THE IRISH ACADEMY OF ENGINEERING
ENGINEERING & TECHNOLOGY

THOUGHT LEADERSHIP IN A TIME OF GREAT CHANGE

National Energy and Climate Plan

The Challenge of High Levels of Renewable Generation In Ireland's Electricity System

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THE IRISH ACADEMY OF ENGINEERING

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CONTENTS

EXECUTIVE SUMMARY

1. Introduction

The Irish Government has committed to decarbonising the country's power industry to a challenging degree. Current Government targets envisage the equivalent of 70% of the country's annual electricity production being produced from renewable resources (mainly wind and solar) by 2030.

The plan also targets net zero carbon electricity production by 2050.

Authorities in the North of Ireland have indicated their intention of meeting similar targets thus facilitating future planning on an All-Island basis.

This report focusses on the ability of the power system to provide a reliable electricity supply ***and*** achieve the 70% renewables target (annual production basis) in 2030. It seeks to identify risks and recommend prudent actions on the part of policymakers. It takes an All-Island view of the future.

It may be noted that a target of 70% renewables for annual production implies an instantaneous renewables penetration which is likely to considerably exceed this figure on a regular basis.

Achieving this target will mean the installation of much more wind and solar generation. However, demand does not necessarily follow available renewable resources so at times, when there is excess renewable supply, some of the island's 70% renewable production will be exported and, of course, when there is insufficient renewable resources, electricity will have to be produced from other sources or imported.

In addition to the foregoing the report comments on important alternative technologies which may become relevant in the 2030 to 2050 period.

The reliability of the All-Island power network will be enhanced by the completion of the North-South Interconnector. Such transmission issues have already been addressed in a recent Academy report[1] and are not further considered here.

A number of useful technical reports dealing with long-term power system reliability (both in international and Irish contexts) have recently been published and are listed in Appendix 1. These reports specifically provide insights into power system reliability in the context of large renewable generation penetration and provide reliable fact-based analyses.

1.1 Conclusions and Recommendations

In order to maintain normal reliability standards while replacing coal, oil and peat generation, Ireland will require significant gas fired generation capacity for the next two decades. The gas turbine generation *capacity* required in 2030 is likely to increase from today, but annual gas *consumption* will probably reduce as generating units will operate with lower load factors, but peak gas demand, for power generation will be significantly higher than today. Power system reliability is therefore critically dependent on secure primary energy supplies (Natural Gas) to the Island of Ireland.

Power system reliability becomes an Energy Security issue.

There is universal agreement that long term decarbonisation of the planet's energy systems requires a major shift to electricity as an energy vector. Ireland has targeted nine hundred thousand Electric Vehicles (EVs) on the road by 2030 as well as six hundred thousand domestic heat pumps. In this context, a failure of the power system would have a catastrophic effect on normal economic life.

Ireland has two sources of gas supply at present– Corrib and pipeline imports via Great Britain (GB). Gas production from Corrib has reduced by almost 50% in the past four years and this steady decline will continue in the next few years. By 2025, Corrib will supply only 15% of Ireland's annual gas demand and less than 10% of maximum daily supply.

By 2030, the island of Ireland will be almost totally dependent on Great Britain (GB) for its gas supply. GB in turn will import up to 75% of its gas due to declining North Sea production.

1 http://iae.ie/wp-content/uploads/2020/10/The-Future-of-Electricity-Transmission-in-Ireland.pdf

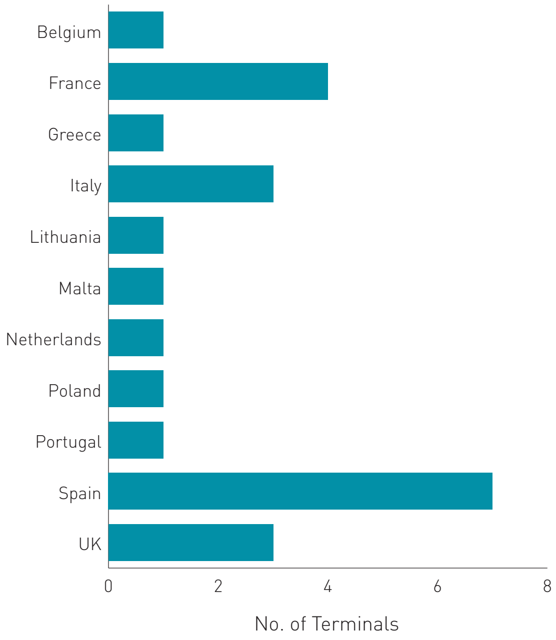
In the Academy's view, developing a liquefied natural gas (LNG) import terminal in Ireland is highly advisable in order to ensure secure and diverse gas supplies. This issue has already been covered in the Academy's report in 2018 on Irish Gas Supply Security.[2]

Recent plans by Gas Networks Ireland explore the possibility of Biomethane production and Hydrogen substitution in order to increase local gas supplies. The former, if feasible at a large scale, will make a relatively small contribution to Irish gas supply by 2030 and cannot be considered as a significant substitute for imported gas. The latter will make little if any contribution prior to 2030.

Gas storage in suitable geological formations is a well-known option when considering secure gas supplies. Unfortunately, such geological storage formations are rare in Ireland and only exist in the Islandmagee area of Co. Antrim. Development efforts for such storage have been underway for more than a decade but success is by no means guaranteed. At best, if the project proceeds, some storage may be available around 2025.

While the Academy supports the development of gas storage in Ireland wherever possible, it is concerned that future gas supply security may depend on one project which has yet to be fully licensed let alone financed.

Operational LNG Terminals Western Europe



It may be noted that Ireland is one of the very few maritime countries in Europe which does not have an LNG import facility.

This supply risk is further compounded by the current lack of any gas storage capacity. These issues must be urgently addressed by policymakers.

Ireland's fleet of gas turbine powered generation plants is designed to operate for short periods (typical five days) on distillate to offset the risk of short term gas supply interruption. Operating these plants for anything other than the short term on distillate would require the planning and implementation of new storage and delivery logistics. It would also considerably increase the country's oil consumption and combustion emissions, add to energy import costs and might well impact the reliability of existing plant.

The Academy believes that reliance on distillate for anything other than short term local gas supply interruptions would be a retrograde step in the country's transition to a decarbonised power industry.

Alternatives to gas fired generation have been proposed and include:

- Pumped Hydro Storage
- Compressed Air Storage
- Battery Storage
- Carbon Capture and Storage
- Increased Interconnection
- Hydrogen Fuel options
- Biofuels
- Marine Energy (Wave/Tidal)
- Nuclear power

The Academy's preliminary views on these technologies are presented in this report and its considered conclusion is that none of these options can be implemented on a scale that would significantly reduce Ireland's gas fired generation capacity by 2030.

Given the proposed level of electrification of the Irish economy and of Irish society by 2030, any significant grid reliability failure would have catastrophic consequences for the country.

2 http://iae.ie/wp-content/uploads/2018/08/IAE_Natural_Gas_Energy_Security.pdf

If the risks to the national electricity system are to be effectively managed, there are no viable alternatives to gas fired power generation in 2030. Gas turbine generation and a secure gas supply will be critically important for Ireland to maintain power system reliability standards in 2030 and probably for a further decade beyond that date.

The cost of Ireland's "Energy transition" has received little attention so far. It should not be underestimated. The MaREI report (referenced later) very usefully provides a preliminary estimate of €32 Billion for the investment required up to 2030 in the power system alone, if the Government target is to be achieved while meeting reliability standards.

A further similar sum (€31 Billion) is estimated by MaREI to be required for the roll out of Electric Vehicle (EV) charging points, the introduction of heat pumps on a wide scale for space heating, and other consumer side investments; bringing the cost of the energy transition to at least €63 Billion by 2030.

It is most important that such estimates are further developed, refined, and submitted to conventional financial and economic analysis. The implications for the cost of electricity should be communicated to electricity customers and Irish industry as soon as possible.

2. INTRODUCTION

The Irish Academy of Engineering (IAE) is currently exploring the implications for the Irish electricity industry –specifically in this paper for the reliability of the Power System –of the Government's National Energy and Climate Plan[3] (NECP 2021 – 2030) published in August 2020. A revision to this plan to cater for the latest agreed Government targets is scheduled for publication in June 2021.

The new plan targets a reduction in GHG emissions of 7% per annum up to 2030. The plan also targets net zero carbon electricity production by 2050.

Authorities in the North of Ireland have indicated their intention of meeting similar targets thus facilitating future planning on an All-Island basis.

This report is based on the renewable generation targets currently listed in the NECP. The Academy recognises that these may be increased in the next revision of the plan reflecting the current Programme for Government.

This report takes an All-Island view of future power system reliability.

Post 2030 new technologies that enhance system reliability may become available and may permit the reduction in use of natural gas fired power generation. It is too early to definitively recommend the adoption of any of these technologies. The Academy has provided a commentary on such technology development and provided preliminary views on their likely viability in an Irish context.

The "Energy Transition" currently being contemplated is an enormous undertaking, presenting technical, financial and social acceptance risks. While preliminary cost estimates are now becoming available, it is essential that these are refined and that the likely impact on the price of electricity is estimated and communicated to customers.

1.1 Background

The NECP has set an immediate (short term) target of increasing annual electricity generated from renewables to 70% of total system production by 2030 and a follow on (long term) target of complete decarbonisation of electricity production by 2050.

The challenges posed to the successful development and operation of the power system consistent with the 70% annual renewables target in the short term may be summarised as follows:

1. The provision of adequate transmission infrastructure to facilitate the addition to the power system of large amounts of renewable energy.
2. The difficulty of ensuring a reliable electricity system while incorporating large amounts of intermittent and non-synchronous power generation.
3. The high capital investment required, and its impact on both electricity prices and energy taxes, in both the new generation and transmission infrastructure required to facilitate the transition to non-carbon emitting fuels, while maintaining system reliability standards.

The Academy has already published a report[4] on challenge no. 1 in October 2020. Challenge no 2 is addressed in this report.

1.2 Power System Reliability

Every power system suffers from minor faults from time to time, usually on the distribution network –storm damage is a typical example. These are highly localised faults and do not generally impact on the high voltage power transmission system (The Grid) which must operate without interruption if large scale uncontrolled power outages are to be avoided.

There are two possibilities of failure at the Grid level.

1.2.1 Adequacy failure

This type of failure is characterised by the failure of the system to provide sufficient generation to meet peak demand. The widespread power outages in Texas in February 2021 were caused by such a failure.

An unusual extremely cold weather event occurred over much of Texas forcing a large increase in demand for electric heating. Simultaneously, the extremely cold weather began to affect fuel supplies and cooling water to conventional generating plant.

3 https://www.gov.ie/en/publication/0015c-irelands-national-energy-climate-plan-2021-2030/
4 http://iae.ie/publications/the-future-of-electricity-transmission-in-ireland/

The primary cause[5] of the system failure was the non-availability of approximately 30GW of gas turbine generation. The IEA report referenced below says quite bluntly:

> "Texas has a power shortage because it has a gas shortage."

In order to maintain system stability, the power system operator in Texas had no choice but to introduce widespread load shedding affecting more than three million people and resulting in many families coping with temperatures lower than -10°C without heating or water for several days.

Managing adequacy becomes much more difficult in a power system with large amounts of intermittent generation. Essentially, such generation provides little contribution to meeting adequacy standards as its output is unpredictable beyond short timescales.

1.2.2 Resilience failure

All major power systems operate use Alternating Current (AC) which is generated at a specific frequency –50 Hz (cycles per second) in Europe and 60 Hz in North America. The use of AC has significant advantages in facilitating efficient high voltage (HV) transmission as well as, more subtly, ensuring that all generators on the system operate in lockstep with one-another (are synchronised).

This is an important consideration when the system has to respond to sudden unexpected events such as the failure of a transformer or sudden loss of generation from a generating unit. Power systems with large amounts of conventional synchronous AC generation are said to possess "inertia". This property is important in maintaining the system in a stable condition when it is subject to short term unexpected events.

The ability of the system to cope with short term shocks is termed "Resilience". Today's renewable generators (wind and solar) are connected to the Grid via DC links[6] and do not provide any significant "inertia" to the overall system. As renewable generation becomes more prevalent on power systems, maintaining resilience standards becomes ever more difficult and complex.

On the 9th of August 2019 a system resilience failure in the East of England resulted in the shedding of approximately 5% of instantaneous GB demand (approximately one million customers). Many mainline trains ground to a halt and were not restarted for several hours.

Resilience failures are complex and often have multiple triggering events. In this case in the UK, a major contributor was a software failure in the control system of a large offshore wind generating plant at Hornsea. While measures had been taken to meet resilience standards given the large amount of non-synchronous generation involved, these were not sufficient to prevent the sudden collapse of a significant part of the GB power system.

A more spectacular resilience failure occurred in the state of South Australia in September 2016. A software fault in the control system of a number of large wind generators resulted in the complete loss of the power system in South Australia during a storm. The system failure affected 850,000 customers some of whom waited for more than 24 hours before supply was restored.

The potential consequences of major adequacy and resilience failures are such that all power system operators design and operate their power systems to meet pre-set adequacy and resilience standards. The consequences of failure are set to become even more severe as decarbonisation policies encourage ever more use of electricity in transport, heating and other industrial applications.

As renewable non-synchronous generation becomes more prevalent the challenge of meeting these standards becomes more difficult.

It should be recognised at the outset that EirGrid and SONI are world leaders in managing the successful adoption of large amounts of non-synchronous generation onto the Irish power system. In over 90 years of operation Ireland has never experienced a total power system failure. This record of reliability is an important consideration for many high tech industries locating in Ireland.

1.3 Intermittency

Intermittent generation is inherent in most renewable power installations. This is not new – hydroelectric power

5 https://www.iea.org/commentaries/severe-power-cuts-in-texas-highlight-energy-security-risks-related-to-extreme-weather-events
6 Modern wind generators operate at variable speed and produce variable frequency AC power. This is typically converted to DC and re-converted back to AC at 50hz for connection to the Grid. The generator is not synchronised with the Grid.

production has always been influenced by annual rainfall. Where hydraulic inflows exceed reservoir capacity, water must be discharged over spillways and is not therefore available for generation. During low flow periods generation is constrained by the lack of water flow.

Managing such uncertainty is important for power system operators. In the early years of the Republic of Ireland, there was a constant concern that a "dry year" would result in insufficient generation at Ardnacrusha to meet peak demand.

Solar energy by nature is more predictable than wind but still very variable. Solar panels will produce zero output at night and little during short winter days. Daily output however is also heavily influenced by weather patterns. This is even more problematic in the case of Wind Generation.

In order to understand the scale of the potential variability it is instructive to look at the wind generation profile for the 24 hours of the 6th of December 2020.

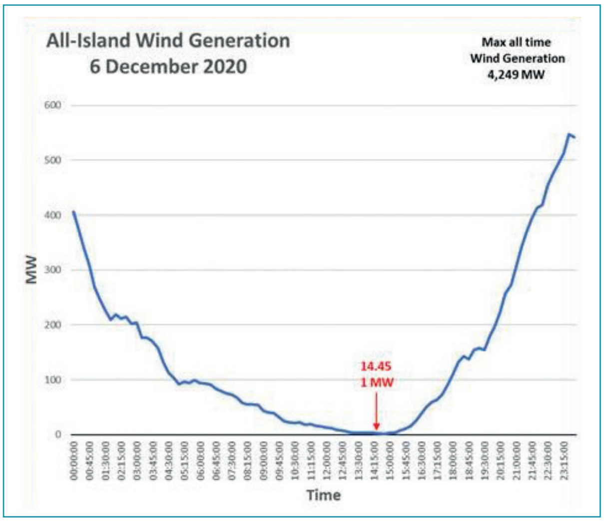
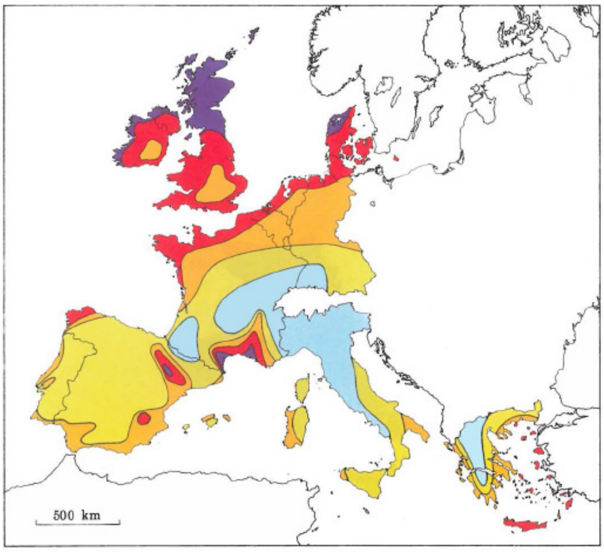


Fig 1.1. Wind Power Output 6th December 2020 (Source EirGrid)

Ireland's portfolio of wind generation capacity exceeded 4,000MW (All-Island) at the time. At 14.15 on Sunday 6th December 2020 this portfolio produced 1MW of power output in total. It's average output over the day was 145MW or approximately 3% of the rated capacity. Traditionally, fossil fuelled generation has been used to maintain system adequacy in such events. In recent years, this has been mainly gas fired.

While this high level of variability poses problems, this is by no means a reason to ignore wind generation in Ireland. Next to Scotland, Ireland has the best wind regime for power generation in Western Europe.

This high annual average mean wind speed in Ireland masks significant, challenging and in most cases unpredictable variations.



Wind resources[1] at 50 metres above ground level for five different topographic conditions										
	Sheltered terrain[2]		Open plain[3]		At a sea coast[4]		Open sea[5]		Hills and ridges[6]	
	m s⁻¹	Wm⁻²	m s⁻¹	Wm⁻²	m s⁻¹	Wm⁻²	m s⁻¹	Wm⁻²	m s⁻¹	Wm⁻²
	> 6.0	> 250	> 7.5	> 500	> 8.5	> 700	> 9.0	> 800	> 11.5	> 1800
	5.0-6.0	150-250	6.5-7.5	300-500	7.0-8.5	400-700	8.0-9.0	600-800	10.0-11.5	1200-1800
	4.5-5.0	100-150	5.5-6.5	200-300	6.0-7.0	250-400	7.0-8.0	400-600	8.5-10.0	700-1200
	3.5-4.5	50-100	4.5-5.5	100-200	5.0-6.0	150-250	5.5-7.0	200-400	7.0-8.5	400-700
	< 3.5	< 50	< 4.5	< 100	< 5.0	< 150	< 5.5	< 200	< 7.0	< 400

Fig 1.2 European Wind Regimes (Source Risø)

Like other climatic phenomena annual mean wind speeds are subject to significant variations from year to year. The impact of these variations on annual wind power output is illustrated in the Fig 1.3 which shows the annual capacity factor, (the ratio of annual wind output to installed wind generation capacity). 2010 was a year with unusually poor wind conditions, with the wind capacity factor falling from an average of 31% to 24%.

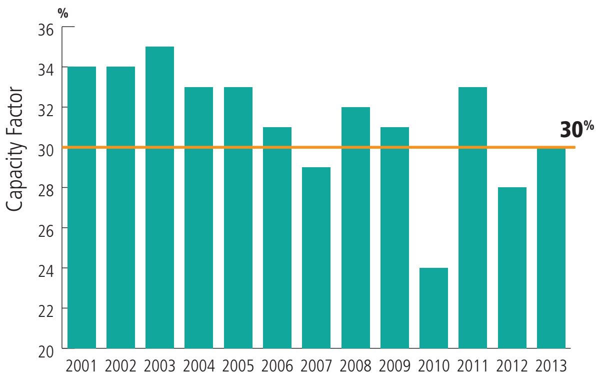


Fig 1.3 Ireland's Annual Wind Capacity Factors. (Source EirGrid)

As would be expected, there are significant seasonal variations in wind power output. Wind power output is normally much higher in Winter for example. But "normally" does not mean "always". The winter of 2010 was characterised by an exceptionally cold spell over Western Europe.

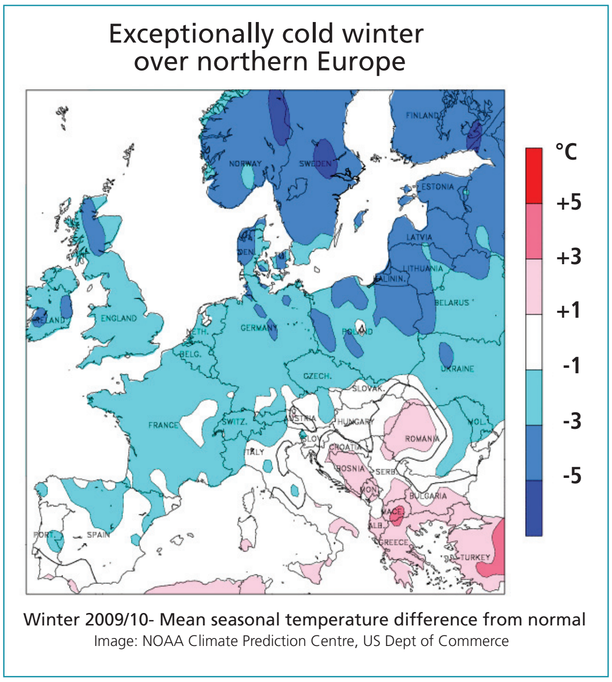


Fig 1.4 Stationary cold weather pattern 2009/10 (Source: Met Eireann)

Such weather patterns are unusual over Western Europe but when they do occur, they are accompanied by exceptionally low wind speeds and the patterns survive for prolonged periods. During the five week period from mid-November 2010 to the final week in December, wind output, at peak demand period, was less than 10% of installed wind generation capacity.

There was a 10 day period in this very cold spell where wind output was close to zero.

In these conditions it is questionable as to whether a significant infeed could be obtained through interconnectors with GB and France. Scotland, which has much of GB's wind generation capacity, was even more affected by the same climatic conditions and France has a high dependence on electric heating, which was promoted to complement its nuclear programme and thus has high domestic electricity requirements when temperatures are extremely low.

The key to understanding the challenges posed by such weather patterns is to acknowledge their extent –not just Ireland or GB, but most of Western Europe.

It has been suggested that storage technologies might be used to manage such multi week periods of low renewable generation and high demand. While such technologies could indeed contribute to solving daily intermittency problems, the cost of implementing such solutions (pumped hydro, or battery storage for example) to provide power over many days makes them entirely unfeasible for the foreseeable future. This issue is revisited in Section 4.

System planners must use sophisticated statistical analyses to produce future generation portfolios which meet both the Government target for annual renewable electricity production and adequacy standards. These are discussed further in Section 2.0

All current plans to cope with intermittency up to 2030 and beyond involve a significant portfolio of gas fired generation. See Section 2.2.

1.4 System Stability

As explained in Section 1.2.1, Adequacy is one failure mode the risk of which is considerably exacerbated by the intermittency of renewable power generation.

The second failure mode is caused by a lack of system "resilience", that is the ability of the power system to absorb short term events such as a lightning strike on a transmission line or a sudden failure of a major generating unit.

This lack of resilience occurs because most renewable generation is produced initially using either Direct Current (DC) or variable frequency Alternating Current (AC) which is subsequently converted to DC and finally converted to AC before connection to the grid.

The result in both cases is that the generators are "Non-Synchronous" and do not contribute to stabilising grid operation in the same way as large conventional rotating generation plant. The more non-synchronous generation that is connected to the grid, the bigger the problem becomes for grid operators to maintain a stable system.

The key parameter is the "System Non-Synchronous Penetration" or SNSP[7]. This is a measure of the instantaneous amount of non-synchronous generation on the system.

In 2020 renewable generation in Ireland accounted for almost 40% of total production and instantaneous SNSP reached 65% at times, the highest anywhere in the world.

In December 2020, a new SNSP target of 75% was set by EirGrid, on a trial basis. This should not be confused with the 70% target for annual renewable generation. In order to achieve the latter target SNSP will have to significantly exceed 70% for considerable periods of time.

Once again sophisticated computer modelling is required to establish future generation portfolios which meet both the Government renewables target and resilience standards.

System Operators seek out specific "System Services" to assist in managing system stability. One of the main services is the provision of operating reserve over a short timeframe (minutes). Some generators are more suitable than others to provide this reserve –hydro plants for example can increase output within a short timeframe.

More recently battery storage has become economic for the provision of such services and a number of new projects are proceeding in Ireland. Even though battery storage can certainly play a role in assisting operators to meet resilience standards, the cost of battery storage (even with a projected decline by 2030) makes such an approach infeasible as a solution to adequacy issues.

7 See Appendix 2 for a detailed definition.

3. SYSTEM STUDIES

The Academy has, on a number of occasions, suggested that studies of adequacy and resilience be undertaken quickly so that urgent planning of the power system can be undertaken particularly in the context of the 70% annual renewable target set for 2030.

Some such studies have recently been published; more are likely over the next year. This report relies on the insights developed so far which the Academy believes are important as the country moves to sharply decarbonise power generation.

Further details of these studies are provided in Appendix 1.

2.1 Demand Forecasts

EirGrid's and SONI's All Island Generation Capacity Statement, GCS 2020, provides the following demand growth estimates for the Ireland.

Unusually, the demand forecast is heavily influenced by plans for a small number of large data centres in Ireland. These centres consume industrial quantities of electricity; without them growth in electricity demand in Ireland for the next decade would be almost flat as a result of increasing efficiency in energy use generally.

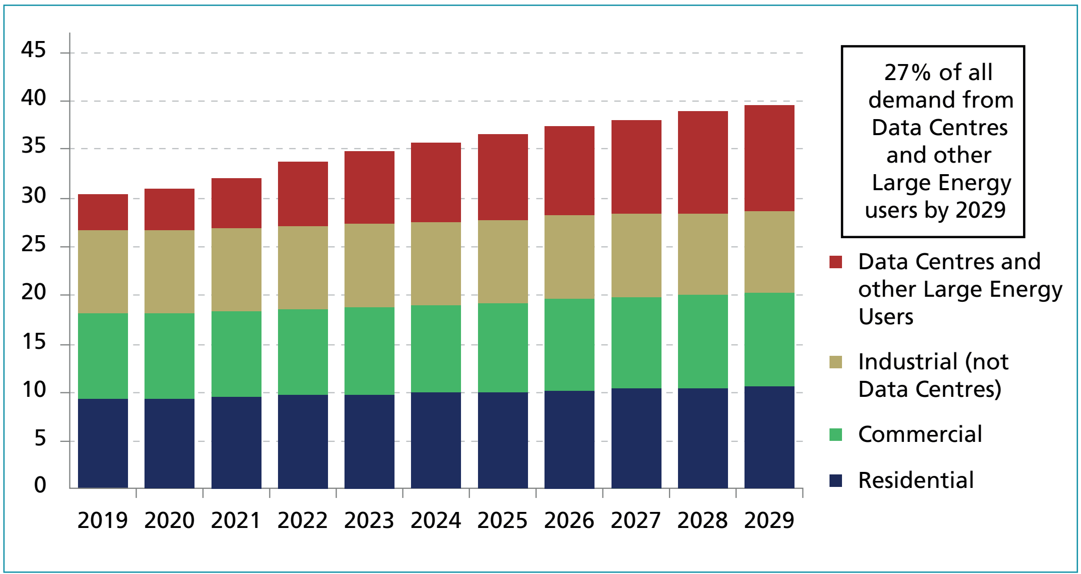


Fig 2.1 Projected composition of annual electricity demand for Ireland. (GCS 2020)

The data in Fig 2.1 is for *annual* electricity demand (TWh). However, adequacy studies must focus on the *peak* electricity demand (GW) at any one time. Based on historical correlations (and with some correction for temperature variation) a system peak can be predicted using the projected annual demand. GCS 2020 estimates this as follows for the All-Island case.

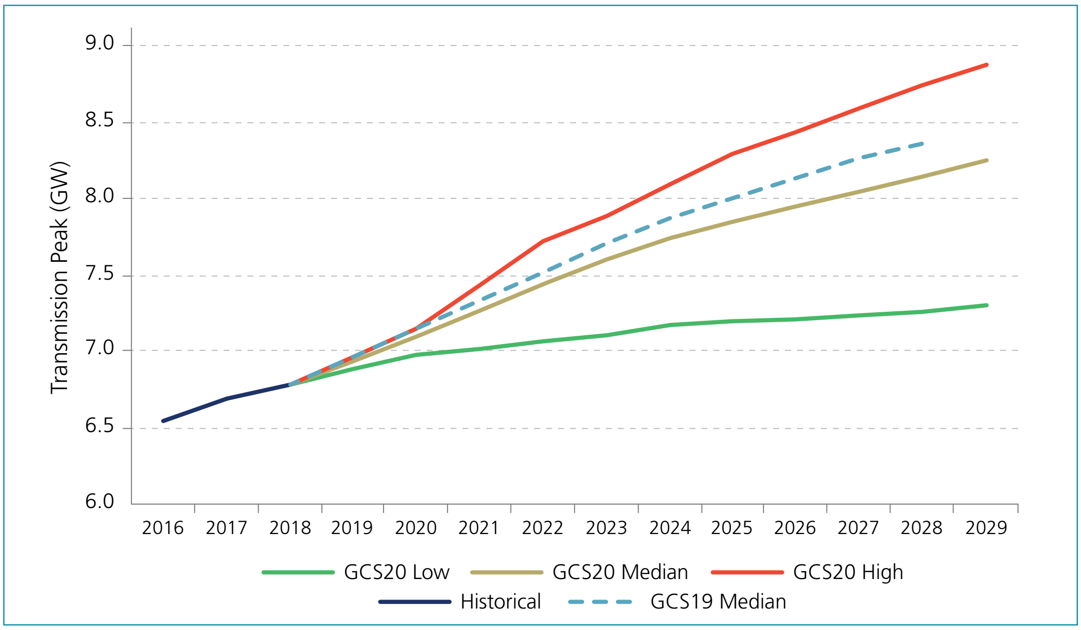


Fig 2.2 All-Island Peak Demand forecasts (Source: EirGrid GCS2020)

In addition to the unusual situation arising from large data centre loads, COVID- 19 will undoubtedly have an effect on economic growth and on electricity demand. Given the possible volatility in demand projections from data centres, real attention must be paid to the likelihood of the low demand curve being realised while possibly planning for the median demand.

2.2 Generation

Using the standard adequacy planning approach, GCS 2020 builds the likely portfolio of plant required for adequacy purposes for each year of the forecast. This considers retirements such as peat and coal plants as well as the projected availability of dispatchable plant generally.

In all cases the maximum capacity of generators may be "de-rated" to provide an estimate of reliable capacity from any particular source. The East-West interconnector for example is derated to 60% of available capacity to allow for circumstances when capacity is not available in the UK.

Energy storage such as pumped hydro can assist in maintaining resilience –and adequacy over a single peak. There are plans to provide battery storage on the system, also primarily for reasons of resilience. Such storage is essentially short term being measured in hours rather than days. Battery storage is not economic at a scale that would meaningfully contribute to the resolution of the adequacy problems.

Shown on the next page is a typical portfolio of *derated dispatchable* generation provided in GCS 2020 which would meet the adequacy standard (All-Island) for all years to 2029. The contribution from the renewable generation portfolio (mainly wind) is in addition to that shown below.

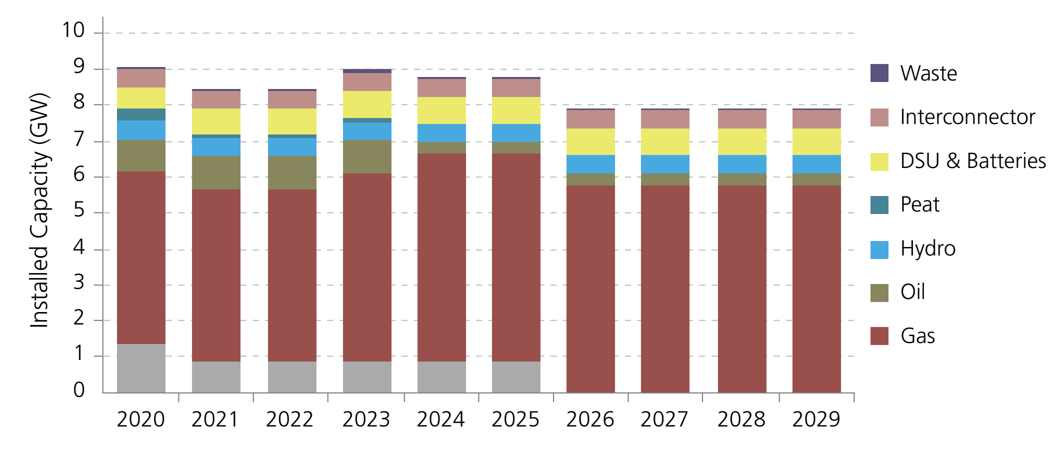


Fig 2.3 Suggested technology portfolio to maintain system adequacy – GCS 2020 (Note: coal fired generation is included in the diagram but not in the label list.)

In 2020 this generation portfolio of mainly synchronous generation amounted to approximately 9,000MW of which approximately 4,800MW consisted of gas fired generation (mostly CCGT plant). This gas fired portfolio is projected to increase to approximately 5,800MW in 2029, an increase of approximately 1,000MW.

In addition to the above a large portfolio of intermittent renewable generation will be required to meet the 70% annual target. GCS 2020 provides the following example of such a renewable generation portfolio (mainly wind) for Ireland (RoI). Installed renewable capacity is estimated at approximately 9,000MW.

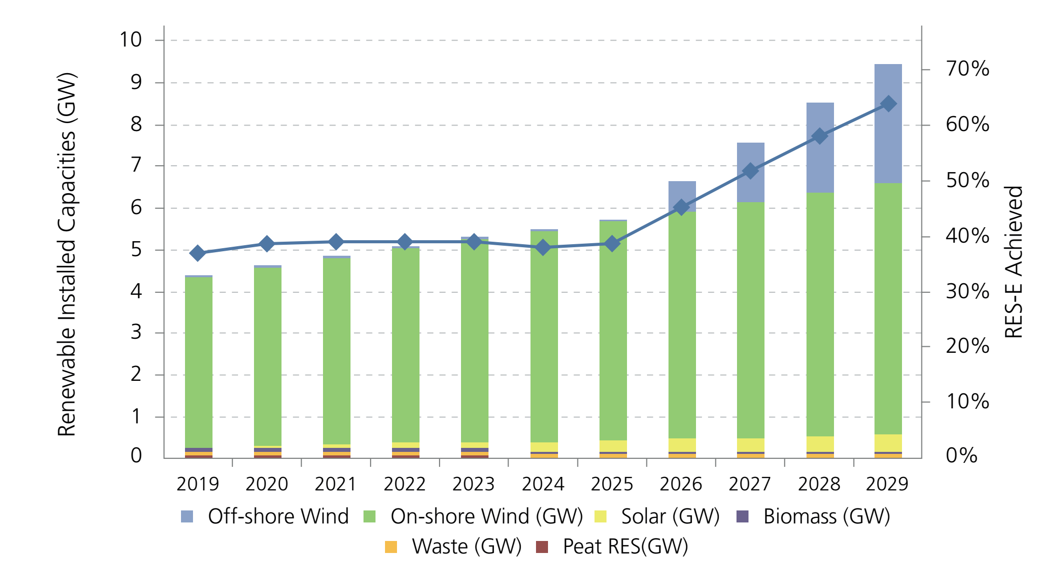


Fig 2.4: Example of renewable energy portfolio which could achieve the 2030 70% annual target in Ireland (ROI) –from GCS2020.

In order to meet both the 70% annual renewable target and maintain *adequacy* standards EirGrid's GCS2020 suggests:

- Gas Fired generation capacity will increase from approximately 4800MW to 5800MW on an All-Island basis.
- Renewable generation will increase from approximately 4500MW to 9300MW in the ROI.

The MaREI study considers an All-Island power system from a European perspective with a considerable focus on interconnection and resilience standards. The study uses a Base Case scenario as well as considering some variations to the basic assumptions.

The MaREI study suggests (Base Case) that the current All-Island Gas Fired generation portfolio of 4981MW will have to increase to 5204MW in 2030 in order to maintain system reliability. MaREI also assumes for its Base Case scenario almost 15,000MW of renewable generation (wind and solar). See Fig 2.5

While GCS 2020 significantly derates interconnection and some generation capacity, the MaREI study does not apply such factors.

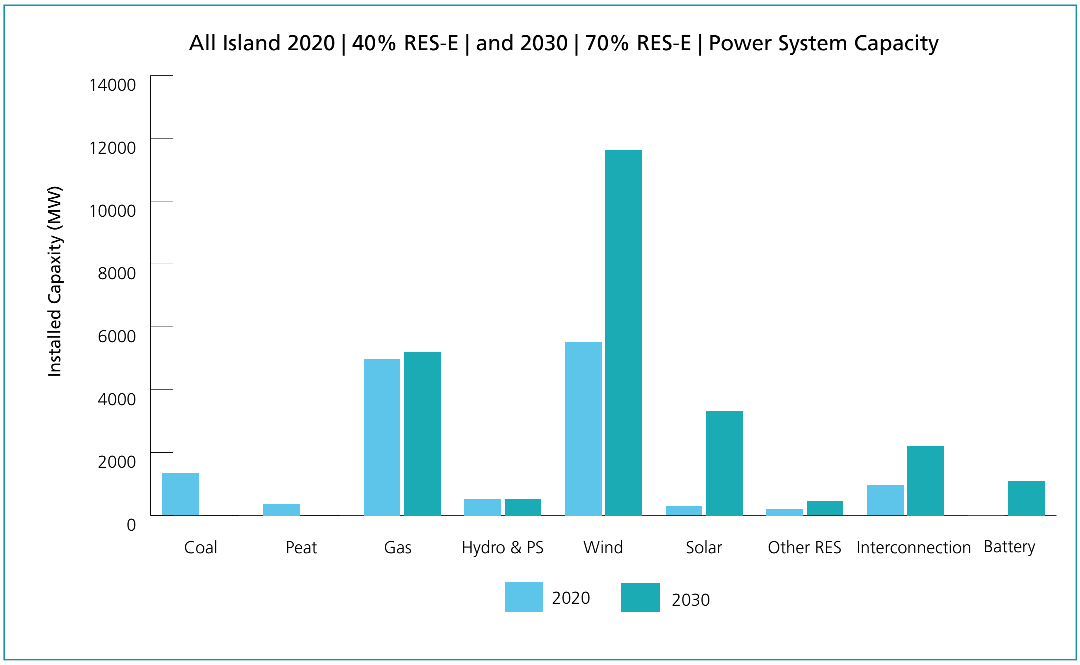


Fig 2.5 Base Case Scenario form the MaREI study.

Table 2.1 summarises the main changes in generation portfolios in 2030 from both studies.

	Gas Fired 2020 (MW)	Gas Fired 2030 (MW)	Renewable 2020 (MW)	Renewable 2030 (MW)
EirGrid[1]	4800	5800	4500[2]	9300[2]
MaREI[3]	4980	5200	5800	15000

([1]EirGrid GCS2020, [2]ROI only, [3]MaREI "Our Zero Mission Future")

Table 2.1

It is noteworthy that both scenarios show a higher gas fired generation capacity in 2030 than in 2020. Regardless of the amount of renewable generation on the system this gas fired capacity is required to meet adequacy and resilience standards.

While gas fired capacity must increase for reliability reasons, the amount of gas used is likely to fall somewhat given that this plant will almost certainly operate at a lower average load factor. The MaREI report estimates a 20% drop in gas fuel usage by 2030.

The changes in fuel usage envisaged over the next half decade or so are very substantial – details are provided in Appendix 2. It is important to understand that while average annual gas demand may fall, peak gas usage in periods of low wind speed will almost certainly rise.

This variation in gas usage is illustrated in the following diagrams showing estimated gas usage during periods of low renewables output and hight renewables output.

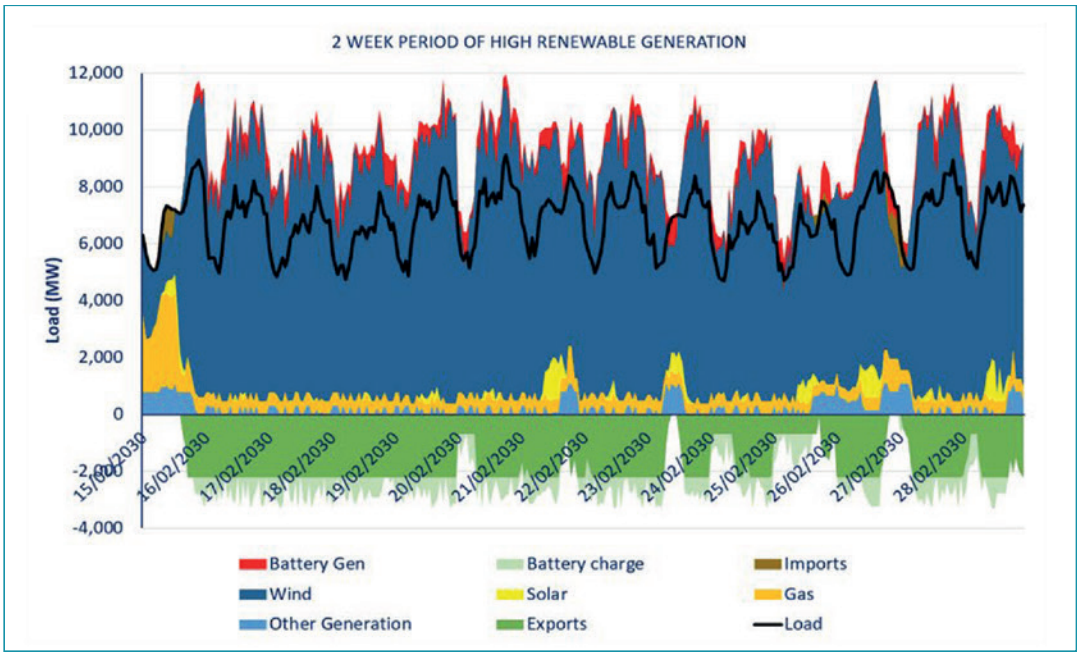


Fig 2.6 Estimated 2030 gas capacity usage (High Renewables Output) MaREI

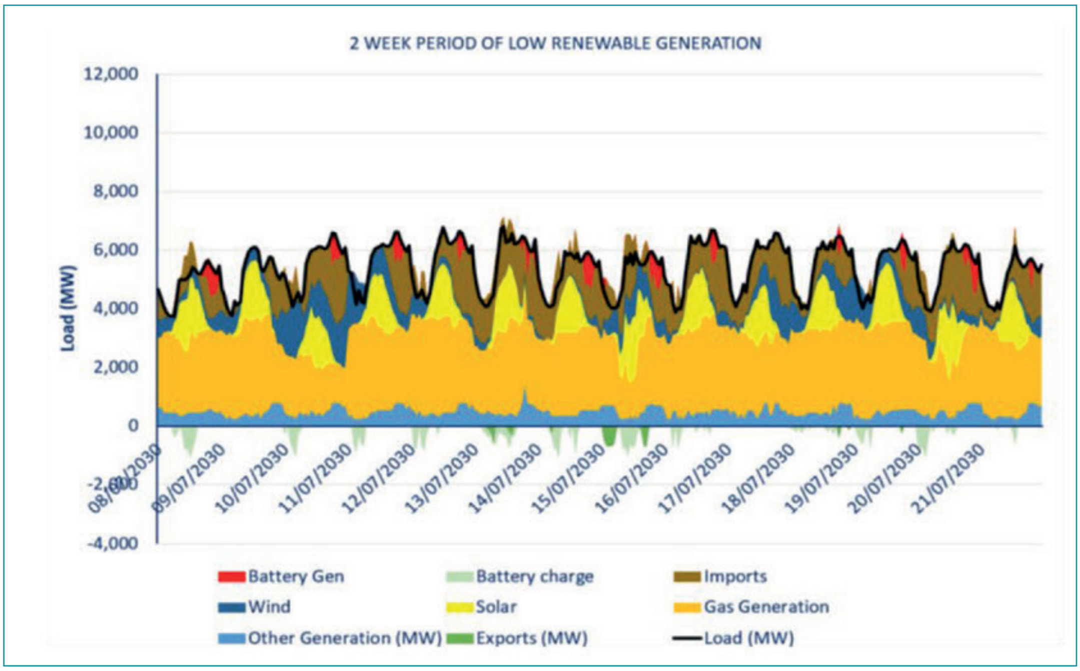


Fig 2.7 Estimated 2030 gas capacity usage (Low Renewables Output) MaREI

The contrast between these two fuelling states is dramatic. It has profound consequences for the technical operation of existing CCGT plant and for the peak fuelling of that plant.

Against this specifically Irish background, it is worth examining what is projected for other developed economies generally in relation to the maintenance of power system reliability standards and specifically the ongoing use of gas turbine generation.

The McKinsey report focusses on the EU and suggests a decarbonisation pathway to 2050. It is a wide ranging document but provides specific analysis for the electricity sector. In capacity terms the McKinsey projection for traditional synchronous generation for Europe shows:

- Coal capacity greatly reduced by 2030 and eliminated by 2050.
- A steady reduction in Nuclear power capacity, approximately halving by 2050.
- Little change in EU Hydro capacity
- Gas fired capacity significantly increasing until 2030 and slightly increasing beyond that to 2050.

In fuel use terms, EU gas consumption shows no decline until 2030 and approximately 80% by 2050.

The report shows a requirement for considerable gas fired capacity and generation across the continent in 2030 and well beyond this date. Indeed, gas fired capacity in 2050 exceeds that of today in the McKinsey scenario while gas consumption declines substantially by then.

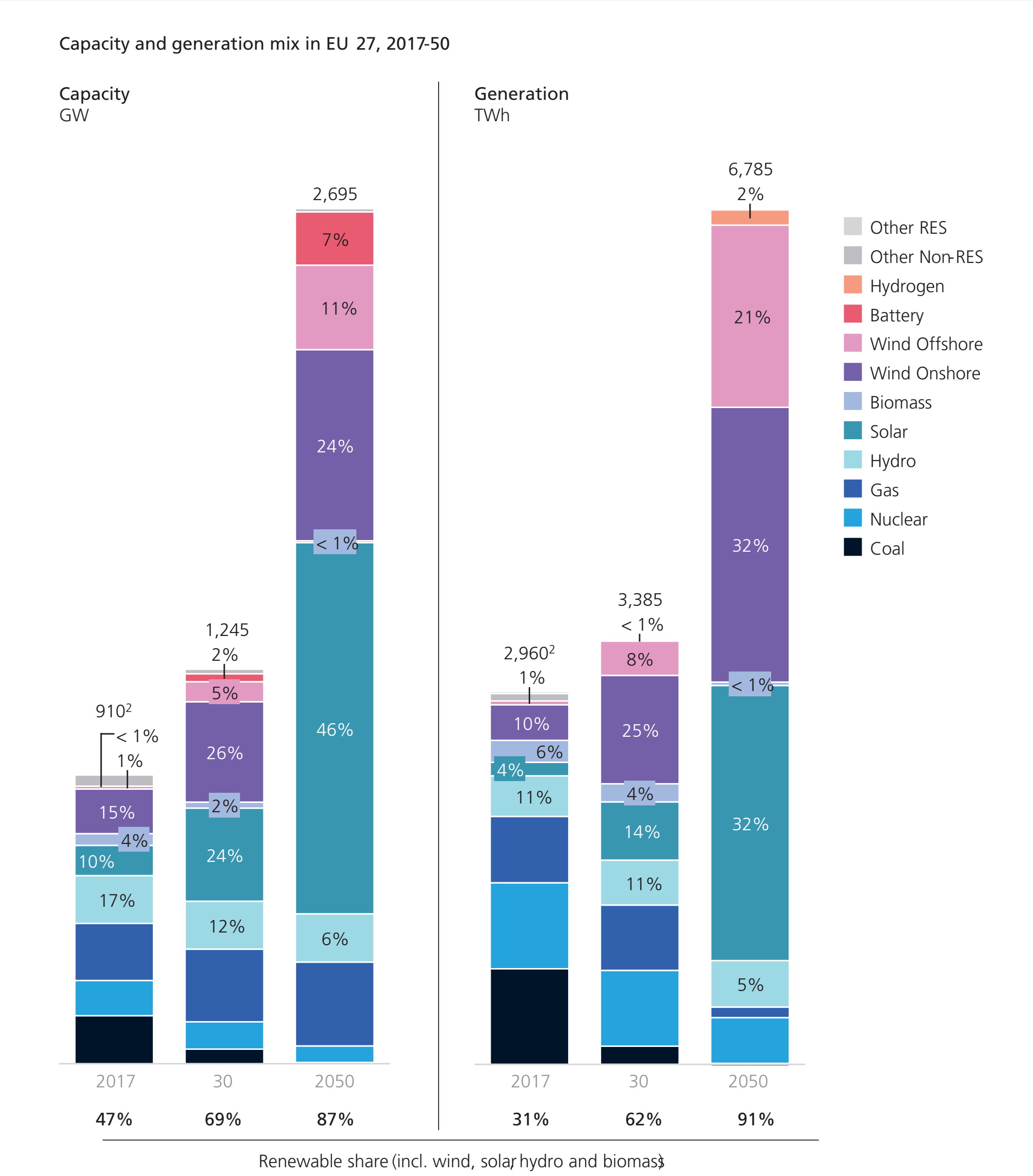


Fig 2.8 The evolution of generation across the EU (McKinsey)

The consistent message in all the foregoing reports and scenarios is that significant gas fired generation capacity is required on the Irish and EU power systems for adequacy and resilience reasons long after 2030. Even though the load factor on such plant will decline somewhat by 2030, it will still be a significant component of European power production in 2050.

2.3 Gas Supply Security

Against a rapid decline in production forecast for the Corrib gas field over the next few years, it is essential that Ireland maintains a reliable natural gas supply for the next two decades for the purpose of power generation and Grid stability.

Ireland has two sources of gas supply at present – the Corrib Field and pipeline imports via Britain. Gas production from Corrib has reduced by almost 50% in the past four years and this steady decline will continue in the next few years. By 2025, Corrib will supply only 15% of Ireland's annual gas demand and less than 10% of maximum daily supply.

By 2030, the Island of Ireland will be almost totally dependent on Great Britain (GB) for all its gas supply. By then, GB will need to import 75% of its gas due to the decline in North Sea production. Britain's gas imports will then come from Norway, Russia, Qatar and various countries outside Europe.

The gas supply route to Ireland will be longer than at present with a greater risk of supply disruption and price volatility. Alternative sources of gas supply and supply routes would significantly improve the security of the Irish supply situation.

The existing gas interconnectors to Scotland have the capacity to deliver the higher import volumes required. The issue is:

> Will the increasingly import dependent GB gas system be able to deliver our much increased peak gas import requirement, at times when GB gas requirements may also peak, due to the increased penetration of gas fired generation on the GB electricity system, as coal and nuclear units are retired?

This problem could become particularly acute, when low wind speeds and low temperatures affect both islands simultaneously, as occurred for a prolonged period in 2010 and most recently in Jan 2021.

In its 2019 Ireland review, the IEA stated:

> "There is high reliance on a limited amount of gas infrastructure, raising concerns for security of gas supply in Ireland. This is independent of the future relationship between the United Kingdom and the European Union. An option for diversification of gas supply routes would be the construction of an LNG import facility to provide Ireland with direct access to the global LNG market."

There has been a significant growth in Liquefied Natural Gas (LNG) imports into Europe in the last ten years. LNG imports accounted for 27% of total EU gas imports in 2019. There are now 36 LNG import terminals in 15 different countries in Europe and a further 20 under construction or planned. Ireland is one of the very few coastal countries in North West Europe without an LNG import facility.

Given the level of electrification of the economy planned for 2030, the consequences of a strategic failure of gas supply to the Island of Ireland are truly alarming.

What measures might be taken to mitigate this risk? Three possible measures suggest themselves:

1. Construct large scale gas storage facilities on the Island of Ireland.
2. Revert to Distillate oil to fuel Ireland's gas fired generation fleet.
3. Invest in the development of an LNG import terminal on the island.

Natural Gas Storage. There is only one location suitable in geological terms for large scale gas storage on the Island of Ireland. This is at Islandmagee in Co. Antrim. Efforts have been underway for the past decade to license and finance a large scale storage project at the site. This could be an important asset in supporting the security of the island's long term strategic gas supply.

Authorities north and south of the border need to satisfy themselves without further delay that this project is indeed feasible, that it will contribute meaningfully to gas supply security against a worst case scenario and that construction will commence within the next few years in order that risks to the Island's power system are appropriately ameliorated.

Distillate Oil fired generation. Most gas fired generators in Ireland have some capacity to be fired with distillate in order to cope with short term gas outages. Neither the storage facilities nor the delivery logistics have been designed for long term firing although such facilities (increased storage, pipelines, road delivery logistics) could conceivably be installed over the medium term.

There may well be technical disadvantages in the long term operation of existing gas turbine generation on distillate fuel. Switching between gas and distillate is known to cause technical and reliability problems on the plant.

Distillate firing is also likely to be considerably more expensive than gas firing.

SEAI estimates[8] that the use of distillate would increase GHG emissions from gas-fired generating plant by close to 30%

The Academy feels that a reversion to long term distillate oil firing would be an expensive retrograde step, increasing both the country's oil consumption and emissions from existing and new combustion plant.

LNG import facilities. In the Academy's view, developing a liquefied natural gas import terminal in Ireland is strongly advisable in order to enhance Ireland's security of gas supply. This issue has already been addressed in a previous Academy report[9] "Natural Gas: Essential for Ireland's Future Energy Security."

The most recent of the reports considered for this publication comes from the US Academy of Sciences, Engineering and Medicine[10]. *"Accelerating Decarbonisation of the US Energy System"* sets out a path for decarbonising the US Energy System by 2050. The scope is much wider than just electricity, but the report acknowledges the key role that electricity will have to play in any US energy transition.

The report acknowledges the wide range of resources available to the US if it is to achieve its decarbonisation target and concludes:

> "A transition to a net-zero economy in the United States by mid-century is technologically feasible, with energy system costs as a share of U.S. gross domestic product that have been manageable over the past decade, but it is on the edge of feasibility. These conditions warrant rapid rates of change and unprecedented levels of funding for RD&D, infrastructure planning, permitting and construction activity, and other changes in public policy and social systems that have to begin immediately across the energy economy, as well as unprecedented actions to build and maintain public support for the net-zero transition."

The report supports the rapid expansion of wind and solar generation but acknowledges that:

> "Although the variability of wind and solar makes it impossible to maintain a reliable electricity system with these sources alone, hydropower, energy storage, bioenergy, nuclear energy, geothermal energy, and natural gas with carbon capture and sequestration are available for building a reliable system."

Specifically, in the case of gas fired generation:

> "Emitting gas-fired generation would decline 10 to 30 percent by 2030 and total capacity would be roughly flat. Some new gas-fired capacity in certain regions could be built during the 2020s to replace ageing assets."

In the context of the Academy's recent report[11] on "The Future of Electricity Transmission in Ireland" it is worth noting that US Academy of Sciences, Engineering and Medicine has this to say:

> "Please note that some regulatory reform will be necessary to achieve many of the above technological goals. In particular, timely siting and permitting of the new electricity transmission infrastructure is likely to prove difficult or impossible without regulatory reform."

Perhaps most importantly, the report observes that:

> "Maintaining public support through a three decade transition to net zero simply cannot be achieved without the development and maintenance of a strong social contract."
>
> "The United States will need specific policies to engage and cultivate public support for the transition, ensure an equitable and just net-zero energy system, and facilitate the recovery of people and communities hurt by the transition."

This latter is a consideration that should be uppermost in the minds of all policymakers, regardless of location.

8 https://www.seai.ie/data-and-insights/seai-statistics/conversion-factors
9 http://iae.ie/publications/iae-report-on-security-of-irelands-gas-supply/
10 https://www.nap.edu/download/25932
11 http://iae.ie/publications/the-future-of-electricity-transmission-in-ireland/

4. ENERGY TRANSITION COSTS

The scale of the Energy Transition being undertaken by developed economies must not be underestimated. Associated with the transition is the capital cost of:

- New electricity Infrastructure (generation, transmission, system services)
- Investment at the consumer end (heat pumps, EV charging points etc)

There remains great uncertainty around the cost of these changes and how these costs may impact consumers, taxpayers and existing industry participants. The recent US report stresses the importance of maintaining a social contract if changes of the magnitude envisaged are to be successfully implemented.

The maintenance of such a contract will require open and honest communication at all times. This is particularly important in the case of costs arising from the transition and where such costs will be borne.

MaREI[12] has usefully prepared some initial estimates[13] of capital expenditure which will almost certainly have to be refined in the future, but which form the basis for a first step in recognising the scale of the changes.

Electricity infrastructure costs up to 2030 are estimated by MaREI as follows:

Category	Item	Costs (€M)
Power Plant	Onshore Wind	7,463
Power Plant	Offshore Wind	4,129
Power Plant	Solar PV	2,428
Power Plant	Batteries	836
Infrastructure	Offshore Grid	694
Infrastructure	ESB Networks	10,000
Infrastructure	Interconnection	1,200
Infrastructure	Other Networks	2,100
System Services	DS3 Costs	3,538
Total		**32,208**

Table 3.1 Electricity infrastructure investment (MaREI)

MaREI has also estimated costs at the customer side:

Category	Item	Costs (€M)
Residential	Heat Pumps	8,250
Residential	Residential Retrofit	22,500
Total		**30,750**

Table 3.2 Electricity (consumer side) investment (MaREI)

Over the next decade, approximately €32Bn will be invested in production facilities and €31Bn in residential upgrades bringing the total estimated expenditure for the next decade to €63Bn.

It should be appreciated that some of these investments may substitute for more conventional investments that might otherwise have been incurred and that they may lead to reduced operating costs. At the moment, proper economic and financial analyses of these investments have neither been undertaken or published.

The Academy urges strongly that these estimates be refined further, that their economic impact be assessed and that the likely impact on consumer prices and Government taxes be understood and communicated to the public.

12 https://eaireland.com/wp-content/uploads/2020/11/Our-Zero-e-Mission-Future-Report.pdf
13 MaREI report section 7.4

5. LONG TERM TECHNOLOGY DEVELOPMENTS

There have been suggestions that most fossil fuel generating plant be phased out by 2030 –most will have to be phased out by 2050 if the zero carbon target is to be reached.

There is no possibility of phasing out gas fired generation capacity in Ireland by 2030, in fact the capacity will in all likelihood have to increase somewhat. It is worth considering some alternative technologies in the context of complete decarbonisation by 2050.

The following is a list of potential alternative technology options which might be used to reduce gas turbine generation. Each option is considered subsequently in more detail, but it must be noted that many of these technologies are at an early stage of development and their ability to meet technical and financial targets are yet to be established.

- Pumped Hydro Storage
- Compressed Air Storage
- Battery Storage
- Carbon Capture and Storage
- Increased Interconnection
- Hydrogen Fuel options
- Biofuels
- Marine Energy (Wave/Tidal)
- Nuclear power

4.1 Pumped Hydro Storage

This is an old technology and is already utilised very effectively on the Irish power system. However, the scale required of such a plant if it were to maintain adequacy standards instead of gas fired generation would entirely dwarf the Turlough Hill scheme.

Other countries do utilise pumped hydro storage at a much larger scale than is done in Ireland. Most recently Australia has announced a large expansion of the Snowy Mountains Hydro Scheme (Snowy 2) with the aim of tackling the intermittency problem arising from wind and solar generation in New South Wales and Victoria.

There are alternative conventional pumped storage sites in Ireland but none large enough to substantially reduce the amount of gas fired generation required in 2030.

Proposals have been made in the past for a large salt water pumped hydro plant on Ireland's west coast. This technology was used in one small plant in Japan (recently closed) and has never been developed further. The technology risk associated with such a plant may cause insurmountable financing difficulties.

Even in the event of a suitable technology/site combination being available, it would be quite impossible to construct such a plant in Ireland prior to 2030. Indeed, if such a plant were to be of sufficient size to substitute for gas fired generation in adequacy studies, it's social acceptance would pose a major challenge.

4.2 Compressed Air Energy Storage (CAES)

This technology utilises a gas turbine, compressor and a suitable geological formation to store large quantities of compressed air during low demand periods. During high demand periods this compressed air is released into a gas turbine, mixed with a suitable fuel, combusted and expanded through a turbine to drive a generator. Using this process, up to 70% of the stored energy can be recovered.

It should be understood however that this process involves the combustion of fossil fuels and, while it may contribute to system efficiency, does not eliminate the requirement for fossil fuel fired generation.

The process requires suitable geological formations in which to establish large scale storage. With the possible exception of certain formations in Antrim, Ireland does not have a suitable geology for this technology.

This technology will not make any contribution to the Irish Power System before 2030

Post 2030, and given the lack of suitable geological storage, CAES is highly unlikely to make a significant contribution to decarbonisation in Ireland.

4.3 Battery Storage

Major progress has been made with both performance and price of battery technology over the past two decades.

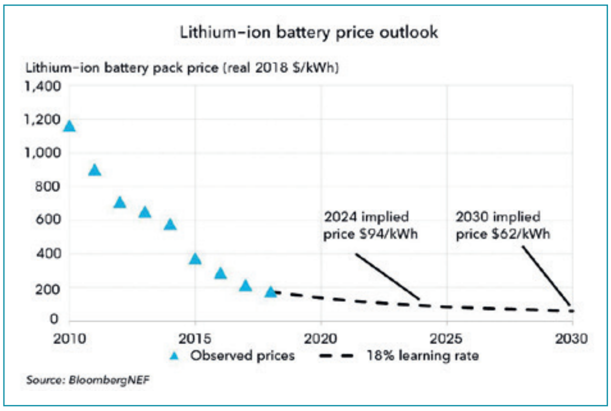


Fig 4.1 Li Ion cost curve (Bloomberg New Energy Finance)

Most of the recent development in battery technology has been driven by the automobile industry and the focus has been on Lithium Ion batteries. The cost curve declined quite dramatically from 2010 to 2020, much of it driven by the scale up of production facilities. The cost has declined from approximately $1200/kWh in 2010 to a forecasted cost of a little over $60/kWh in 2030 (Bloomberg New Energy Finance).

Could Lithium Ion battery storage technology be used to manage periods of low wind output in the future, as battery costs continue to fall?

Using the Bloomberg NEF figures, the capital cost of installing batteries to meet 10 days average daily electricity demand, in 2030, would be at least $60Bn (€50Bn at current exchange rates), excluding network connection costs. This is manifestly unaffordable; a battery storage solution to the adequacy problem will require the development of new battery technologies costing a fraction of the projected 2030 costs. Such a technology is not yet on the horizon.

4.4 Carbon Capture and Storage (CCS)

Carbon capture and geological storage (CCS) is a technique for trapping carbon dioxide emitted from large point sources such as power plants, compressing it, and transporting it to a suitable storage site where it is injected into the ground.

The CCS concept is pretty simple and has been under consideration for several decades. There are concerns around the long term reliability of geological storage, but most expert analysis concludes that it is possible, using appropriate geological formations, to store carbon dioxide safely for the exceedingly long term –typically millennia.

The main barrier to CCS has consistently been its cost. Removing CO2 from power plant exhaust gases significantly reduces the conversion efficiency of the plant and consequently raises the cost of electricity produced. Given the constraints indicated by the basic laws of physics, this barrier will remain regardless of technical progress.

It is the Academy's view that given the current state of technology development, CCS will not provide any contribution to decarbonisation in Ireland prior to 2030. Post 2030 much will depend on further research and CCS may indeed provide a contribution to maintaining the adequacy standards on the Irish power system by permitting the ongoing operation of gas fired plant using "carbon abated" gas.

Gas Networks Ireland (GNI) has plans to commence CCS using the depleted Kinsale Head gas field in 2028.

4.5 Interconnection

Interconnection with other power systems is a well proven technology and does offer some possibility of easing the adequacy problem. This is very evident in a country like Denmark which could not manage as much intermittent generation on its system as it does without large numbers of diverse interconnectors to Germany, Sweden, Norway, The Netherlands and the UK (planned).

However, Ireland's interconnectors, both existing and future, will have to be de-rated, in adequacy calculations, to reflect the fact that surplus generation in neighbouring jurisdictions may not be available when required. Already mentioned has been the occurrence of long periods (weeks) of exceptionally low wind output during winter high pressure events in Ireland. This same high pressure weather system will also affect Ireland's neighbours in the UK and in France. Such is the geographical scale of these events.

GCS 2020 derates Ireland's existing Moyle and East West Interconnector to 60% of the nominal capacity. These contributions from the East West Interconnector and the Moyle interconnector have already been included in the

GCS 2020 scenarios. It should be noted that there is considerable uncertainty in this assumption. EirGrid states in GCS 2020:

> "The East-West interconnector connects the transmission systems of Ireland and Wales with a capacity of 500 MW in either direction. However, it is difficult to predict whether or not imports for the full 500 MW will be available at all times. Informed by the SEM Capacity Market decision, we used a 60% External market derating factor, i.e. 300 MW, and appropriate availability statistics."

Two further interconnectors are currently being planned for this decade; these two new interconnectors have been assumed operational (but not derated) in the MaREI study. This inclusion has not impacted on the requirement for more than 5000MW of gas fired generation in 2030.

Project	Location	Estimated Capacity (MW)	Estimated Cost (Million Euro)	Estimated Completion Date
Celtic Interconnector[14]	Ireland - France	700	1,000	2025
GreenLink Interconnector[15]	Ireland - UK	500	400	2023

Table 4.1 Proposed Interconnectors.

It is highly unlikely that increased interconnection will result in a substantial reduction in gas fired generation capacity, particularly considering the closure of coal, oil and peat fired generation in the next decade. This will become evident in the GCS studies of the early 2020s.

Further interconnection may contribute post 2030 but certainly not enough to eliminate gas capacity from adequacy considerations. The fundamental issue of a lack of geographical weather diversity will persist and will not be alleviated by increasing amounts of interconnection.

The derating of interconnector capacity requires further detailed consideration. The Amber Alerts issued by the Single Electricity Market Operator in Ireland in Dec 2020 and Jan 2021 highlighted the fact that the assumptions, made, to date, by system operators in Ireland that both electricity interconnectors could reliably be expected to contribute at least half of their rated capacity, when wind generation was low, and generation margins in Ireland were tight, may not be correct.

On those occasions GB wind generation was also low and the different market arrangements on the two islands encouraged power flows from west to east rather than the reverse, thus exacerbating the electricity supply problem in Ireland.

14 http://www.eirgridgroup.com/the-grid/projects/celtic-interconnector/the-project/
15 https://www.greenlink.ie/

4.6 Hydrogen fuel options

The European Union, in the context of its "Green Deal" proposal has indicated strong support for research into the use of "green" hydrogen (or e-hydrogen) as an energy vector of the future. In a "Clean Planet for All" the commission comments as follows about hydrogen:

> "Hydrogen has long been used by the chemical industry as a feedstock in industrial processes. Its role is likely to become more prominent in a fully decarbonised energy system. To play this role, hydrogen will have to be produced by water electrolysis using carbon-free electricity or from natural gas steam reforming using Carbon Capture and Storage. Hydrogen thus produced can then contribute to decarbonise various sectors: first, as storage in the power sector to accommodate for variable energy sources; second, as an energy carrier option used in heating, transport and industry and, finally, as a feedstock for industry such as steel, chemicals and e-fuels in those sectors that are most difficult to decarbonise."

At its simplest, the "Hydrogen Strategy" envisages:

- Large scale hydrogen production by electrolysis using "cheap" renewable electricity. This is e-hydrogen. Production is particularly cheap if it can be associated with wind power which might otherwise be curtailed.
- Storage of e-hydrogen in large underground caverns
- Transportation of e-hydrogen using current or new gas grids.
- Use of e-hydrogen as a fuel for transport and for heavy industry –including power generation in CCGT plants.

There are a number of variations on the strategy:

- Hydrogen might be produced by, for example, reforming methane in conjunction with carbon capture and storage.
- Initial use of the gas grid might involve the addition of hydrogen to existing natural gas rather than its replacement.
- Transport could also involve liquefaction and shipping by road and sea transport.

Most commentators on the possibility of the hydrogen economy foresee that it may initially be applied in areas that are difficult to electrify such as shipping and heavy transport. Beyond that significant barriers must be overcome:

- Hydrogen may cause embrittlement of existing steel gas transmission infrastructure and may require its own dedicated pipelines.
- Beyond a 20% dilution of Natural Gas, hydrogen may require a changeout of all burners in domestic appliances.

The hydrogen economy will evolve slowly in Ireland, if only because of our lack of suitable geological structures for use as storage. See Fig 4.2.

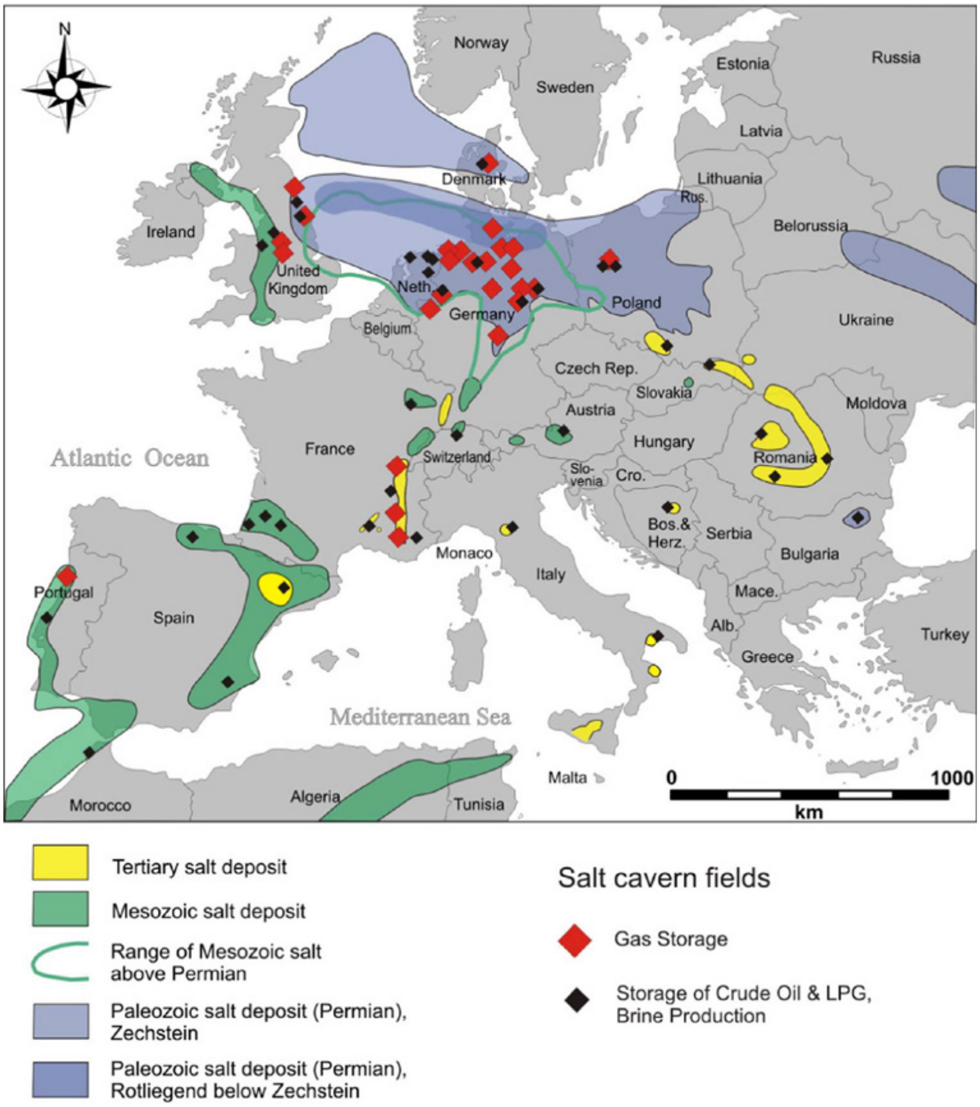


Fig 4.2 Suitable gas storage formations in Europe

Given the views of both Gas Networks Ireland and the UK's Energy Networks Association, Hydrogen will make little contribution to the decarbonisation of Ireland's electricity supply by 2030. Its contribution to that goal by 2050 remains uncertain.

4.7 Biofuels

Gas Networks Ireland has indicated its intention[16] to develop Biomethane production in Ireland at an industrial scale. It is targeting 20% of national gas supply from Biomethane by 2030. Biomethane is carbon neutral and this source could indeed become significant by 2050 given that much of it could be captured from Ireland's agricultural industry.

The target of 20% of current gas demand (approximately 11TWh) is approximately 25% of the estimated maximum Biomethane production possibility in Ireland. This is indeed a particularly challenging target for 2030. GNI estimates that this target will require the construction of 340 anaerobic digestion plants all connected to the main gas grid.

GNI defines its role as follows:

> "Gas Networks Ireland's role will be as facilitator of the roll-out of renewable gas. We will be an advocate for change, and we will put in place the network to transport the renewable gas. A partnership of Government, investors, local producers and large energy users will ultimately ensure the successful delivery of this vital new indigenous resource."

The Academy is highly supportive of plans to capture Biogas in Ireland. The industry will require significant Government support, and this appears to be forthcoming. However, the pace of development remains slow against the ambitious targets set for 2030. The Academy believes that, in terms of national energy security, it would not be prudent to rely on meeting the 2030 target given the highly dispersed nature of such a nascent industry and the requirement for significant private investment in more than 300 production facilities.

Biomethane is an attractive fuel as it could be burned directly in gas fired generation in 2030 and beyond with little or no plant modification.

4.8 Marine Energy

Over the past decade there has been considerable investment in new tidal and wave energy technologies. As of yet there is little to show for this effort.

Tidal power generation is not new, conventional hydro technology has been successfully applied to sites with suitable tidal conditions in several locations. Most recently major plans for a tidal plant at the mouth of the Severn river have been proposed.

However, the environmental impact of such plans is large and has roused considerable public opposition. Additionally, the economics of such plants do not appear favourable against the ever decreasing cost of wind and solar power.

Wave Energy has also been heavily researched over the past decade and would indeed be attractive in Ireland given the excellent wave energy regime off the west coast. The problem which has yet to be solved is the construction of conversion devices light enough to be economic and heavy enough to survive extreme storm energy levels.

Against the falling cost of wind and solar energy, it will require a huge technological breakthrough to make wave energy competitive. Such a breakthrough is not currently on the horizon.

Marine Energy will make little contribution to decarbonising the Irish power system by 2030. Considerable uncertainty remains over its long term financial feasibility.

16 https://www.gasnetworks.ie/vision-2050/future-of-gas/GNI_Vision_2050_Report_Final.pdf

4.9 Nuclear Power

In the middle of the last century, Nuclear power was held out as the long term answer to mankind's energy challenge. The industry has seen more than its fair share of ups and downs since then. Accidents at Three Mile Island, Chernobyl and Fukushima have led to much criticism of the technology from the wider public, particularly in the West. Additionally, ever increasing costs have tainted the financial cost benefit analyses essential to long term industry funding.

Following the Fukushima accident, Germany decided to abandon its nuclear industry even though it had consistently performed well. New construction in the United States slowed to a halt and large cost overruns at two major plants in Europe (Olkiluoto in Finland and Flammenville in France) discouraged new investment.

Japan is slowly returning its nuclear fleet to operation following the Fukushima incident while the UK is proceeding with major investment in large new nuclear plant. Hinkley Point C (2 X 1600 MW), using French technology (as at Flammenville) is under construction with a planned commissioning date of 2026 for the first unit.

The UK has indicated that it intends to proceed with further investment in Nuclear plant over the coming decade.

Outside Europe and the US, significant construction continues in China and, more recently, in middle Eastern countries. Today, approximately 10% of the world's electricity is produced from Nuclear power in more than 440 nuclear reactors.

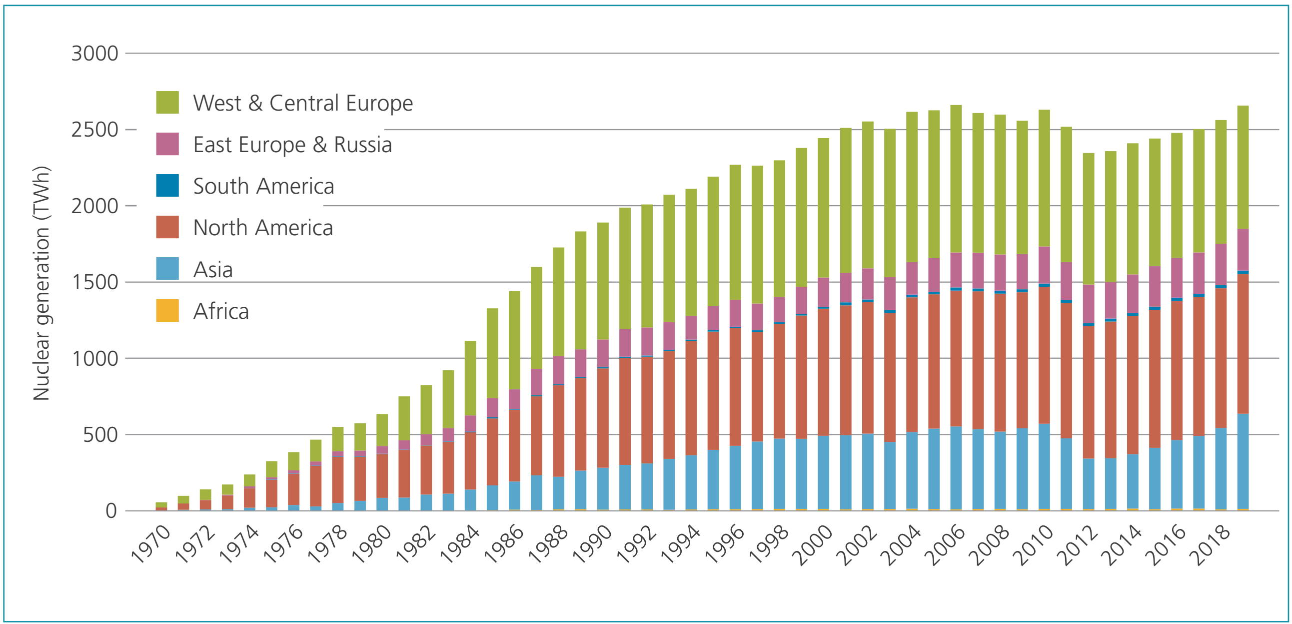


Fig 4.3 Global nuclear electricity production

Nuclear reactors produce more electricity in the world than all the solar, wind and geothermal plants combined.

At the start of 2020, 53 new nuclear reactors were under construction in the world. Eleven of these are in China but countries as diverse as Turkey, Bangladesh, and the UAE are actively investing in Nuclear plant.

In Ireland, there is little sign of social acceptance of nuclear power. Even if this were to change there is no possibility of the technology making any contribution to decarbonising the power industry prior to 2030.

Beyond 2030, it is possible that views on the social acceptability of nuclear may change and it is worth considering what the technology might contribute.

A recent study of the issue by the group "18 for 0" provides a reasonably clear view of how the industry might be integrated into the Irish power system in the long term.

Nuclear technology has been developing in two rather different streams in the recent past:

- Conventional plant has become ever larger in unit size (>1GW) in an attempt to reduce costs. This in turn has led to difficulty in integrating such large plants in anything other than exceptionally large power systems. Regulatory, construction and technological risks have soared; consequently, the plants have become ever more difficult to finance in the absence of a sovereign guarantee. This is very evident in the UK at the moment as the country progresses its new nuclear plant.
- An alternative approach starts from the premise that reactor size needs to reduce (100MW – 300MW) and become much more modular and capable of factory type manufacture rather than once off construction projects. Such Small Modular Reactors (SMRs) are currently in development by a number of companies with support from several Governments.

Despite the research efforts, only a limited number of such plants will be operational before 2030. There is, however, a high possibility of success with such plants in the longer term and certainly this could lead to a renaissance in the industry post 2030.

Such plants would make possible the complete decarbonisation of the Irish power system before 2050 and deserve consideration in the post 2030 period.

It will be for policymakers to persuade Irish citizens of the social acceptability of such technology.

CONCLUSIONS

- In order to maintain a reliable power network in 2030 with 70% renewables penetration, Ireland will require between 5000MW and 6000MW of gas turbine generation capacity.
- Ireland's natural gas supply is becoming ever more vulnerable to disruption as Corrib and North Sea production declines. The Academy believes that Ireland should move urgently to reinforce the security of its gas supplies. The construction of its own LNG terminal remains an attractive option in this context.
- Gas storage on a large scale would undoubtably assist in meeting reliability standards for Irish gas turbine power generation. The only suitable geological formation for such storage is at Islandmagee in Co. Antrim. Efforts have been underway over the last decade to permit and finance such storage. While the Academy is supportive of any efforts to create large scale gas storage on the Island of Ireland, it is mindful of the risks associated with such projects and is cautious about placing any reliance on the project in terms of strategic gas security pending further study, licensing and financing.
- There exists the possibility of reverting to oil firing (distillate) for Ireland's thermal generation fleet in 2030. Such a reversion would require considerable planning and investment in increased site storage and delivery logistics. It would also increase costs, significantly increase emissions from the combustion process and may be technically undesirable in the case of existing plant. The Academy believes that this would be a retrograde step in the transition to a decarbonised power system.
- The recent MaREI study indicates that Ireland will need to spend over €60Bn in funding its energy transition over the next decade. The Academy strongly suggests that these estimates are further refined and that the likely effects of these costs on consumers and taxpayers are established and communicated.
- Post 2030 a number of possible routes to decarbonisation may become available. Based on the current status of these new technologies the Academy comments as follows:
- Pumped Hydro solutions may be technically feasible and justifiable in certain instances, but at the scale required, are highly unlikely to be socially acceptable in Ireland.
- Compressed Air Energy Storage is highly unlikely to provide a solution to the intermittency problem given the early stage of the technology development and the limited geological storage formations in Ireland.
- Nuclear power will not make any contribution to managing the Irish Power System by 2030. Current European technologies require large scale (>1GW) installations for economic reasons. These plants are unlikely ever to be acceptable on the Irish system. The newer technologies –Small Modular Reactors, do however hold out much promise in the 2030 -2050 period. It is of course highly questionable as to whether these technologies would ever be socially acceptable in Ireland.
- Battery Storage will not provide an acceptable economic solution to intermittency prior to 2030 but may contribute in the following decades if costs reduce and battery life for high cycle equipment increases. In the shorter term battery installations will provide System Services and assist in maintaining system resilience.
- It will not be possible to dispense entirely with natural gas for power generation. The use of this gas in 2050 will require abatement of some kind in terms of its carbon emissions –most likely carbon capture and storage.
- Hydrogen is a much promoted technology at present but, in the Irish context, suffers from limited suitable geological storage. Its low level of conversion inefficiency is also a difficult hurdle. Bearing in mind the recent work of Gas Networks Ireland and the Energy Networks Association of the UK, Hydrogen will make little contribution to the Irish power system before 2030. After that Hydrogen will contribute, perhaps in the direct fuelling of gas turbines by 2050.
- Increased interconnection will aid in maintaining overall power system reliability. However, the contribution of increased interconnection to solving the system adequacy problem will be limited due to likely simultaneous shortages of renewable

generation in neighbouring countries experiencing similar weather conditions. Ireland will still require between 5000MW and 6000MW of gas turbine generating capacity for at least the next decade and probably for considerably longer.

- Biomethane has the potential to contribute to the decarbonisation of gas as a fuel in Ireland given the relative size of the Irish agricultural industry. The Academy supports the plans currently being promoted to develop a new Biomethane industry. Given the scale of the task however, the Academy believes that there is a high risk that targets set for 2030 will not be achieved and other measures will have to be considered in the meantime to ensure the security of Irish gas supplies.
- Marine Energy will not make any contribution to managing the Irish power system before 2030 because the technologies do not currently exist at any level of scale and are not financeable. It will require a significant technical breakthrough before such technologies might be considered as applicable in the Irish context. At present there is no indication of such a breakthrough on the horizon.

APPENDIX 1

Recent Studies

Studies of particular relevance are:

1. Net Zero Europe[17]. McKinsey and Company. November 2020
2. Accelerating Decarbonisation of the US Energy System[18] US Academy of Sciences, Engineering and Medicine February 2021
3. Our Zero Mission Future[19]. Published by MaREI and The Electricity Association of Ireland. November 2020
4. GCS 2020. All-Island Generation Capacity Statement 2020 – 2029[20] published by EirGrid & SONI. August 2020

The McKinsey report is a wide ranging and high level examination of the pathway to climate neutrality in the EU by 2050. It does not specifically focus on the power sector but does deal with the EU wide issues relating to electricity production and transmission. Taking BREXIT into account, it specifically excludes the UK.

The US report provides a rigorous analysis of the current situation and the measures likely to be necessary to decarbonise the US economy by 2050. It shows a considerable understanding of the uncertainties and risks inherent in any current plans and stresses the requirement for a "social contract" if the public are to be supportive over three decades.

The report published by MaREI examines the Irish power system within a European context, paying particular attention to resilience issues as the percentage of renewables increases on the system. It does consider adequacy issues within a particular "low-wind" scenario. However, it does not "derate" interconnectors to the extent that GCS2020 does.

The EirGrid/SONI report estimates future demand growth in Ireland and suggests a likely portfolio of generating plant to meet this demand, achieve 70% renewables penetration and maintain adequacy standards. It does not consider resilience issues. It is very much a bottom up approach and takes account of current and future interconnection. The report "derates" the capacity of certain generators and interconnectors based on experience.

The Academy looks forward to many more detailed studies which will be required as Ireland plans for long term climate neutrality. Important lessons are already emerging and are the focus of this report.

17 https://www.mckinsey.com/~/media/McKinsey/Business%20Functions/Sustainability/Our%20Insights/How%20the%20European%20Union%20could%20achieve%20net%20zero%20emissions%20at%20net%20zero%20cost/Net-zero-Europe-vF.pdf?shouldIndex=false
18 https://www.nap.edu/download/25932
19 https://eaireland.com/wp-content/uploads/2020/11/Our-Zero-e-Mission-Future-Report.pdf
20 https://www.eirgridgroup.com/site-files/library/EirGrid/All-Island-Generation-Capacity-Statement-2020-2029.pdf

APPENDIX 2

Generation Fuel Changes 2020-2026

The following table shows the projected mix of existing, dispatchable, plant that is expected to be connected to the electricity systems in Ireland and Northern Ireland by 2026.

Energy Source	Ireland MW	Northern Ireland MW	Total MW
Gas/Distillate Oil	3663	1001	4664
Gas		12	12
Distillate Oil	324	399	723
Waste	78		78
Biomass		18	18
Hydro/Pumped Storage	508		508
Interconnection	500	450	950
Demand Side Units	571	135	706
Total	**5644**	**2015**	**7659**
% Gas Fired	65	50	61

The energy source mix in this table can be contrasted with the mix in the plant retired, by 2026, shown in the following table

Energy Source	Ireland MW	Northern Ireland MW	Total MW
Gas/Distillate Oil	90		90
Peat/Biomass	118		118
Peat	228		228
Coal/Heavy Fuel Oil	855	476	1331
Heavy Fuel Oil	590		590
Total	**1881**	**476**	**2357**
% Gas Fired	5	0	4

From the above it is evident that there will be a very substantial loss of energy source diversity amongst dispatchable plant in the next five years and a correspondingly increased dependence on gas fired generation, with distillate oil as a standby fuel. The table understates the potential dependence on gas/distillate oil and purely distillate oil fired plants as the Capacity Auction results indicate that future generating plant additions will predominantly be open cycle gas turbines, powered by these fuels.

Annual gas demand is projected to fall, with the extent of the fall being determined by the minimum number of synchronous generating units which system operators consider have to be connected to the system at all times, for secure system operations. The MaREI report estimates that annual gas consumption in 2030 will be approximately 80% of today's value. In contrast peak gas demand, in periods of low wind speed will certainly increase substantially if a high reliance on distillate fired generation is to be avoided, to minimise both emissions and energy import costs.

APPENDIX 3

Definitions

Adequacy may be defined as:

> The ability of the power system to supply the aggregate electrical demand and energy requirements of the end-use customers at all times, considering scheduled and reasonably expected unscheduled outages of system elements.

Adequacy analysis looks at the performance of the system over a reasonable time period and, particularly, the probability that it will supply the peak demand in that timeframe.

Resilience may be defined as:

> The ability of the power system to operate through and recover from high-impact, low-probability (HILP) events.

Resilience analysis looks at the response of the system, often in the sub second timeframe, to disruptive events such as the sudden loss of a system component. Systems with large amounts of synchronous generation are inherently more resilient than those with large amounts of non-synchronous generation.

Synchronous v Non-Synchronous Generation

At the turn of the last century a famous "War of Currents" was fought between Tomas Edison who supported an electricity industry based on Direct Current technology (DC) and Nikolai Tesla who supported Alternating Current technology (AC). Tesla won since AC offered technical and cost advantages that DC could not provide. For over 100 years all large power systems have been dominated by AC technology.

AC systems facilitate the transformation of electricity to higher voltages thus reducing transmission losses and, more subtly, provide for the synchronisation of all generators across the power system. These generators effectively operate in total lockstep and maintain the stability of the system in the face of any sudden disruptions. The power system is said to have considerable "inertia" as a result of operating in a synchronous mode.

Over the past 50 years, power electronic technology has evolved to such a degree that current and voltage can now be controlled by large banks of electronic components. Such applications were first introduced in high voltage DC interconnectors operating between entirely separate systems not synchronised with one another. These were able to exchange power over DC links subject to ever more complex electronic and software control.

Solar panels generate DC power, and, for efficiency reasons, most modern wind turbines also generate using DC (actually variable AC converted to DC). This is then converted to AC using electronic control and synchronised with the power grid. Unfortunately, this approach cannot easily reproduce the "inertia" effects of the traditional AC power system and renewable generators therefore do not contribute to the stability of the system.

System Non-Synchronous Penetration (SNSP)

Small amounts of non-synchronous generation are not a problem on the power system. As renewable generation increases however System Operators have to consider the System Non-Synchronous Penetration (SNSP) and adopt measures to ensure stability.

SNSP = (DC Generation+ HVDC Imports) ÷ (System Demand + HVDC Exports)

Increasing SNSP increases the risk of system instability and complex measures are required to manage it. At present this issue is managed mainly by maintaining a certain minimum amount of synchronous generation on the power system at all times.

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