Energy (GWh)	282	281	281	281	282	281	281	281	282
Curtailed Energy (GWh)	6-13	8-14	6-11	10-16	8-14	11-18	11-19	11-19	12-20
Constrained Energy (GWh)	1	0	~0	2	3	2	2	~0	~0
Curtailed + Constrained Energy (GWh)	7-14	8-14	6-11	12-18	11-17	13-20	13-21	11-19	12-20
Curtailment (%)	2-5	3-5	2-4	4-6	3-5	4-7	4-7	4-7	4-7
Constraint (%)	1	0	~0	1	1	1	1	~0	~0
Curtailment and Constraint (%)	3-6	3-5	2-4	5-7	4-6	5-8	5-8	4-7	4-7



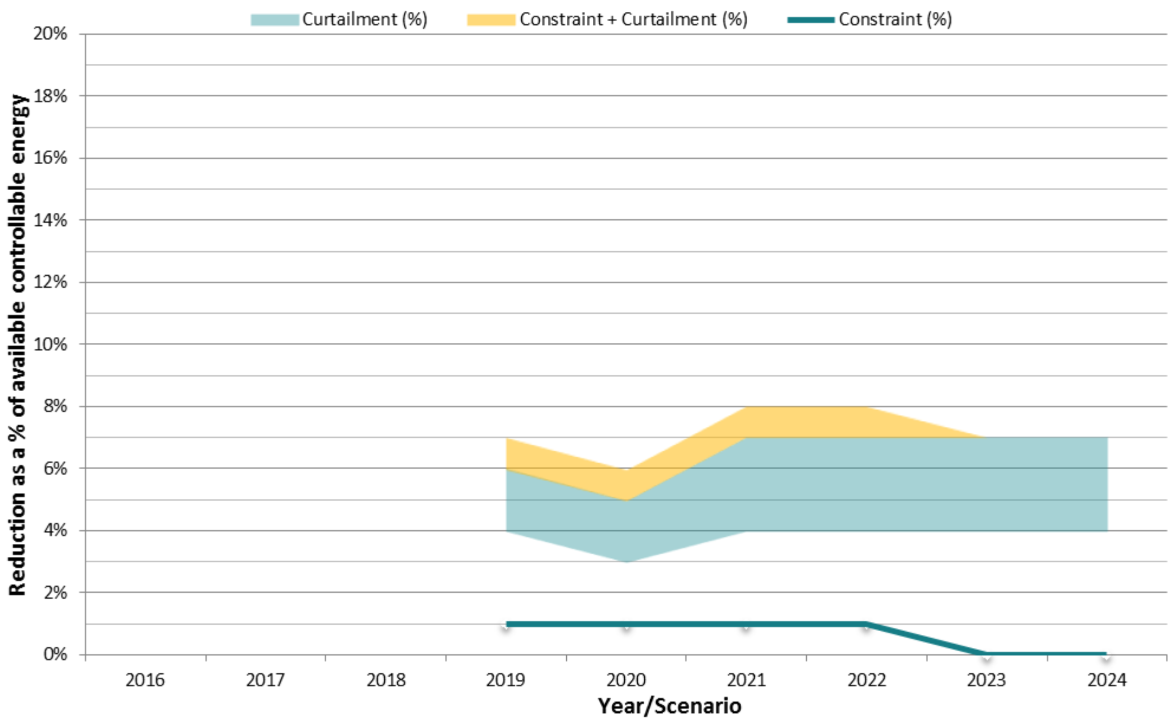
5.7 Coolkeeragh

Coolkeeragh – Wind Generation Results									
Year/Scenario	2016	2017	2018	2019	2020	2021	2022	2023	2024
Wind Capacity at Node									
Additional Wind (MW)	0	0	0	0	0	0	0	0	0
Existing Wind (MW)	12	12	12	12	12	12	12	12	12
Total Wind (MW)	12	12	12	12	12	12	12	12	12
Of which is Controllable (MW)	12	12	12	12	12	12	12	12	12
Results									
Available Energy (GWh)	31	31	31	31	31	31	31	31	31
Curtailed Energy (GWh)	1-1	1-2	1-1	1-2	1-2	1-2	1-2	1-2	1-2
Constrained Energy (GWh)	~0	0	~0	~0	~0	~0	~0	~0	~0
Curtailed + Constrained Energy (GWh)	1-1	1-2	1-1	1-2	1-2	1-2	1-2	1-2	1-2
Curtailment (%)	2-5	3-5	2-4	4-6	3-5	4-7	4-7	4-7	4-7
Constraint (%)	1	0	~0	~0	~0	~0	~0	~0	~0
Curtailment and Constraint (%)	3-6	3-5	2-4	4-6	3-5	4-7	4-7	4-7	4-7



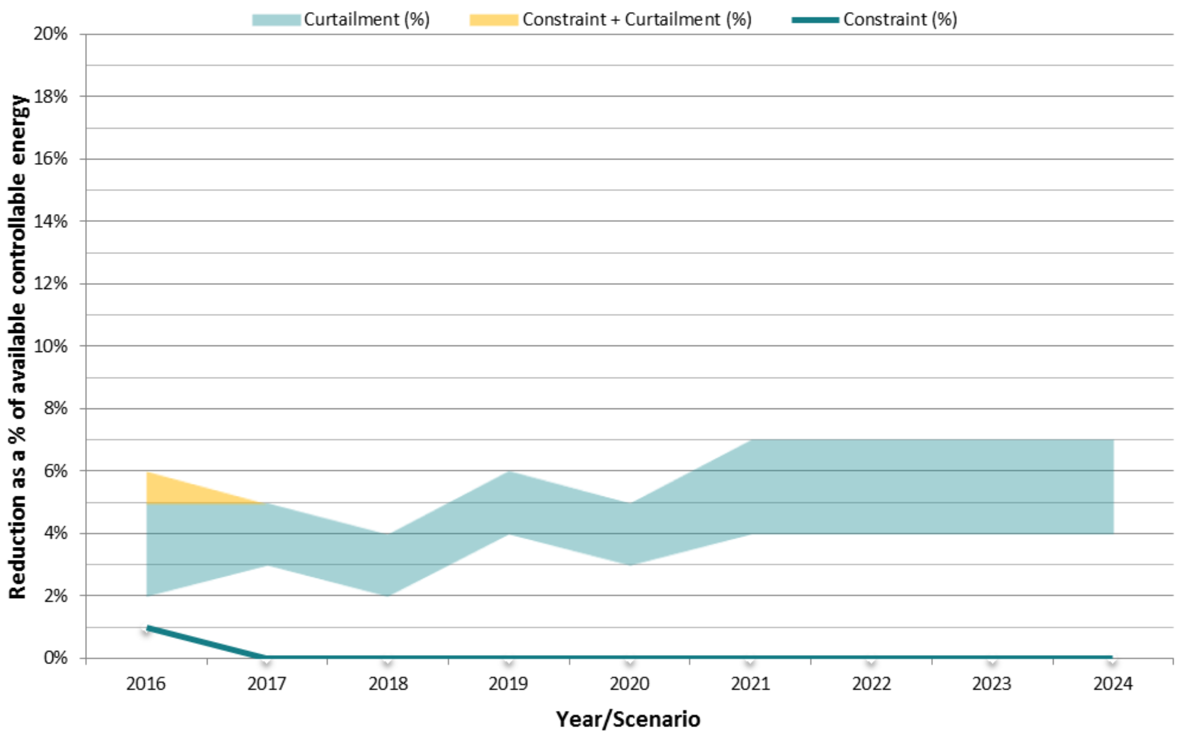
5.8 Drumquin

Drumquin – Wind Generation Results									
Year/Scenario	2016	2017	2018	2019	2020	2021	2022	2023	2024
Wind Capacity at Node									
Additional Wind (MW)	0	0	0	114	0	0	0	0	0
Existing Wind (MW)	0	0	0	0	114	114	114	114	114
Total Wind (MW)	0	0	0	114	114	114	114	114	114
Of which is Controllable (MW)	0	0	0	114	114	114	114	114	114
Results									
Available Energy (GWh)	0	0	0	295	296	295	295	295	296
Curtailed Energy (GWh)	0-0	0-0	0-0	10-17	8-15	12-20	12-21	12-21	13-22
Constrained Energy (GWh)	0	0	0	3	4	3	3	~0	~0
Curtailed + Constrained Energy (GWh)	0-0	0-0	0-0	13-20	12-19	15-23	15-24	12-21	13-22
Curtailment (%)	0-0	0-0	0-0	4-6	3-5	4-7	4-7	4-7	4-7
Constraint (%)	0	0	0	1	1	1	1	~0	~0
Curtailment and Constraint (%)	0-0	0-0	0-0	5-7	4-6	5-8	5-8	4-7	4-7



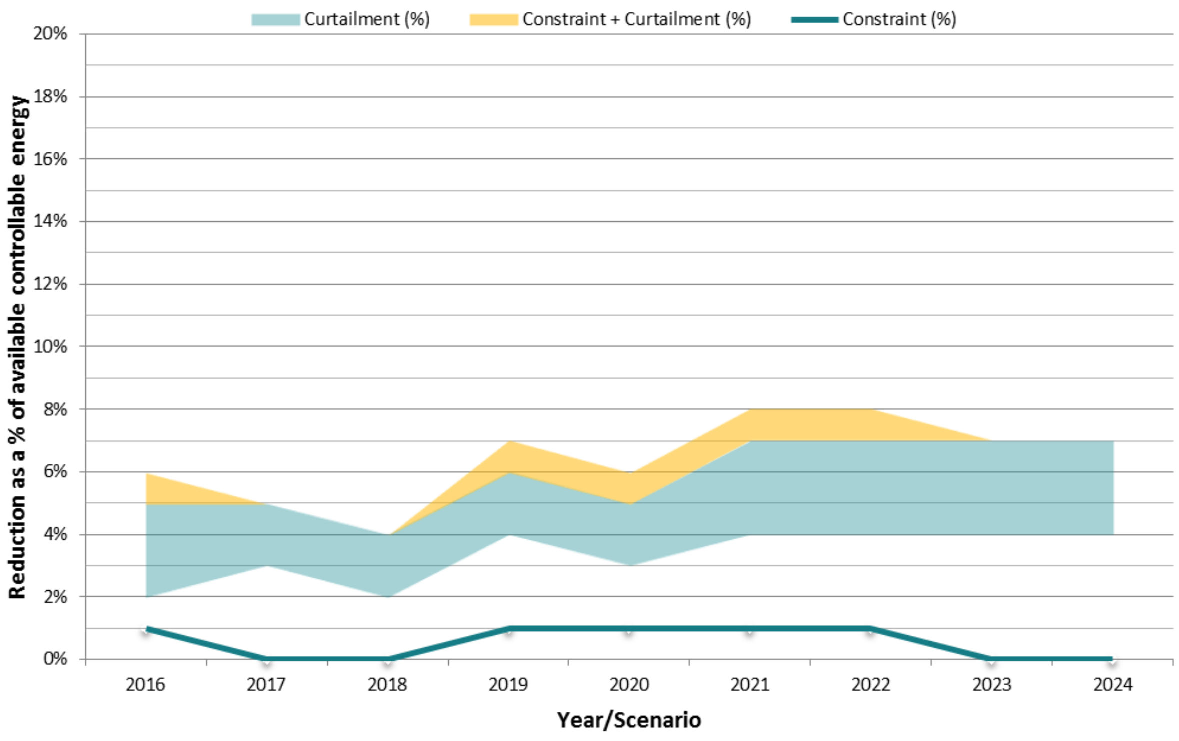
5.9 Dungannon

Dungannon – Wind Generation Results									
Year/Scenario	2016	2017	2018	2019	2020	2021	2022	2023	2024
Wind Capacity at Node									
Additional Wind (MW)	0	0	0	0	0	0	0	0	0
Existing Wind (MW)	18	18	18	18	18	18	18	18	18
Total Wind (MW)	18	18	18	18	18	18	18	18	18
Of which is Controllable (MW)	18	18	18	18	18	18	18	18	18
Results									
Available Energy (GWh)	46	46	46	46	46	46	46	46	46
Curtailed Energy (GWh)	1-2	1-2	1-2	2-3	1-2	2-3	2-3	2-3	2-3
Constrained Energy (GWh)	~0	0	0	0	0	0	0	0	0
Curtailed + Constrained Energy (GWh)	1-2	1-2	1-2	2-3	1-2	2-3	2-3	2-3	2-3
Curtailment (%)	2-5	3-5	2-4	4-6	3-5	4-7	4-7	4-7	4-7
Constraint (%)	1	0	0	0	0	0	0	0	0
Curtailment and Constraint (%)	3-6	3-5	2-4	4-6	3-5	4-7	4-7	4-7	4-7



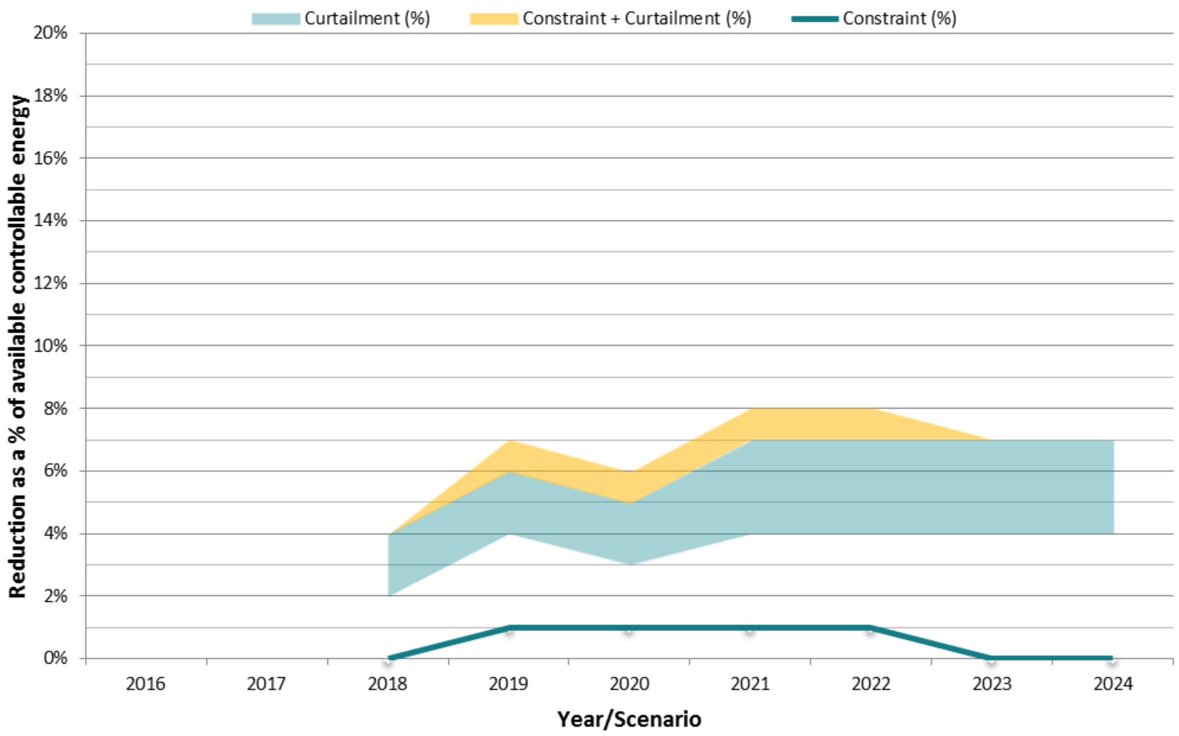
5.10 Enniskillen

Enniskillen – Wind Generation Results									
Year/Scenario	2016	2017	2018	2019	2020	2021	2022	2023	2024
Wind Capacity at Node									
Additional Wind (MW)	0	15	0	0	0	0	0	0	0
Existing Wind (MW)	17	17	32	32	32	32	32	32	32
Total Wind (MW)	17	32	32	32	32	32	32	32	32
Of which is Controllable (MW)	17	32	32	32	32	32	32	32	32
Results									
Available Energy (GWh)	44	83	83	83	83	83	83	83	83
Curtailed Energy (GWh)	1-2	2-4	2-3	3-5	2-4	3-6	3-6	3-6	4-6
Constrained Energy (GWh)	~0	~0	~0	1	1	1	1	~0	~0
Curtailed + Constrained Energy (GWh)	1-2	2-4	2-3	4-6	3-5	4-7	4-7	3-6	4-6
Curtailment (%)	2-5	3-5	2-4	4-6	3-5	4-7	4-7	4-7	4-7
Constraint (%)	1	~0	~0	1	1	1	1	~0	~0
Curtailment and Constraint (%)	3-6	3-5	2-4	5-7	4-6	5-8	5-8	4-7	4-7



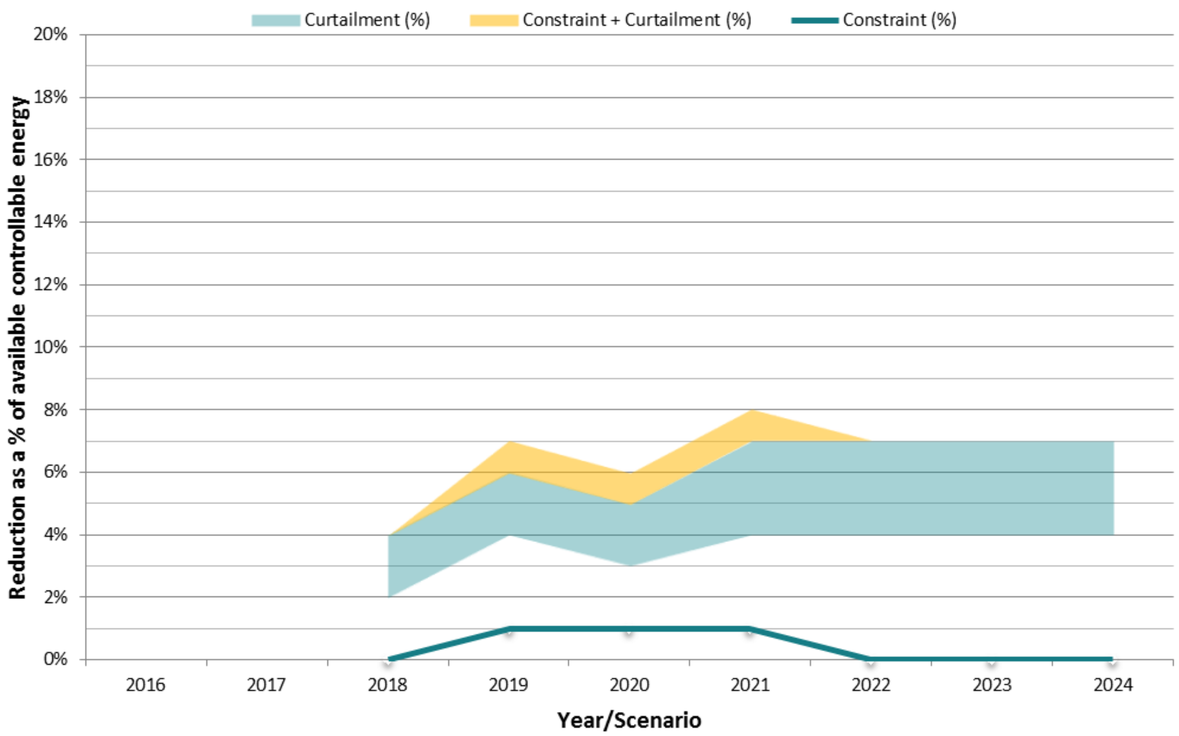
5.11 Garvagh

Garvagh – Wind Generation Results									
Year/Scenario	2016	2017	2018	2019	2020	2021	2022	2023	2024
Wind Capacity at Node									
Additional Wind (MW)	0	0	28	34	0	0	0	0	0
Existing Wind (MW)	0	0	0	28	62	62	62	62	62
Total Wind (MW)	0	0	28	62	62	62	62	62	62
Of which is Controllable (MW)	0	0	28	62	62	62	62	62	62
Results									
Available Energy (GWh)	0	0	72	160	161	160	160	160	161
Curtailed Energy (GWh)	0-0	0-0	2-3	6-9	5-8	6-11	7-11	6-11	7-12
Constrained Energy (GWh)	0	0	~0	1	2	1	1	0	0
Curtailed + Constrained Energy (GWh)	0-0	0-0	2-3	7-10	7-10	7-12	8-12	6-11	7-12
Curtailment (%)	0-0	0-0	2-4	4-6	3-5	4-7	4-7	4-7	4-7
Constraint (%)	0	0	~0	1	1	1	1	0	0
Curtailment and Constraint (%)	0-0	0-0	2-4	5-7	4-6	5-8	5-8	4-7	4-7



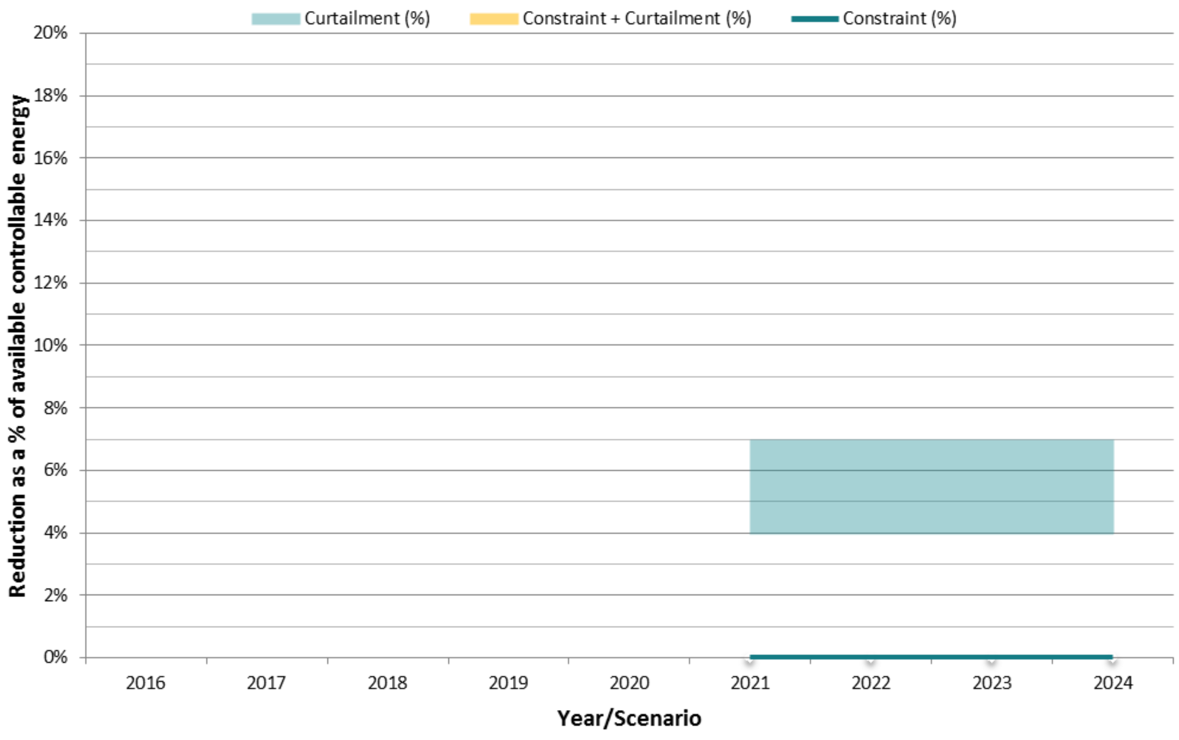
5.12 Gort

Gort – Wind Generation Results									
Year/Scenario	**2016**	**2017**	**2018**	**2019**	**2020**	**2021**	**2022**	**2023**	**2024**
Wind Capacity at Node									
Additional Wind (MW)	0	0	70	0	0	0	0	0	0
Existing Wind (MW)	0	0	0	70	70	70	70	70	70
Total Wind (MW)	0	0	70	70	70	70	70	70	70
Of which is Controllable (MW)	0	0	70	70	70	70	70	70	70
Results									
Available Energy (GWh)	0	0	183	183	183	183	183	183	183
Curtailed Energy (GWh)	0-0	0-0	4-8	6-11	5-9	7-12	8-13	7-13	8-13
Constrained Energy (GWh)	0	0	~0	1	2	1	1	~0	~0
Curtailed + Constrained Energy (GWh)	0-0	0-0	4-8	7-12	7-11	8-13	9-14	7-13	8-13
Curtailment (%)	0-0	0-0	2-4	4-6	3-5	4-7	4-7	4-7	4-7
Constraint (%)	0	0	~0	1	1	1	~0	~0	~0
Curtailment and Constraint (%)	0-0	0-0	2-4	5-7	4-6	5-8	4-7	4-7	4-7



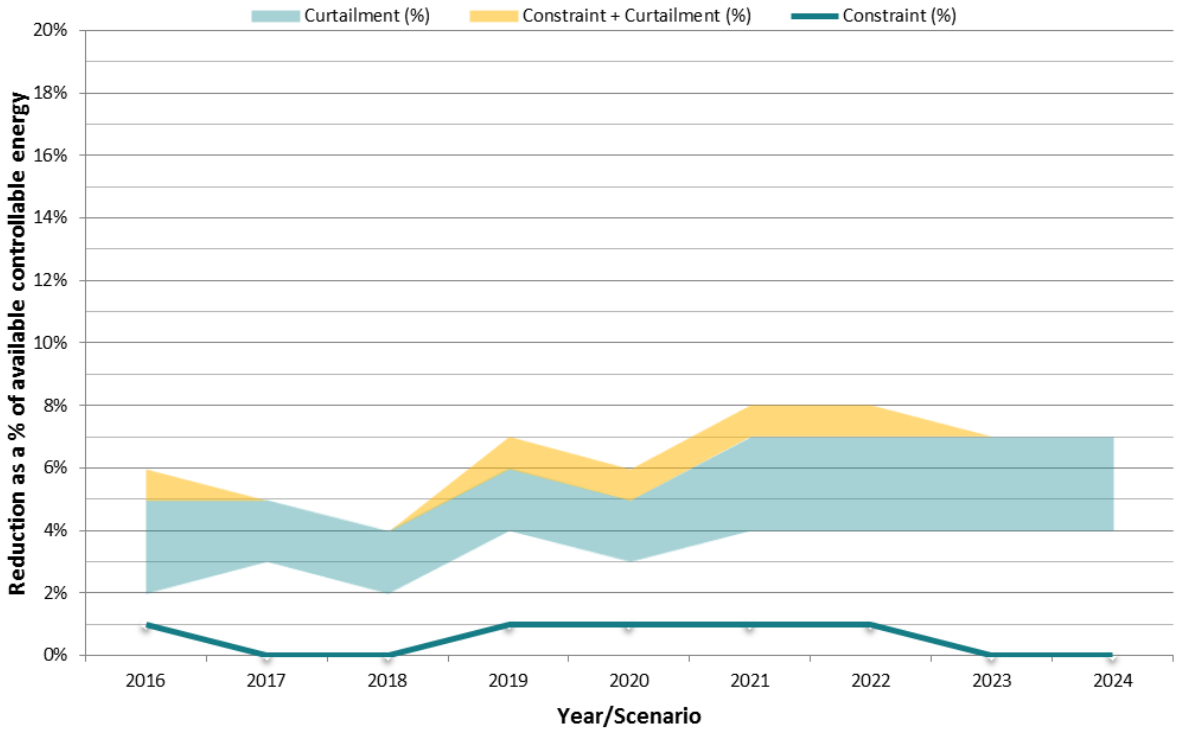
5.13 Kells

Kells – Wind Generation Results									
Year/Scenario	2016	2017	2018	2019	2020	2021	2022	2023	2024
Wind Capacity at Node									
Additional Wind (MW)	0	0	0	0	0	11	0	0	0
Existing Wind (MW)	0	0	0	0	0	0	11	11	11
Total Wind (MW)	0	0	0	0	0	11	11	11	11
Of which is Controllable (MW)	0	0	0	0	0	11	11	11	11
Results									
Available Energy (GWh)	0	0	0	0	0	30	30	30	30
Curtailed Energy (GWh)	0-0	0-0	0-0	0-0	0-0	1-2	1-2	1-2	1-2
Constrained Energy (GWh)	0	0	0	0	0	0	0	0	0
Curtailed + Constrained Energy (GWh)	0-0	0-0	0-0	0-0	0-0	1-2	1-2	1-2	1-2
Curtailment (%)	0-0	0-0	0-0	0-0	0-0	4-7	4-7	4-7	4-7
Constraint (%)	0	0	0	0	0	0	0	0	0
Curtailment and Constraint (%)	0-0	0-0	0-0	0-0	0-0	4-7	4-7	4-7	4-7



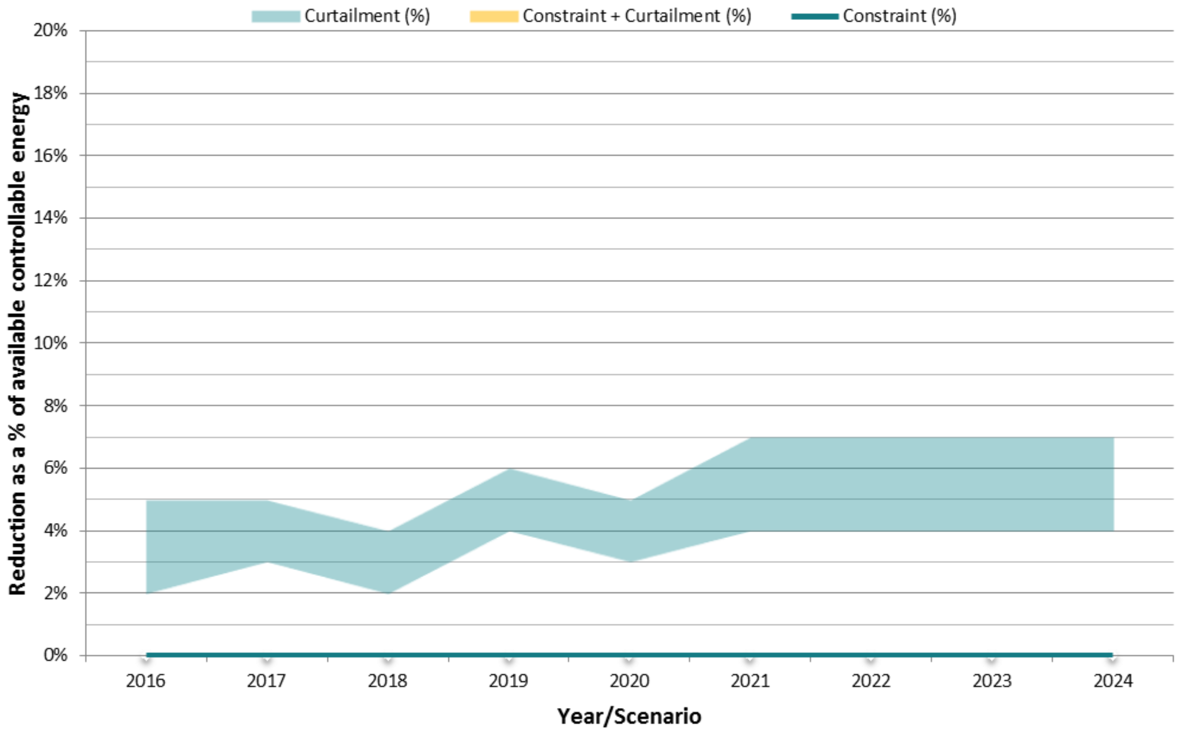
5.14 Killymallaght

Killymallaght – Wind Generation Results									
Year/Scenario	2016	2017	2018	2019	2020	2021	2022	2023	2024
Wind Capacity at Node									
Additional Wind (MW)	0	18	0	0	0	0	0	0	0
Existing Wind (MW)	21	21	39	39	39	39	39	39	39
Total Wind (MW)	21	39	39	39	39	39	39	39	39
Of which is Controllable (MW)	21	39	39	39	39	39	39	39	39
Results									
Available Energy (GWh)	54	101	101	101	101	101	101	101	101
Curtailed Energy (GWh)	1-3	3-5	2-4	4-6	3-5	4-7	4-7	4-7	4-7
Constrained Energy (GWh)	~0	~0	~0	1	1	1	1	~0	~0
Curtailed + Constrained Energy (GWh)	1-3	3-5	2-4	5-7	4-6	5-8	5-8	4-7	4-7
Curtailment (%)	2-5	3-5	2-4	4-6	3-5	4-7	4-7	4-7	4-7
Constraint (%)	1	~0	~0	1	1	1	1	~0	~0
Curtailment and Constraint (%)	3-6	3-5	2-4	5-7	4-6	5-8	5-8	4-7	4-7



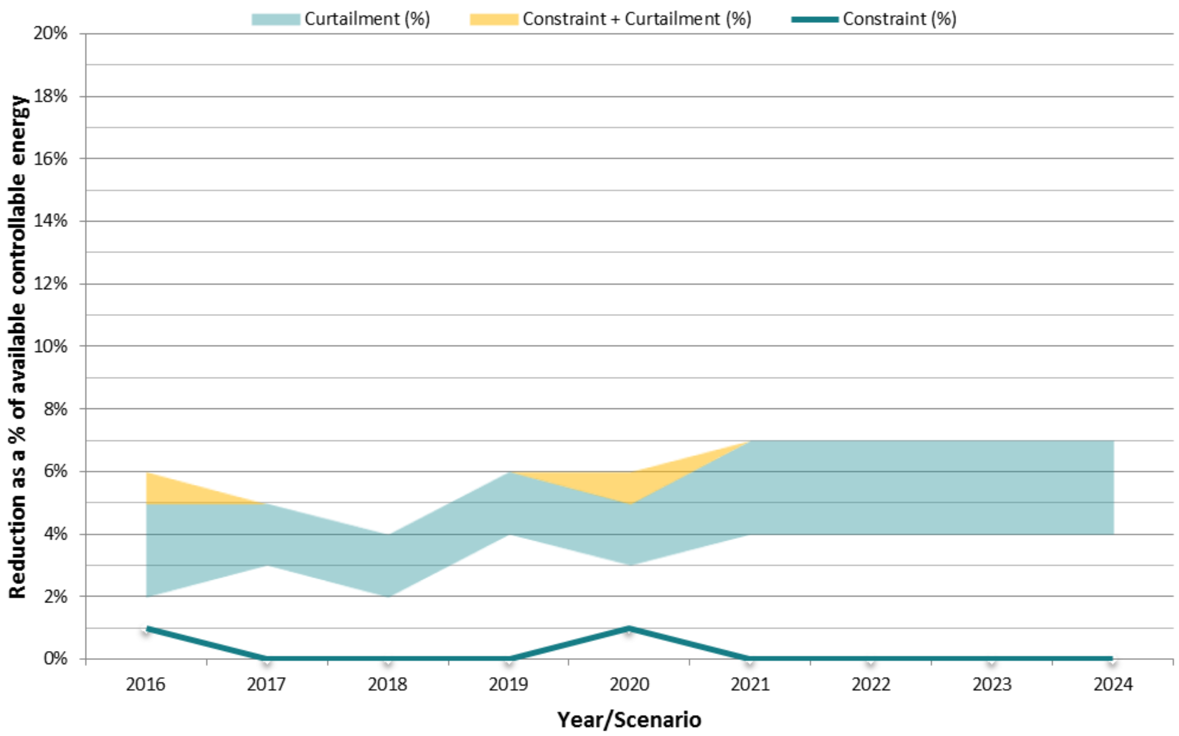
5.15 Larne

Larne – Wind Generation Results									
Year/Scenario	**2016**	**2017**	**2018**	**2019**	**2020**	**2021**	**2022**	**2023**	**2024**
Wind Capacity at Node									
Additional Wind (MW)	0	0	0	0	0	0	0	0	0
Existing Wind (MW)	15	15	15	15	15	15	15	15	15
Total Wind (MW)	15	15	15	15	15	15	15	15	15
Of which is Controllable (MW)	10	10	10	10	10	10	10	10	10
Results									
Available Energy (GWh)	39	39	39	39	39	39	39	39	39
Curtailed Energy (GWh)	1-1	1-1	1-1	1-2	1-1	1-2	1-2	1-2	1-2
Constrained Energy (GWh)	0	0	0	0	0	0	0	0	0
Curtailed + Constrained Energy (GWh)	1-1	1-1	1-1	1-2	1-1	1-2	1-2	1-2	1-2
Curtailment (%)	2-5	3-5	2-4	4-6	3-5	4-7	4-7	4-7	4-7
Constraint (%)	0	0	0	0	0	0	0	0	0
Curtailment and Constraint (%)	2-5	3-5	2-4	4-6	3-5	4-7	4-7	4-7	4-7



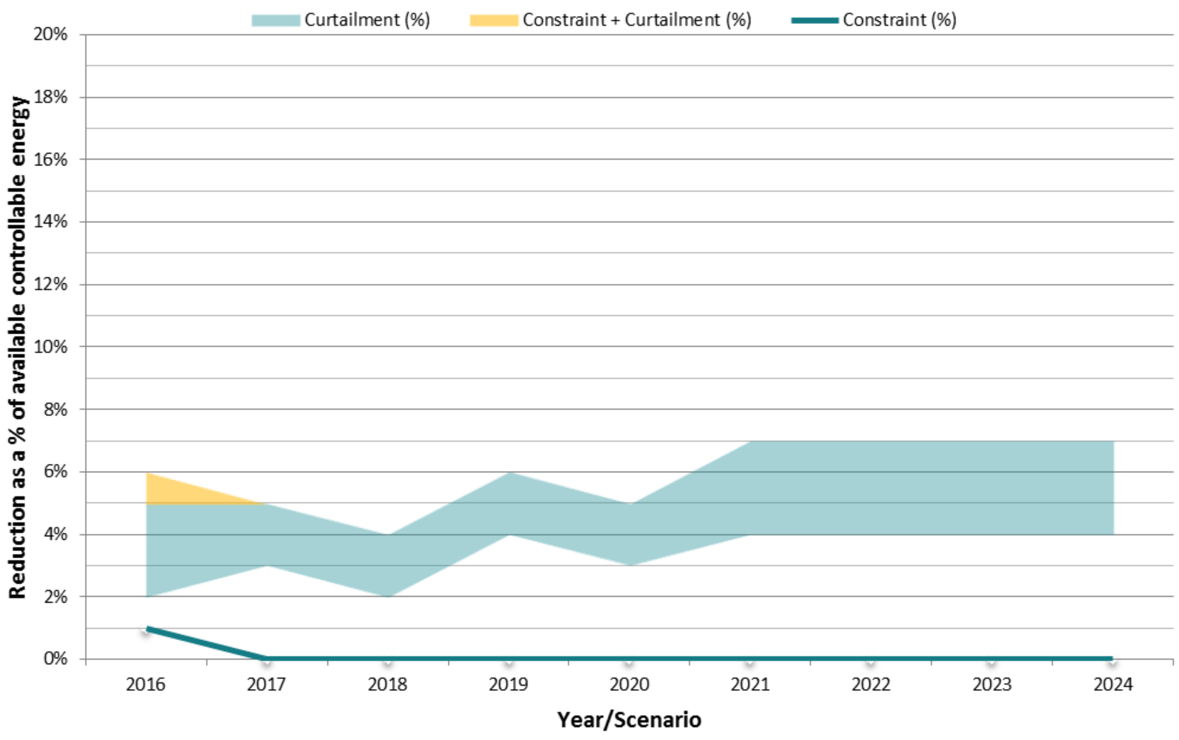
5.16 Limavady

Limavady – Wind Generation Results									
Year/Scenario	**2016**	**2017**	**2018**	**2019**	**2020**	**2021**	**2022**	**2023**	**2024**
Wind Capacity at Node									
Additional Wind (MW)	0	0	0	0	0	0	0	0	0
Existing Wind (MW)	38	38	38	38	38	38	38	38	38
Total Wind (MW)	38	38	38	38	38	38	38	38	38
Of which is Controllable (MW)	12	12	12	12	12	12	12	12	12
Results									
Available Energy (GWh)	98	98	98	98	98	98	98	98	98
Curtailed Energy (GWh)	1-1	1-2	1-1	1-2	1-2	1-2	1-2	1-2	1-2
Constrained Energy (GWh)	~0	0	~0	~0	~0	~0	~0	~0	~0
Curtailed + Constrained Energy (GWh)	1-1	1-2	1-1	1-2	1-2	1-2	1-2	1-2	1-2
Curtailment (%)	2-5	3-5	2-4	4-6	3-5	4-7	4-7	4-7	4-7
Constraint (%)	1	0	~0	~0	1	~0	~0	~0	~0
Curtailment and Constraint (%)	3-6	3-5	2-4	4-6	4-6	4-7	4-7	4-7	4-7



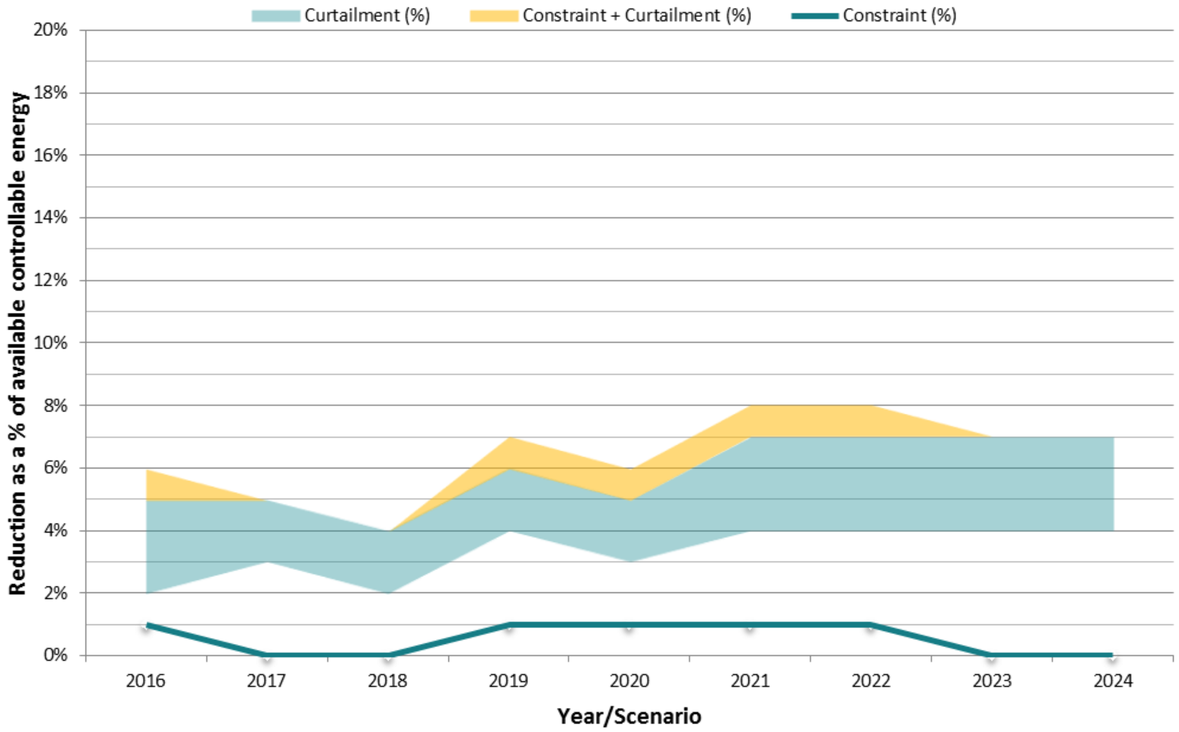
5.17 Lisaghmore

Lisaghmore – Wind Generation Results									
Year/Scenario	2016	2017	2018	2019	2020	2021	2022	2023	2024
Wind Capacity at Node									
Additional Wind (MW)	0	0	0	0	0	0	0	0	0
Existing Wind (MW)	15	15	15	15	15	15	15	15	15
Total Wind (MW)	15	15	15	15	15	15	15	15	15
Of which is Controllable (MW)	15	15	15	15	15	15	15	15	15
Results									
Available Energy (GWh)	39	39	39	39	39	39	39	39	39
Curtailed Energy (GWh)	1-2	1-2	1-2	1-2	1-2	2-3	2-3	2-3	2-3
Constrained Energy (GWh)	~0	0	~0	~0	~0	~0	~0	~0	~0
Curtailed + Constrained Energy (GWh)	1-2	1-2	1-2	1-2	1-2	2-3	2-3	2-3	2-3
Curtailment (%)	2-5	3-5	2-4	4-6	3-5	4-7	4-7	4-7	4-7
Constraint (%)	1	0	~0	~0	~0	~0	~0	~0	~0
Curtailment and Constraint (%)	3-6	3-5	2-4	4-6	3-5	4-7	4-7	4-7	4-7



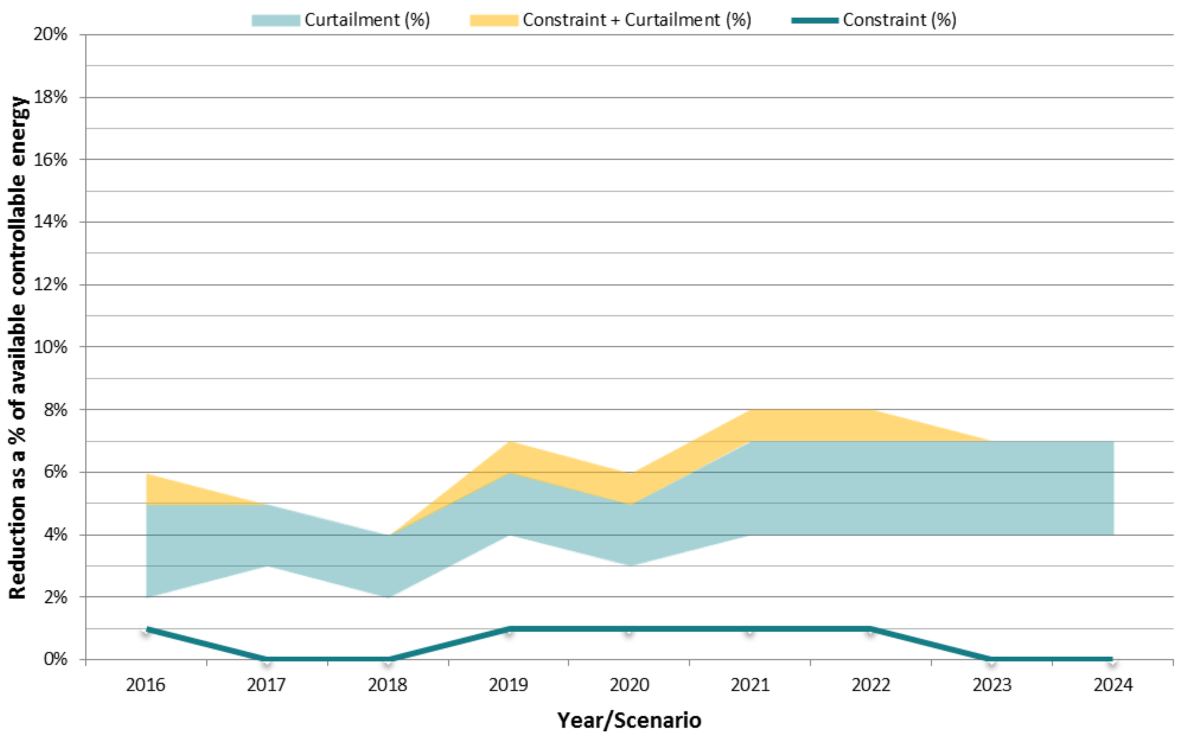
5.18 Loguestown

Loguestown – Wind Generation Results									
Year/Scenario	2016	2017	2018	2019	2020	2021	2022	2023	2024
Wind Capacity at Node									
Additional Wind (MW)	0	0	0	0	0	0	0	0	0
Existing Wind (MW)	12	12	12	12	12	12	12	12	12
Total Wind (MW)	12	12	12	12	12	12	12	12	12
Of which is Controllable (MW)	12	12	12	12	12	12	12	12	12
Results									
Available Energy (GWh)	31	31	31	31	31	31	31	31	31
Curtailed Energy (GWh)	1-1	1-2	1-1	1-2	1-2	1-2	1-2	1-2	1-2
Constrained Energy (GWh)	~0	0	~0	~0	~0	~0	~0	~0	~0
Curtailed + Constrained Energy (GWh)	1-1	1-2	1-1	1-2	1-2	1-2	1-2	1-2	1-2
Curtailment (%)	2-5	3-5	2-4	4-6	3-5	4-7	4-7	4-7	4-7
Constraint (%)	1	0	~0	1	1	1	1	~0	~0
Curtailment and Constraint (%)	3-6	3-5	2-4	5-7	4-6	5-8	5-8	4-7	4-7



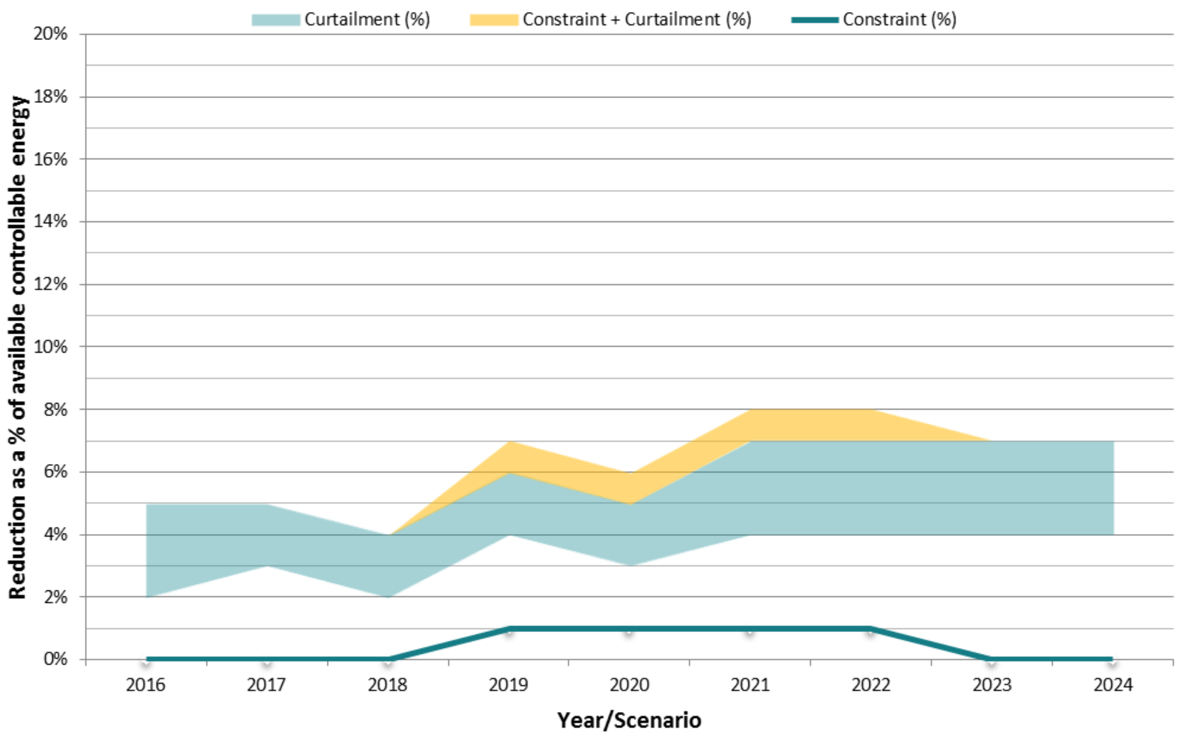
5.19 Magherakeel

Magherakeel – Wind Generation Results									
Year/Scenario	2016	2017	2018	2019	2020	2021	2022	2023	2024
Wind Capacity at Node									
Additional Wind (MW)	0	35	0	0	0	0	0	0	0
Existing Wind (MW)	89	89	123	123	123	123	123	123	123
Total Wind (MW)	89	123	123	123	123	123	123	123	123
Of which is Controllable (MW)	89	123	123	123	123	123	123	123	123
Results									
Available Energy (GWh)	231	320	320	320	321	320	320	320	321
Curtailed Energy (GWh)	5-11	9-17	7-13	11-19	9-16	13-22	13-23	13-23	14-23
Constrained Energy (GWh)	1	~0	~0	3	4	3	3	~0	~0
Curtailed + Constrained Energy (GWh)	6-12	9-17	7-13	14-22	13-20	16-25	16-26	13-23	14-23
Curtailment (%)	2-5	3-5	2-4	4-6	3-5	4-7	4-7	4-7	4-7
Constraint (%)	1	~0	~0	1	1	1	1	~0	~0
Curtailment and Constraint (%)	3-6	3-5	2-4	5-7	4-6	5-8	5-8	4-7	4-7



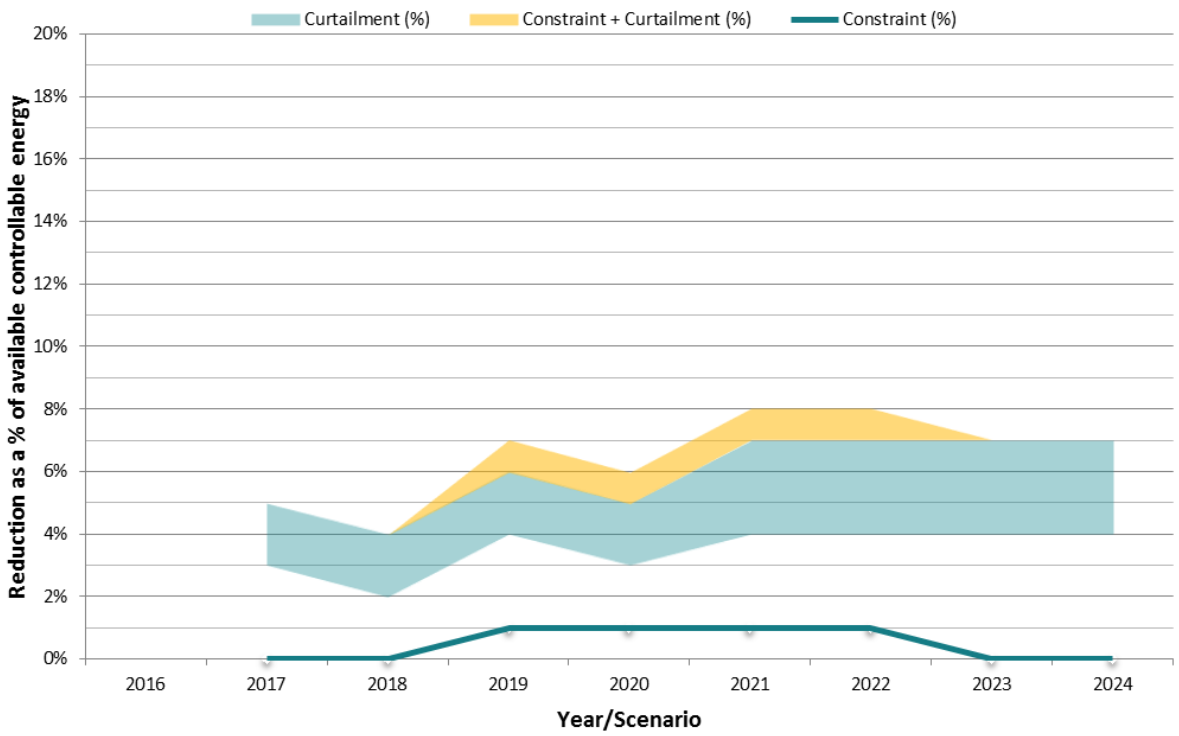
5.20 Omagh

Omagh – Wind Generation Results									
Year/Scenario	2016	2017	2018	2019	2020	2021	2022	2023	2024
Wind Capacity at Node									
Additional Wind (MW)	0	0	0	0	0	0	0	0	0
Existing Wind (MW)	126	126	126	126	126	126	126	126	126
Total Wind (MW)	126	126	126	126	126	126	126	126	126
Of which is Controllable (MW)	108	108	108	108	108	108	108	108	108
Results									
Available Energy (GWh)	328	327	327	327	328	327	327	327	328
Curtailed Energy (GWh)	6-13	8-15	6-12	10-17	8-14	11-19	12-20	11-20	12-20
Constrained Energy (GWh)	2	~0	~0	2	3	3	3	~0	~0
Curtailed + Constrained Energy (GWh)	8-15	8-15	6-12	12-19	11-17	14-22	15-23	11-20	12-20
Curtailment (%)	2-5	3-5	2-4	4-6	3-5	4-7	4-7	4-7	4-7
Constraint (%)	1	~0	~0	1	1	1	1	~0	~0
Curtailment and Constraint (%)	3-6	3-5	2-4	5-7	4-6	5-8	5-8	4-7	4-7



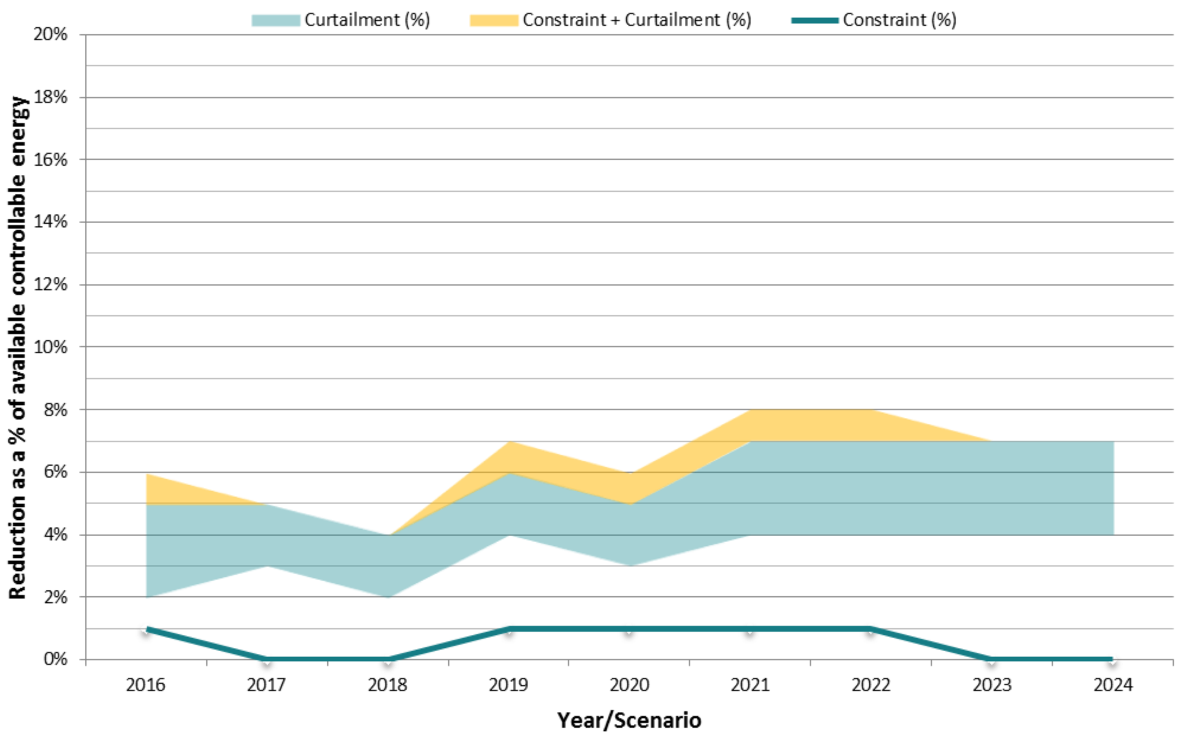
5.21 Rasharkin

Rasharkin – Wind Generation Results									
Year/Scenario	2016	2017	2018	2019	2020	2021	2022	2023	2024
Wind Capacity at Node									
Additional Wind (MW)	0	9	18	28	0	0	0	0	0
Existing Wind (MW)	0	0	9	27	55	55	55	55	55
Total Wind (MW)	0	9	27	55	55	55	55	55	55
Of which is Controllable (MW)	0	9	27	55	55	55	55	55	55
Results									
Available Energy (GWh)	0	24	71	143	143	143	143	143	143
Curtailed Energy (GWh)	0-0	1-1	1-3	5-8	4-7	6-10	6-10	6-10	6-10
Constrained Energy (GWh)	0	0	~0	1	2	1	1	0	0
Curtailed + Constrained Energy (GWh)	0-0	1-1	1-3	6-9	6-9	7-11	7-11	6-10	6-10
Curtailment (%)	0-0	3-5	2-4	4-6	3-5	4-7	4-7	4-7	4-7
Constraint (%)	0	0	~0	1	1	1	1	0	0
Curtailment and Constraint (%)	0-0	3-5	2-4	5-7	4-6	5-8	5-8	4-7	4-7



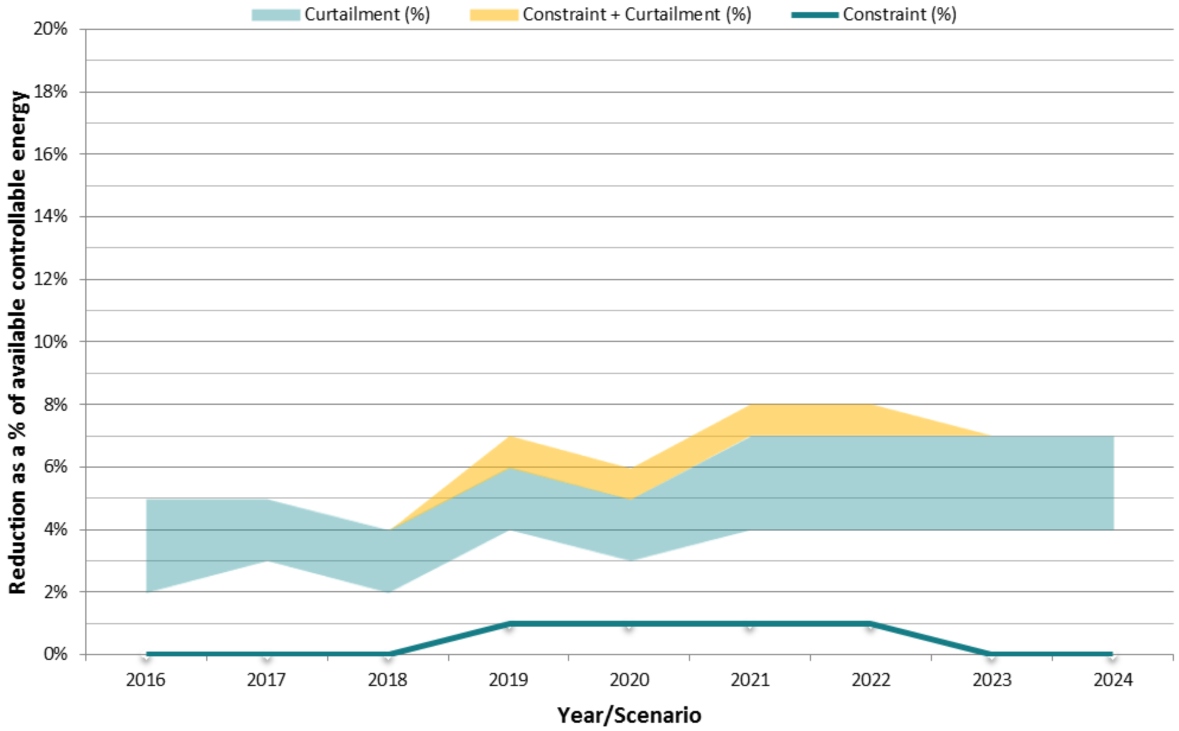
5.22 Slieve Kirk

Slieve Kirk – Wind Generation Results									
Year/Scenario	**2016**	**2017**	**2018**	**2019**	**2020**	**2021**	**2022**	**2023**	**2024**
Wind Capacity at Node									
Additional Wind (MW)	0	0	0	0	0	0	0	0	0
Existing Wind (MW)	74	74	74	74	74	74	74	74	74
Total Wind (MW)	74	74	74	74	74	74	74	74	74
Of which is Controllable (MW)	74	74	74	74	74	74	74	74	74
Results									
Available Energy (GWh)	192	192	192	192	192	192	192	192	192
Curtailed Energy (GWh)	4-9	6-10	4-8	7-11	5-10	8-13	8-13	8-14	8-14
Constrained Energy (GWh)	1	~0	~0	2	2	2	2	~0	~0
Curtailed + Constrained Energy (GWh)	5-10	6-10	4-8	9-13	7-12	10-15	10-15	8-14	8-14
Curtailment (%)	2-5	3-5	2-4	4-6	3-5	4-7	4-7	4-7	4-7
Constraint (%)	1	~0	~0	1	1	1	1	~0	~0
Curtailment and Constraint (%)	3-6	3-5	2-4	5-7	4-6	5-8	5-8	4-7	4-7



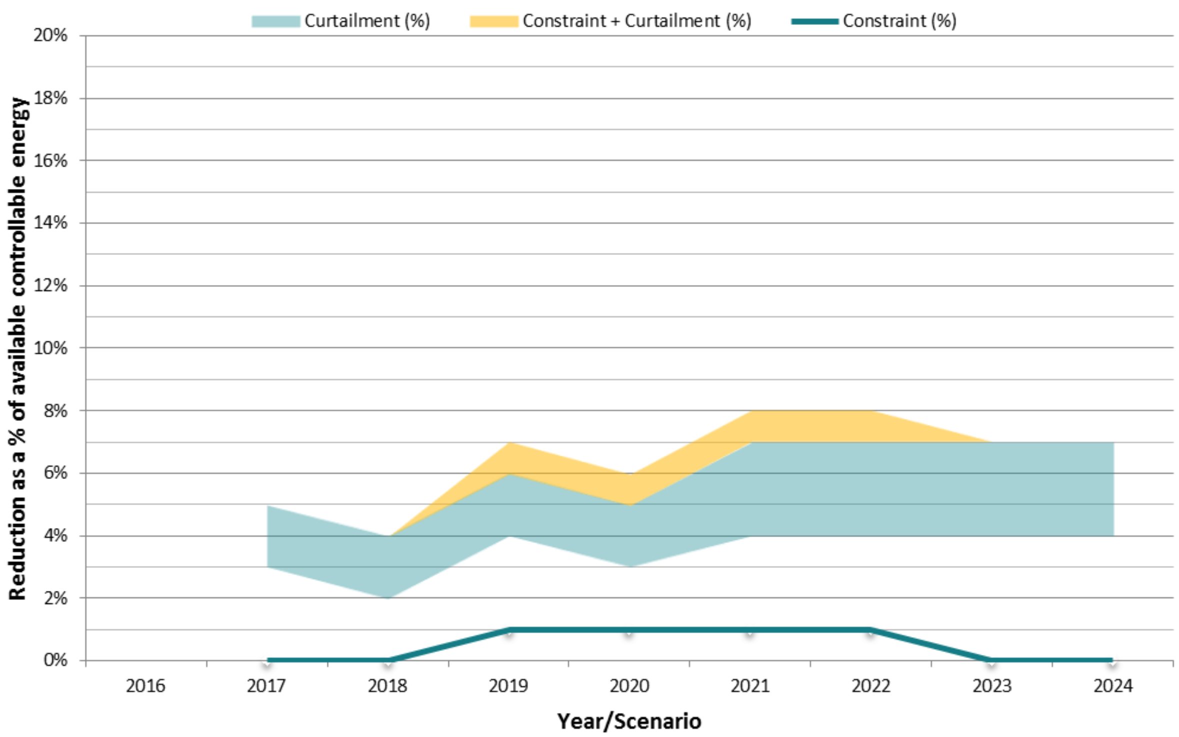
5.23 Strabane

Strabane – Wind Generation Results									
Year/Scenario	2016	2017	2018	2019	2020	2021	2022	2023	2024
Wind Capacity at Node									
Additional Wind (MW)	0	0	0	0	0	0	0	0	0
Existing Wind (MW)	27	27	27	27	27	27	27	27	27
Total Wind (MW)	27	27	27	27	27	27	27	27	27
Of which is Controllable (MW)	21	21	21	21	21	21	21	21	21
Results									
Available Energy (GWh)	71	71	71	71	71	71	71	71	71
Curtailed Energy (GWh)	1-3	2-3	1-2	2-3	2-3	2-4	2-4	2-4	2-4
Constrained Energy (GWh)	~0	~0	~0	~0	1	1	~0	~0	~0
Curtailed + Constrained Energy (GWh)	1-3	2-3	1-2	2-3	3-4	3-5	2-4	2-4	2-4
Curtailment (%)	2-5	3-5	2-4	4-6	3-5	4-7	4-7	4-7	4-7
Constraint (%)	1	~0	~0	1	1	1	1	~0	~0
Curtailment and Constraint (%)	3-6	3-5	2-4	5-7	4-6	5-8	5-8	4-7	4-7



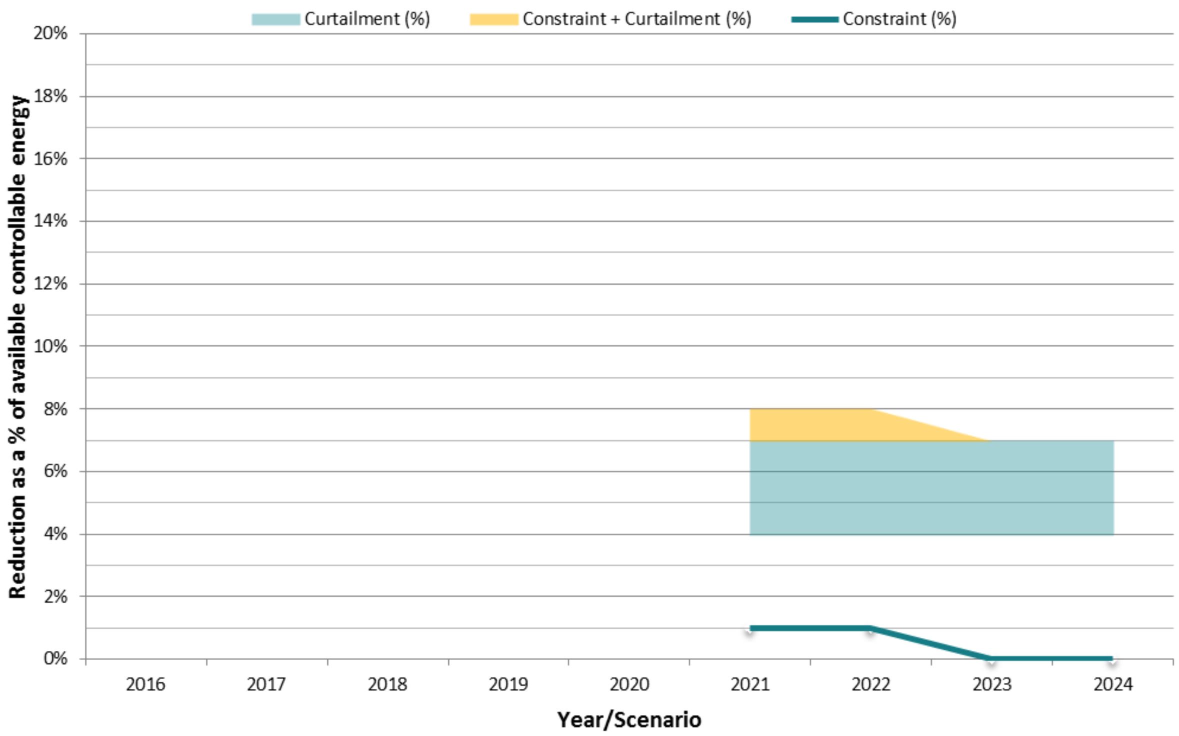
5.24 Tremoge

Tremoge – Wind Generation Results									
Year/Scenario	2016	2017	2018	2019	2020	2021	2022	2023	2024
Wind Capacity at Node									
Additional Wind (MW)	0	45	33	0	0	0	0	0	0
Existing Wind (MW)	0	0	45	78	78	78	78	78	78
Total Wind (MW)	0	45	78	78	78	78	78	78	78
Of which is Controllable (MW)	0	45	78	78	78	78	78	78	78
Results									
Available Energy (GWh)	0	116	202	202	202	202	202	202	202
Curtailed Energy (GWh)	0-0	3-6	4-9	8-13	6-11	9-14	9-15	8-15	9-16
Constrained Energy (GWh)	0	~0	~0	2	2	2	1	~0	~0
Curtailed + Constrained Energy (GWh)	0-0	3-6	4-9	10-15	8-13	11-16	10-16	8-15	9-16
Curtailment (%)	0-0	3-5	2-4	4-6	3-5	4-7	4-7	4-7	4-7
Constraint (%)	0	~0	~0	1	1	1	1	~0	~0
Curtailment and Constraint (%)	0-0	3-5	2-4	5-7	4-6	5-8	5-8	4-7	4-7



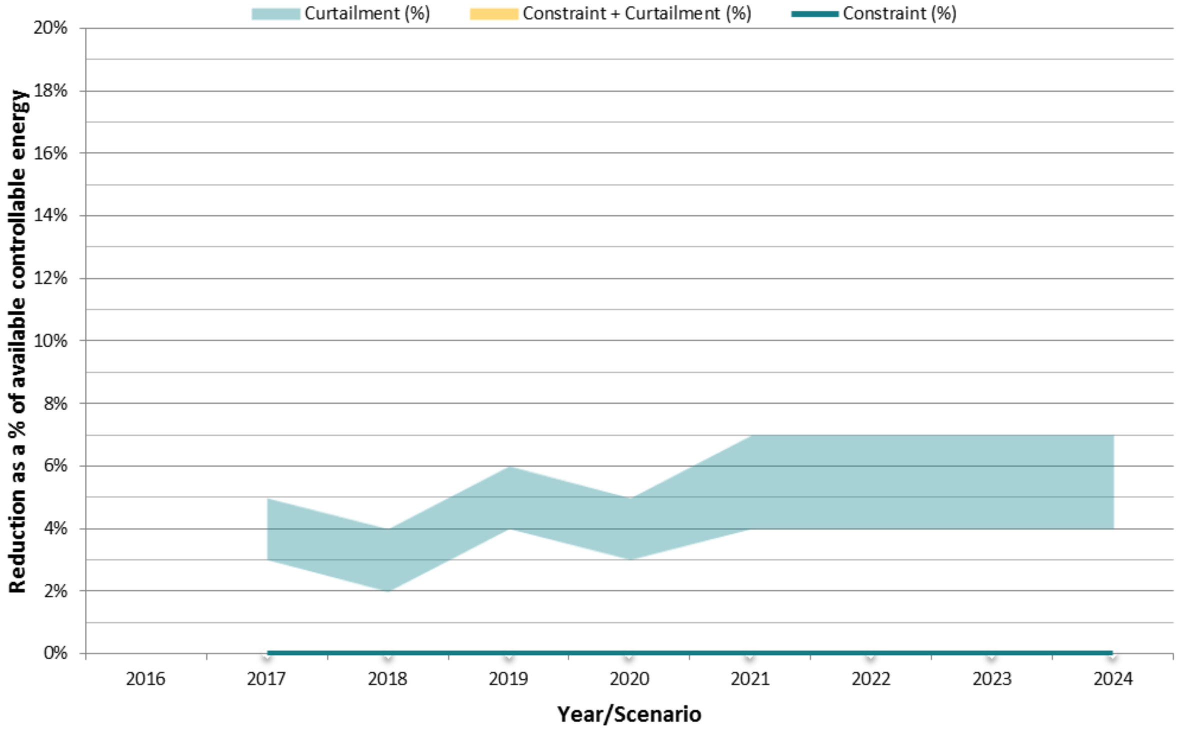
5.25 CAM PV

CAM PV Generation Results									
Year/Scenario	2016	2017	2018	2019	2020	2021	2022	2023	2024
PV Capacity at Node									
Additional PV (MW)	0	0	0	0	0	11	0	0	0
Existing PV (MW)	0	0	0	0	0	0	11	11	11
Total PV (MW)	0	0	0	0	0	11	11	11	11
Of which is Controllable (MW)	0	0	0	0	0	11	11	11	11
Results									
Available Energy (GWh)	0	0	0	0	0	10	10	10	10
Curtailed Energy (GWh)	0-0	0-0	0-0	0-0	0-0	0-1	0-1	0-1	0-1
Constrained Energy (GWh)	0	0	0	0	0	~0	~0	~0	~0
Curtailed + Constrained Energy (GWh)	0-0	0-0	0-0	0-0	0-0	0-1	0-1	0-1	0-1
Curtailment (%)	0-0	0-0	0-0	0-0	0-0	4-7	4-7	4-7	4-7
Constraint (%)	0	0	0	0	0	1	1	~0	~0
Curtailment and Constraint (%)	0-0	0-0	0-0	0-0	0-0	5-8	5-8	4-7	4-7



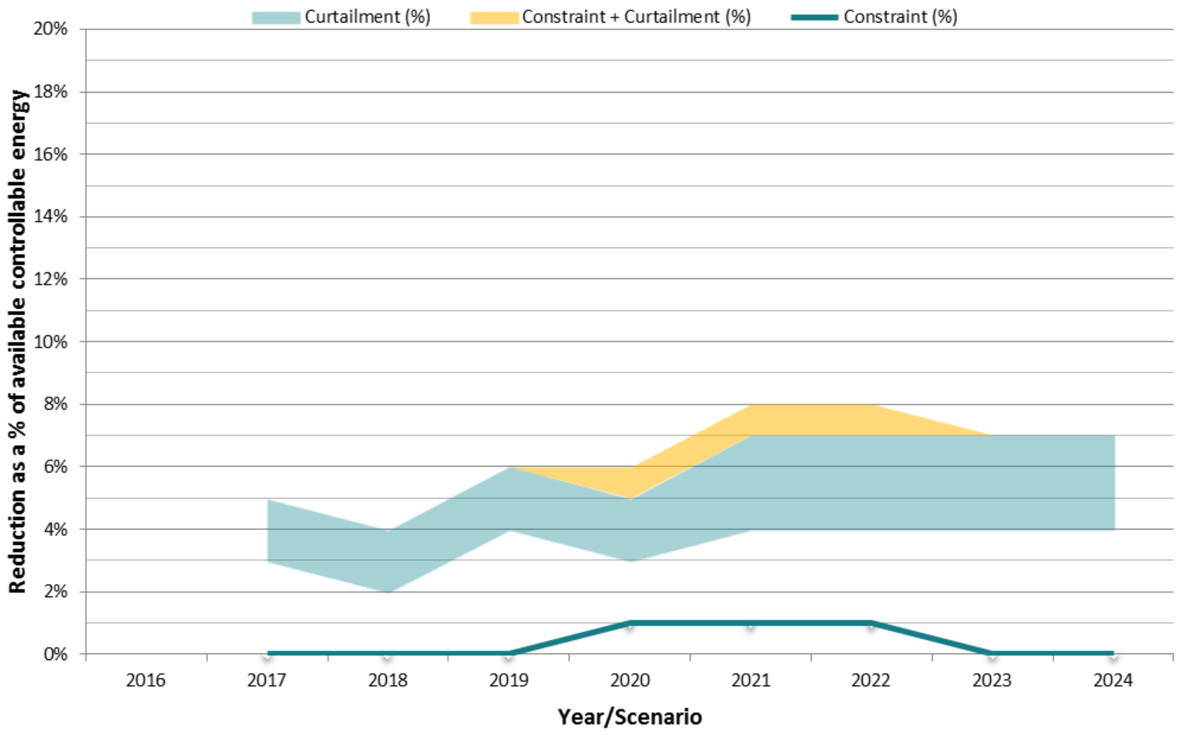
5.26 Lisburn PV

Lisburn PV Generation Results									
Year/Scenario	2016	2017	2018	2019	2020	2021	2022	2023	2024
PV Capacity at Node									
Additional PV (MW)	0	35	0	0	0	0	0	0	0
Existing PV (MW)	0	0	35	35	35	35	35	35	35
Total PV (MW)	0	35	35	35	35	35	35	35	35
Of which is Controllable (MW)	0	35	35	35	35	35	35	35	35
Results									
Available Energy (GWh)	0	30	30	30	30	30	30	30	30
Curtailed Energy (GWh)	0-0	1-2	1-1	1-2	1-2	1-2	1-2	1-2	1-2
Constrained Energy (GWh)	0	0	0	0	0	0	0	0	0
Curtailed + Constrained Energy (GWh)	0-0	1-2	1-1	1-2	1-2	1-2	1-2	1-2	1-2
Curtailment (%)	0-0	3-5	2-4	4-6	3-5	4-7	4-7	4-7	4-7
Constraint (%)	0	0	0	0	0	0	0	0	0
Curtailment and Constraint (%)	0-0	3-5	2-4	4-6	3-5	4-7	4-7	4-7	4-7



5.27 Rasharkin PV

Rasharkin PV Generation Results									
Year/Scenario	2016	2017	2018	2019	2020	2021	2022	2023	2024
PV Capacity at Node									
Additional PV (MW)	0	20	0	0	0	0	0	0	0
Existing PV (MW)	0	0	20	20	20	20	20	20	20
Total PV (MW)	0	20	20	20	20	20	20	20	20
Of which is Controllable (MW)	0	20	20	20	20	20	20	20	20
Results									
Available Energy (GWh)	0	17	17	17	17	17	17	17	17
Curtailed Energy (GWh)	0-0	0-1	0-1	1-1	0-1	1-1	1-1	1-1	1-1
Constrained Energy (GWh)	0	0	~0	~0	~0	~0	~0	0	0
Curtailed + Constrained Energy (GWh)	0-0	0-1	0-1	1-1	0-1	1-1	1-1	1-1	1-1
Curtailment (%)	0-0	3-5	2-4	4-6	3-5	4-7	4-7	4-7	4-7
Constraint (%)	0	0	~0	~0	1	1	1	0	0
Curtailment and Constraint (%)	0-0	3-5	2-4	4-6	4-6	5-8	5-8	4-7	4-7



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