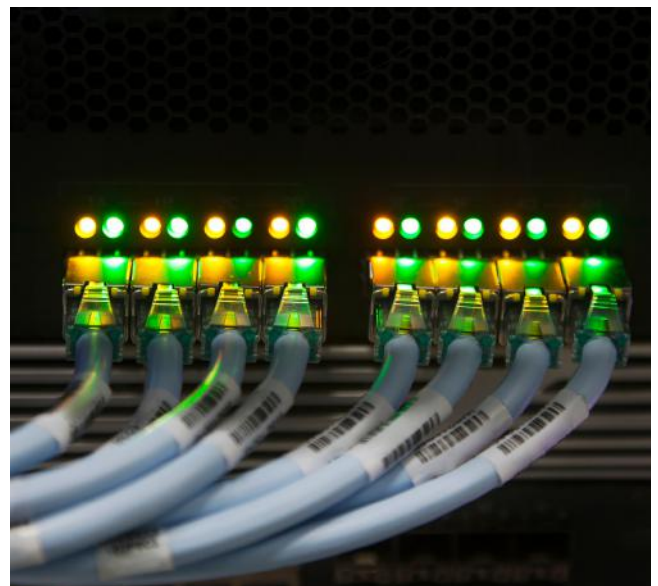


# NUCLEAR ENERGY DEVELOPMENT IN IRELAND

PRELIMINARY STUDY



## About 18 for 0

18 for 0 is a voluntary group of professionals concerned about the credibility of current proposals to achieve net zero emissions in Ireland by 2050.

Ireland must implement a wider range of options than is outlined in the current Climate Action Plan in order to achieve the required carbon emissions reductions in an affordable and environmentally responsible manner that also retains stability and security in the electricity grid. We aim to present the environmental and economic case for modern nuclear energy to a wider Irish audience and to outline Ireland's capability to operate a robust nuclear power programme.



***Starting a national conversation about the future of Irish electricity production and the potential role nuclear power may play***

Preliminary Study: Nuclear Energy Development in Ireland  
December 2020

Produced by: 18for0  
[www.18for0.ie](http://www.18for0.ie)

The findings, interpretations, views, and conclusions expressed in this study are those of the authors and do not purport to reflect the official policy or position of any other agency, organization, employer or company.

## Overview

Achieving an affordable and reliable net-zero carbon emissions energy system is one of the most critical challenges of our time. Ireland must reduce emissions in the current transport, heat, and electricity sectors, while meeting the growing energy demands<sup>1</sup> of existing users, data centres and other energy-intensive industry. To meet this challenge, all available technologies, and their potential role in our future energy system, must be assessed urgently.

A key element in Ireland's current emission reduction strategy is to decarbonise electricity generation using renewable energy and natural gas, and to increasingly electrify heat and transport. Even if Ireland can overcome the many technical, social, environmental and economic challenges and successfully implement that strategy, it will not achieve a net-zero emissions power sector despite its significant capital cost, largely due to the high carbon emissions of natural gas plants. Ireland will also continue to rely on imports of fossil fuels (natural gas).

Nuclear power offers a promising solution to the challenge outlined above and yet is not currently being considered by the Government of Ireland as an option for electricity generation. Nuclear power generation is an ultra low-carbon emission source that has provided safe, secure electricity for over 60 years and in more than 30 countries. Heat and hydrogen produced in nuclear power stations is also capable of decarbonising other energy sectors where emission reduction is more challenging.

Considering the significant appetite for change that Ireland has demonstrated in recent years, and the strong support of the Citizens' Assembly for the transformational changes required for us to become a net-zero emissions economy and society, it is appropriate now to take a fresh look at nuclear energy.

This document is a preliminary analysis of the main factors that must be considered prior to the establishment of a nuclear energy programme in Ireland and is intended to act as a springboard for a national conversation about the future of Irish electricity production. The implications of current energy strategy and the potential role nuclear power could play in providing clean, safe and secure energy are discussed. The analysis was conducted using guidance provided by the International Atomic Energy Agency (IAEA) for countries beginning to consider nuclear energy development.

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<sup>1</sup><https://dbe.gov.ie/en/Publications/Publication-files/Government-Statement-Data-Centres-Enterprise-Strategy.pdf>

## Key findings

- The current national strategy for power generation is not sufficient to keep Ireland on a pathway to become a net zero emissions society - innovative change to current energy policy is urgently required
- No technology that is currently permitted in Ireland is commercially available at the scale required to fully decarbonise the power sector by 2050 - legislative change is also required
- Integrating 18% nuclear energy could decarbonise Ireland's power sector by 2037, with the remaining power being supplied predominantly by renewable energy.
- A hybrid electricity system powered mainly by renewable and nuclear energy is likely to be significantly superior to one that prioritises renewables alone, as it would offer:
  - ✓ Lower emissions
  - ✓ Lower cost of electricity and capital cost
  - ✓ Lower use of limited resources (land and materials)
  - ✓ A more reliable and stable power supply
  - ✓ Less reliance on imported fossil fuels (natural gas)
- Replacing fossil fuel power stations with nuclear energy, where suitable, would enable a just transition for energy workers and optimise use of existing grid infrastructure.
- There is a strong economic case for nuclear energy in Ireland, which indicates good prospects for private or public financing, particularly for small modular reactors (SMRs).
- A power development programme that includes 18% nuclear would support the case for the interconnection and energy storage infrastructure being planned for 2030.
- Ireland already has much of the technical capability to develop a robust nuclear energy programme, and additional human resources could be acquired through recruiting and training national and international personnel.
- An 18% nuclear power programme in Ireland could directly provide 1300 high-skilled, long-term domestic jobs, in addition to approximately 4000 ancillary jobs. This would present an excellent opportunity to continue the post COVID-19 economic recovery
- Ireland's membership of the single European market for nuclear materials and technology ensures a secure supply of nuclear fuel and facilitates investment, R&D, sharing of expertise, safeguard activities and disposal of nuclear waste.
- Well-established technical solutions would facilitate interim storage of nuclear waste in Ireland and its long-term disposal either here or abroad. Innovative technical solutions currently in development present further opportunities in this regard.
- Amending the Acts currently impeding nuclear power generation in Ireland is likely to be legislatively straightforward.
- Ireland is well positioned to establish the legal and regulatory framework necessary for a successful nuclear power programme, including an independent nuclear regulator.
- Nuclear power development can help to reach the objectives of the Irish Climate Action Plan, the National Planning Framework, and Ireland's performance indicators for the UN Sustainable Development Goals 7 and 13.

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## Introduction

This preliminary study was prompted by concerns that Ireland’s power generation sector is not being placed on a sufficiently robust path towards net zero emissions electricity. To initiate a national conversation about this topic, the study assesses two of the most important aspects for Ireland to consider where nuclear energy is concerned; is nuclear energy needed here and, if so, could Ireland implement a successful nuclear energy programme?

A successful nuclear power programme requires extensive preparatory work, including the development of a national position and infrastructure. The first step is to determine whether or not a nuclear power programme will be beneficial, safe, secure, peaceful, and sustainable for the nation. The International Atomic Energy Agency (IAEA) has laid out the activities to be completed to prepare the necessary infrastructure in accordance with their Milestones Approach<sup>2</sup>. That industry-standard document lists the three phases in nuclear programme development as:

**Phase 1:** Before a decision is taken to launch a nuclear power programme, a Pre-Feasibility Study will help a country establish a strong national position and answer the key question: why nuclear? This process begins early in Phase 1 after nuclear power is included as an option in the energy strategy.

**Phase 2:** Preparatory work for the contracting and construction of a nuclear power plant after a policy decision has been taken; in this phase, key organizations as well as the legal and regulatory frameworks are established.

**Phase 3:** Activities to contract, licence and construct the first nuclear power plant are undertaken.

The IAEA Milestones Approach outlines 19 nuclear infrastructure issues requiring particular attention in each of the phases.



For expediency at this very early stage of Phase 1, we address 12 infrastructure issues that are pertinent to assessing whether nuclear energy is suitable for Ireland. By the end of Phase 1, a comprehensive pre-feasibility study should have been completed by a nuclear energy programme implementing organisation, addressing all 19 infrastructure issues.

<sup>2</sup><https://www.iaea.org/publications/10873/milestones-in-the-development-of-a-national-infrastructure-for-nuclear-power>

## Nuclear technology review

Although this preliminary study is largely applicable to any modern commercial nuclear power technology, certain sections were best addressed by considering more specific technologies. In order to address these sections, a technology review was conducted using a high-level overview of the main features of an existing modern reactor and some of the leading designs of small modular reactors (SMRs) available for near-term deployment. The technology review can be accessed in Appendix A.

This section provides a summary of the key points, and determines the technologies considered throughout this document.

The four smaller reactors assessed are currently under development. They have outputs of 300 MW or less and may be built independently or as modules in a larger complex, with capacity added incrementally as required. They are:

- NuScale pressurised water reactor; design certification was approved in the USA in 2020
- GE-Hitachi boiling water reactor; undergoing licensing in the USA and Canada
- Terrestrial Energy integrated molten salt reactor; being licensed in Canada
- Moltex molten salt reactor; at an early stage of licensing in Canada.

The Westinghouse AP1000 an American designed reactor that has already been commercially deployed. Four units with an output of 1150 MW are already operating in China and two more are nearing completion in the USA. A power plant of this size would operate most effectively if used in conjunction with dedicated interconnector capacity.

Preliminary results indicate that the NuScale and GE-Hitachi reactors are the most likely to be capable of providing cost-effective, clean energy in Ireland from as early as 2030, while the Terrestrial Energy and Moltex Technologies could be available by the mid-2030s. The Westinghouse unit was also found to be effective at reducing emissions, although it may be less favourable than the smaller reactors regarding its economics and it has a greater interconnection requirement.

# 1. National Position

Ireland has no clearly stated national position on the development of a nuclear power programme. Typically, such a national position is established by the end of Phase 1 of the International Atomic Energy Agency (IAEA) Milestones Approach as part of a deliberative technical and political process, and provides a credible answer to why nuclear power is or is not being chosen.

A national position is formed of four distinctive elements:

- National policy development
- Energy analysis and planning
- Pre-feasibility study
- Engaging the public and relevant stakeholders

The first element, national policy development, can begin to be addressed at this very early stage of the first phase of the milestones approach. This is informed by existing energy planning and includes the potential role of nuclear power in accomplishing development goals, and in adhering to national commitments.

In this section, important national positions and commitments regarding environmental protection and sustainable development are considered in the context of the development of a nuclear programme.

## Climate Action Plan 2019

Ireland's commitments to meet ambitious greenhouse gas (GHG) emissions reduction targets have been missed by a large margin<sup>3</sup>. National GHG emissions in 2018, for example, were higher than in 2013, the start of the accounting period for our current EU binding commitment.

The Irish Government's Climate Action Plan 2019<sup>4</sup> (CAP19) sets out an ambitious course of action to address the climate disruption that it says "is already having diverse and wide-ranging impacts on Ireland's environment, society, economic and natural resources". It initiates policy actions to 2030 and aims to define a roadmap consistent with achieving a net zero carbon energy system by 2050.

The main features of CAP19 for power generation in 2030, compared to 2020, include:

- renewable electricity supply increase from 30% to 70%
- renewable capacity increase from 4,500 MW to around 13,500 MW
- all coal, peat and oil fired power stations to close
- hydro pumped storage plant increase from 290 MW to 650 MW
- battery storage plant increased to 1,700 MW
- interconnection increase from 500 MW to 1,700 MW, and
- greenhouse gas emissions fall from around 10.3 million tons to 4 - 5 million tons.

Full implementation of CAP19 for power generation by 2030 is described as a significant challenge by EirGrid, partially because the electricity grid must be enhanced to remain stable while being supplied by over 95% non-synchronous generation for extended periods.

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<sup>3</sup><http://www.epa.ie/ghg/currentsituation/> Total ESD Emissions: 45Mt (2018) versus 42.2Mt (2013)

<sup>4</sup><https://www.dccae.gov.ie/documents/Climate%20Action%20Plan%202019.pdf>



CAP19 contains no specific policy statement on how to keep annual power sector emissions on an emissions reduction pathway beyond 2030. Once the power plant identified in CAP19 is developed, installing more such plant is unlikely to achieve significant additional emissions reduction benefits.

Potential options beyond 2030 include using surplus renewable energy to produce biofuels, synthetic gas, hydrogen or a 'Power-to-x' technology, although these have not yet been proven at scale and their commerciality for power generation is still uncertain. CAP19 also established a steering group to examine the feasibility of using carbon capture and storage (CCS) in Ireland, another technology whose commerciality and availability is uncertain.

If none of these technologies become commercially available at scale within a reasonably short timeframe, there will be no policy-compliant technology that allows us to continue beyond 2030 on a path to net zero emissions electricity. Therefore, it is entirely consistent with our environmental commitments to assess the potential of nuclear energy - a proven, low-emissions technology - to assist in reaching our environmental targets.

## **National Policy Position: Nuclear Safety and Radiation Protection**

The National Policy Position for Nuclear Safety and Radiation Protection outlines the current general policy position of Ireland in relation to nuclear safety and radiation protection. It was developed in line with scientific evidence and our commitments as a member of the EU and other international organisations, including the IAEA, Euratom, and OECD Nuclear Energy Agency (NEA).

Although the paper doesn't define an Irish position on the domestic development of nuclear energy, it states that a change in energy policy to include nuclear power should be informed by factors including public health and safety, environmental protection and security, and waste management.

The National Policy paper maintains that "it is worth noting" that the Minister for Communications, Energy and Natural Resources "stated that any discussion on the future of Ireland's energy supply must include consideration of the nuclear option."<sup>5</sup>

## **National Planning Framework**

The National Planning Framework<sup>6</sup> (NPF) is the government's high-level strategic plan for shaping the future growth and development of Ireland to 2040. It draws from the National Climate Policy Position, citing "the national objective of achieving transition to a competitive, low carbon, climate-resilient and environmentally sustainable economy by 2050." Many of the 9 National Strategic Outcomes outlined in the framework would support the development of nuclear energy in Ireland, a measure that would directly address Outcome 8 – the transition to a low carbon and climate resilient society.

The NPF defines the three pillars of Ireland's national energy policy as (1) sustainability, (2) security of supply and (3) competitiveness. It states that "in planning Ireland's future energy landscape and in transitioning to a low carbon economy, the ability to diversify and adapt to new energy technologies is essential." This is a strong mandate to formally investigate nuclear power as a low carbon energy technology, based on its sustainability, positive impact on security of supply, and competitiveness.

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<sup>5</sup><https://www.dccae.gov.ie/en-ie/environment/publications/Pages/National-Policy-Position-for-Nuclear-Safety-and-Radiation-Protection.aspx>

<sup>6</sup><https://www.gov.ie/en/publication/774346-project-ireland-2040-national-planning-framework/>

## Sustainable Development Goals

Sustainable development meets the needs of the present without compromising the ability of future generations to meet their own needs. The UN developed the 17 interconnected Sustainable Development Goals (SDGs) to sustainably address the challenges faced globally to 2030. Ireland played a significant role in the development of the SDGs, and has demonstrated commitment to their fulfilment through the most recent Irish Sustainable Development Goals National Implementation Plan from 2018<sup>7</sup>, formally establishing national policy, governance mechanisms, and stakeholders.



The National Planning Framework reinforced the importance of these goals in Irish development, stating “There is significant alignment between the UN SDGs and the National Planning Framework’s National Strategic Outcomes (NSOs) in areas such as climate action, clean energy...”.

Of particular relevance are our commitments to SDG7: Ensure access to affordable, reliable, sustainable and modern energy for all; and SDG 13: Take urgent action to combat climate change and its impacts. A 2018 government review of the national performance in reaching these goals indicated poor performance from Ireland with respect to SDG 13, projecting that Ireland would not meet EU 2020 emissions reduction targets. In relation to SDG 7, it noted that Ireland’s current dependence on fossil fuel imports is expensive and environmentally unsustainable, contributing to insecurity – and mentioned Ireland’s plan to develop a coordinated energy security policy encouraging the diversification of energy supplies.

However, the report also stated that a low carbon future will ultimately involve moving away from fossil fuels altogether<sup>8</sup>, without providing any examples of viable alternatives to fossil fuels. It is notable that Coalition 2030’s 2018<sup>9</sup> report cited lack of political will and concrete plans as a major hurdle to achieving SDG 7.

<sup>7</sup><https://www.gov.ie/en/publication/7cde9f-the-sustainable-development-goals-national-implementation-plan-2018-/>

<sup>8</sup><https://www.gov.ie/en/publication/98a1f5-ireland-voluntary-national-review-2018/>

<sup>9</sup><https://www.ireland2030.org/report-2018>

## 2. Funding and Financing

The funding of a nuclear power project refers to the government funding required to establish and maintain the necessary infrastructure, including a regulatory body and legal framework. The financing of a nuclear power project is typically the responsibility of the operating body.

A fundamental step in the determination of the funding and financing of a power sector development project is an assessment of the project's base economic sense in a national context. Funding and financing mechanisms are more likely to be accessible if a positive economic case exists for including nuclear energy in a decarbonised electricity system by 2050. A basic economic assessment is presented in Appendix B, and is summarised below.

Note that the EU is currently conducting research into market mechanisms to best achieve a net zero carbon society. A discussion of this important topic can be found in Appendix C.

Traditionally, most nuclear energy projects have been developed by State agencies or well-capitalised utilities due to the traditionally large size and capital costs of such projects. In the past decade, nuclear plant designers have prioritised the operational effectiveness of their products and their ability to prosper in electricity systems that are increasingly dominated by intermittent and non-synchronous power plant. Of particular note are Small Modular Reactors (SMRs), whose simplicity, size and comparatively low capital costs are attractive to private operators worldwide.

The economic assessment<sup>10</sup>, presented in detail in Appendix B, assesses the basic economics of the Irish electricity system from 2030 to 2050, assuming CAP19 has been fully implemented by 2030, under two strategies:

### **Strategy 1: Extending CAP19**

This is the current default position, in which renewables account for all of the growth in power plant using the range of technologies suggested in CAP19 for adoption in Ireland by 2030. Storage and interconnection expands as predicted by EirGrid for 2040 but natural gas capacity is retained at 2030 levels.

### **Strategy 2: Including Nuclear**

Nuclear energy directly replaces fossil fuel plant after 2030 in this strategy. Renewables are retained at near-2030 levels and include dispatchable renewables that are assumed to have the same characteristics as small nuclear plants. If dispatchable renewables are not commercially available when required, additional nuclear or other low carbon technology is used instead. Storage and interconnection expands as in Strategy 1.

As our technology review identified the GE-Hitachi X-300 SMR as one of the reactors most likely to be commercially available by 2030, and GE-Hitachi is an experienced supplier of high-quality equipment in most aspects of nuclear engineering, the GE-Hitachi X-300 SMR is the test case for this economic study.

The assessment consists of 3 primary elements:

- 1) Impact on the total cost of producing electricity – affordability for the customer
- 2) Impact on the capital cost of the power plant – affordability for the industry
- 3) Impact on emissions and renewables targets – compliance with EU obligations

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<sup>10</sup> The economic case is compiled from data from CAP19, EirGrid, Irish Wind Energy Association and industry, in that order of priority

### Assessment of the 3 primary impacts

1) Fully implementing CAP19 increases the production cost<sup>11</sup> of electricity considerably to €112 / MWh in 2030, as shown in Table 1. Note that CAP19 doesn't indicate how the power sector will develop beyond 2030. Indeed, no technology is currently available and permitted in Ireland that can enable us to achieve net zero emissions by 2050, as discussed in Section 1 National Position.

Table 1 Production cost of electricity by extending CAP19 or including nuclear

		CAP19		Extending CAP19		Including nuclear	
		2020	2030	2040	2050	2040	2050
Production cost	€/MWh	65	112	104	98	97	85

Simply extending CAP19 policy actions beyond 2030 in Strategy 1 would reduce this production cost to €98 / MWh by 2050 whereas the strategy that includes nuclear would reduce it to €85 / MWh – indicating potential for significant economic benefit for the customer by introducing SMRs.

The cumulative production cost of electricity from 2030 to 2050 is estimated to be over€6 billion less in the strategy that includes nuclear compared to simply extending CAP19.

Although not included in this assessment, SMRs are likely to also earn significant income from the provision of essential system services which would reduce overall system operating costs and further lower the wholesale market cost of electricity. This is explained in more detail in Chapter 3 Electrical Grid.

2) The capital cost of the new renewable and gas-fired power plant required to implement CAP19 is over €23 billion by 2030. Simply extending CAP19 policy actions beyond 2030 would incur additional capital costs of €21.2 billion by 2050, as shown in Table 2. Including nuclear power would reduce these additional costs to €1.9 billion, indicating a saving in capital cost of €2.3 billion.

Table 2 Power plant capital costs per decade to 2050

		CAP19	Extending CAP19		Including nuclear	
		2030	2040	2050	2040	2050
Capital cost	€ billion / 10 yrs	23.3	9.5	11.8	9.4	9.5

These estimates exclude system costs, which are the total costs accrued beyond the perimeter of power plants to supply electricity. Variable renewables cause a number of additional system costs, including from increased outlays for distribution and transmission, balancing costs, and the cost of back-up generation. System costs for low-carbon energy systems are significantly smaller when nuclear energy is included in the mix alongside variable renewables<sup>12</sup>. This means these costs, which are ultimately paid for by the consumer, are likely to be significantly lower for the strategy including nuclear.

<sup>11</sup> Production cost is the annual revenue earned by all generators based on their LCOE divided by the annual national electricity demand

<sup>12</sup> NEA (2019), The Costs of Decarbonisation: System Costs with High Shares of Nuclear and Renewables, OECD Publishing, Paris.

This indicates that there could be increased affordability for the industry by introducing SMRs. Their capital outlay is at a level that is attractive to private investment, particularly when the plant is designed, operated or overseen by organisations with excellent records in their fields.

**3)** Fully implementing CAP19 would reduce annual emissions to 4.9 Million tons by 2030, as shown in Table 3. Simply extending CAP19 policy actions beyond 2030 would keep annual emissions from the electricity sector at around this level until 2050, which is significantly above the level required for a net zero emissions energy system. Emissions stay high because the increase in renewables, interconnection and storage is not enough to satisfy the higher demand for electricity in 2050, and the shortfall is made up by gas turbines that operate in a less efficient mode than currently.

Introducing nuclear would reduce annual emissions to 0.9 Million tons by 2050, predominantly from Combined Heat and Power plants and waste incineration. Thus would place Ireland firmly on a path to a net zero emissions energy system.

Getting electricity to net zero or net negative emissions will most likely require some form of carbon removal system that has yet to be commercially developed at scale. The direct storage of carbon dioxide gas is currently not permitted<sup>13</sup> in Ireland, although CCS is currently being assessed by a steering group established by CAP19.

Table 3 Emissions and renewables impacts of the two scenarios

		CAP19		Extending CAP19		Including nuclear	
		2020	2030	2040	2050	2040	2050
Renewables supply		39%	68%	71%	76%	67%	69%
Emissions intensity	kg CO <sub>2</sub> /MWh	334	112	109	100	19	17
Annual Emissions	M tons CO <sub>2</sub>	10.9	4.9	5.3	5.3	0.9	0.9

The electricity produced by renewables increases to 76% by 2050 by extending CAP19, whereas it remains reasonably steady at 69% in the case including nuclear generation. This suggests no impediment to meeting our relevant EU obligations, as nuclear energy ensures significant emissions reduction improvement while maintaining high renewable electricity production.

This initial economic assessment indicates that introducing nuclear power to Ireland can improve affordability for both the customer and the industry, while remaining consistent with EU emissions and renewable energy obligations. This suggests a strong economic case to underpin funding and financing of a nuclear energy programme in Ireland, particularly where SMRs are concerned.

<sup>13</sup> <http://www.irishstatutebook.ie/eli/2011/si/575/made/en/print>

### 3. Electrical Grid

Ireland’s electricity transmission grid is a network of 400 kV, 275 kV, 220 kV and 110 kV high voltage lines and cables which, together with the grid in Northern Ireland, is operated on an all-island basis by EirGrid Group. While the grid is adequate for its current needs, it is undergoing significant change so that renewables can supply 70% of electricity demand by 2030.

Ireland has a high voltage alternating current (HVAC) interconnector with Northern Ireland while a second under construction would increase internal interconnection to 1,100 MW. There is a high voltage direct current (HVDC) interconnection with Great Britain and another in planning, while the first HVDC interconnection to continental Europe is also in planning. The EU has a 2030 interconnection target capacity for Ireland of 15% of our electricity production.

Electricity demand is expected to grow by 50% by 2040 and micro generators, autoproducers and smart metering may alter the load profile somewhat.

The total installed power plant capacity is projected to more than double by 2040, the majority of which may be non-synchronous generators - 60% renewables and 20% interconnection and energy storage. Most of the synchronous generation after 2025 will be from fossil fuel gas turbines. The graph below summarises the projected capacity growth under two different scenarios as described in detail in Appendix B.

### Projected growth in generating capacity

Strategy 1 extends CAP19; Strategy 2 replaces fossil fuels with nuclear

■ Renewables ■ Fossils ■ Interconnection & Others ■ Nuclear

2020 start of Climate Action Plan



2030 after Climate Action Plan



2040 under Strategy 1



2050 under Strategy 1



2040 under Strategy 2



2050 under Strategy 2



Chart: 18for0 • Source: CAP19, EirGrid & 18for0 • Created with Datawrapper



## Challenge integrating non-synchronous generation

EirGrid is attempting to increase the instantaneous system non-synchronous penetration (SNSP) limit from 65% to over 95% by 2030 to facilitate national renewable energy targets, and this will require vastly enhanced system services to ensure dynamic system stability.

EirGrid expects<sup>14</sup> that the grid operating regime envisaged for 2030 and beyond will present a significant extra challenge to incorporating the low emissions, dispatchable capacity that will be required if emissions from power generation are to continue to reduce in the decade up to 2040.

Non-synchronous generation, including wind, solar and HVDC interconnection, provide none of the inertia currently needed to keep grid frequency stable and to resist sudden changes due to faults or transients. Research is still ongoing into whether and how the grid can remain stable and reliable in the total absence of inertia that is currently provided by large synchronous generators.

## Nuclear energy in Ireland's grid

A system stability study would be required equally for nuclear power plants as for the carbon capture and storage (CCS) plants that are being examined for deployment after 2030.

The nuclear power plants in this study are all steam-driven and provide more inertia than open cycle gas turbines of similar output, including gas turbines in a CCS plant. SMRs tend to be smaller and would be better suited to Ireland's electrical grid than CCS plants or the fossil fuel power plant that SMRs would replace in Strategy 2: Including Nuclear in Appendix B.

The largest plant in our study, at 1150 MW, would probably become the largest single infeed on the system and could present grid stability challenges, although the minimum all-island electricity power reserve will increase<sup>15</sup> to around 525 MW by 2030 if planned interconnection projects materialise. Potential solutions, including hybrid energy systems, energy storage and Grid Constraints, are discussed briefly in Appendix D Additional electrical grid information

SMRs could greatly benefit system security in the 2030 grid as they are small, dispatchable generators that offer fuel diversity and provision of essential system services - including inertia, fault ride-through and reactive power - coupled with flexible energy storage capability.

## Grid Code and connection conditions

All nuclear power plants assessed in the technology review in Appendix A are likely to satisfy the Grid Code and most connection conditions. Modern nuclear reactors are designed for flexibility in generator output and can also supply essential system services, including inertia, fault ride-through and reactive power. Derogation may be required from connection condition CC 7.3.1.1 (s) Time to Synchronise from Instruction.

While there is no secondary fuel provision for nuclear powered generators, this is not expected to be a critical issue as nuclear fuel would itself be a new alternative fuel source for the power system and many years' supply can easily be stored on site, thus ensuring its long-term availability.

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<sup>14</sup> p73 <http://www.eirgridgroup.com/site-files/library/EirGrid/EirGrid-TES-2019-Report.pdf>

<sup>15</sup>The Irish system requires operating reserves amounting to 75% of its largest single infeed for system stability reasons. The planned 700MW Celtic Interconnector would increase this requirement to 525MW. [http://www.eirgridgroup.com/site-files/library/EirGrid/OperationalConstraintsUpdateVersion1\\_93\\_Apr\\_2020.pdf](http://www.eirgridgroup.com/site-files/library/EirGrid/OperationalConstraintsUpdateVersion1_93_Apr_2020.pdf)

## 4. Site and supporting facilities

There are two processes<sup>16</sup> relating to the safety considerations for the site of a nuclear installation — the siting process and the site evaluation process. These processes consist of five stages:

- Site survey stage;
- Site selection stage;
- Site characterization stage (site verification and site confirmation);
- Pre-operational stage;
- Operational stage.

The siting process for a nuclear installation consists of the first two stages of these five, i.e. site survey and site selection. In the site survey stage, large regions are investigated to find potential sites and to identify one or more candidate sites. In the site selection stage, the characteristics of candidate sites are assessed and compared with each other to determine the preferred candidate sites.

Site characteristics important to siting include the likelihood of external natural hazards, feasibility of emergency plans, economics, topography, grid access, transport infrastructure, and availability of any required cooling water.

Public acceptance of nuclear power is a crucial element of any nuclear power development plans. Lessons can be learned from other countries in relation to their experiences of siting nuclear facilities. A UK DECC study<sup>17</sup>, for example, found that “increasing community participation and empowerment in siting processes builds trust between community stakeholders and siting authorities and can improve siting outcomes”.

The site selection process must engage in a transboundary public consultation, as part of the environmental impact assessment of a proposed development.

Previous work by ESB in the 1970s identified five sites in Ireland as being suitable to site a nuclear power station. A new survey could potentially assess these sites as suitable for a modern nuclear power station as a starting point, and would also identify alternative suitable sites.

At present, all coal and peat plants, and several gas plants are scheduled to close before 2030. These sites and their surroundings should be explored as areas for development, tapping into existing local engineering skill sets and an existing grid infrastructure.

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<sup>16</sup> [https://www-pub.iaea.org/MTCD/Publications/PDF/P1837\\_web.pdf](https://www-pub.iaea.org/MTCD/Publications/PDF/P1837_web.pdf)

<sup>17</sup> “Working with communities Geological Disposal” - Literature Review Department of Energy and Climate Change April 2016  
[https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment\\_data/file/637265/gdf-working-with-communities-literature-review.pdf](https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/637265/gdf-working-with-communities-literature-review.pdf)

## 5. Human resource development

Workforce refers to all personnel involved in a potential nuclear power programme. Workforce planning is the systematic identification and analysis of the size, type and quality of workforce required for such a programme. This planning determines the expected mix of necessary experience and competencies, and identifies the steps that should be taken to get the right number of the right people in the right place at the right time.

The International Atomic Energy Agency (IAEA) specifies a process<sup>18</sup> which takes into account the workforce requirements of the three main organisations involved in their milestones approach for each phase of the nuclear programme development:

- The nuclear energy programme implementing organization (NEPIO);
- The regulatory body;
- The nuclear power plant operating organisation.

This approach addresses the direct jobs created by a nuclear power programme, but it is worth noting that for every direct job in the EU nuclear industry, an additional 3.2 jobs are created<sup>19</sup>.

### The nuclear energy programme implementing organization (NEPIO)

In Phase 1, the NEPIO is established and individuals with relevant competencies are employed to develop the pre-feasibility study. This would include involvement from expert consultants, particularly from countries with established nuclear power programmes, who would help in training a national staff. The NEPIO requires an estimated 10-50 staff in Phases 1 and 2, and is no longer required by Phase 3.

### Regulatory body

Regulatory activities are required in all phases of nuclear power development and operation. Currently, regulatory activities for the use of ionising radiation are carried out by the Environmental Protection Agency (EPA) through the Office of Radiation Protection and Environmental Monitoring (ORM). Following a review in 2015, the IAEA stated that the EPA benefits from experienced, technically competent and well-motivated staff. This would be a strong foundation for a dedicated nuclear safety regulatory body.

In line with the Ionizing Radiation Regulations 2019, Radiation Protection Advisors (RPAs) would be required during the designing and building phase as well as during normal operation of the facility. Ideally, Irish workers would gain experience on projects within Euratom to develop a national staff, in addition to contracting international experts. Including the existing workforce in this area and technical support, approximately 50-150 staff would be required by the regulatory body in all phases.

### Operating Organisation

An operational organisation is established during Phase 2. By Phase 3, the personnel required to construct, commission, and operate a nuclear power plant are in Ireland and fully trained. The

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<sup>18</sup> <http://indico.ictp.it/event/a11195/session/102/contribution/74/material/0/0.pdf>

<sup>19</sup> FORATOM (2019), Impact Report - Vision to 2050, Foratom – European Atomic Forum

majority of these workers are first employed 3-6 years prior to initial plant operation, and represent a wide distribution of skills and specialities.

As with any major infrastructure project, a large number of construction workers would be required by the operating organisation during construction of a nuclear power plant. Small modular reactors (SMRs) are characterised by their modular approach to construction, significantly reducing their on-site construction timescales, which allows the nuclear programme to be executed on a turnkey basis. This reduces the need for certain nuclear specialists in Ireland, as the main components can be pre-manufactured and assembled on site.

Where specialists are required, international contractors are an option, some of whom<sup>20</sup> already operate in Ireland in various sectors. Additionally, vendor assistance is typical in the establishment of a training programme to develop a national staff for construction and operation and maintenance.

The operation of a nuclear plant bears many similarities to the operation of other thermal plants, such as peat, coal and gas. The nature of the work includes skilled trades (including machinery operations), engineers, other professionals, and technicians, with nuclear engineers comprising approximately 5% of the workforce.

A plant identified in the technology review in Appendix A, GE-Hitachi's X-300 SMR, requires 75 onsite operational staff for the running of the plant, while the IAEA projects<sup>21</sup> that every MW of nuclear capacity requires roughly 0.7 staff to cover the production, technical, planning, training and business functions of SMRs. A twin 300 MW SMR station could thus provide over 400 secure jobs for its 60 years of operation.

There is, as yet, no clear plan for the many workers in the peat, coal and gas plants that are closing as part of the national emissions reduction strategy. Some of these staff could be retrained for the nuclear sector. In the UK, for example, EDF has retrained many coal plant workers for employment in the nuclear sector, typically in a process requiring 18 months of largely on-the-job training. EDF uses consultant services to implement this training, and this could also be an option for Ireland.

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<sup>20</sup> Atkins, Wood and AMEC, for example

<sup>21</sup>[https://www-pub.iaea.org/MTCD/Publications/PDF/te\\_1193\\_prn.pdf](https://www-pub.iaea.org/MTCD/Publications/PDF/te_1193_prn.pdf)

## 6. Environmental protection

Production of electricity from any form of primary energy has some environmental effect. The principal environmental impacts concern land use and materials consumed but also entail emissions to air, water and land over its lifetime, as well as long-term management of waste products.

A balanced assessment requires comparison of all relevant energy production options, covering the entire lifetime of the power plant, from preparation of the site, through construction, operation and maintenance of the plant, and on to eventual repurposing or restoration of the site.

As with any power development project, a nuclear power plant would be subject to national planning, permitting, licensing, environmental protection and other legislation, some of which will need to be amended or enacted specifically to address any impacts that are particular to a nuclear plant.

This would include a full Environmental Impact Assessment and Strategic Environmental Assessment prior to licensing in accordance with Irish and EU law, and for which the International Atomic Energy Agency (IAEA) provides guidelines. These assessments would enable the provision of site-specific and technology-specific environmental protection measures.

Small releases of gaseous and liquid effluents that occur routinely during normal plant operation will be part of the environmental impact assessment and licensing. Large radionuclide releases are low probability events that are primarily treated through the nuclear safety programme, although they are also addressed in the environmental impact assessment.

Facilities and activities involving the use of radioactive sources are regulated by the Environmental Protection Agency (EPA) through the Office of Radiation Protection and Environmental Monitoring (ORM). The EPA is considered to be an effective and independent regulatory body<sup>22</sup>. Ireland is also considered to be an active participant in the global regulatory framework for radiation safety<sup>23</sup>.

### Comparative study

This study assesses the environmental impacts of using nuclear energy as an alternative to the technologies identified in CAP19 for the period after 2030 - gas fired plant with and without carbon capture and storage (CCS), onshore and offshore wind, and solar PV. The impacts considered are land use, resource and materials utilisation and CO<sub>2</sub> emissions.

The nuclear plant for this assessment is the GE-Hitachi X-300 small modular reactor (SMR), as identified in the technology review in Appendix A. Operating at 90% capacity factor, this SMR would produce 2.4TWh annually, producing a total of 142 TWh over its 60-year lifetime.

Table 4 contains a qualitative comparison of the main environmental impacts of generating 142 TWh over 60 years using the various technologies under consideration. Technologies with a shorter design life than SMRs are assumed to be replaced with new plant up to 3 times on the same site to maintain power supply for the full 60 years.

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<sup>22</sup><https://www.iaea.org/newscenter/pressreleases/iaea-mission-says-irelands-regulatory-body-effective-recommends-further-action-on-patient-protection>

<sup>23</sup>[https://www.epa.ie/pubs/conferencesandevents/2016-02-12\\_BRN\\_IRRS%20DECLG%20mission%20report%20final\\_KS.pdf](https://www.epa.ie/pubs/conferencesandevents/2016-02-12_BRN_IRRS%20DECLG%20mission%20report%20final_KS.pdf)

Table 4 Qualitative comparison of producing 142 TWh over 60 years

Technology	Capacity MW	Capacity Factor	Design life Years	Concrete & cement <sup>24</sup> Tonnes	Metals <sup>25</sup> Tonnes	Land use Hectares	CO <sub>2eq</sub> <sup>26</sup> MTonnes
Wind onshore <sup>27</sup>	771	35%	25	764,000	257,000	7,870 <sup>28</sup>	2
Wind offshore	520	52%	25	303,000	173,000	n/a (sea)	2
Solar PV	2,455	11%	15	149,000 <sup>29</sup>	666,000	3,700 <sup>30</sup>	7
Gas OCGT	300	90%	25	46,000	5,760	6	92
Gas CCGT	300	90%	25	46,000	5,760	6	64
CCGT with CCS	300	90%	25	>50,000	>5,760	7	17
Nuclear SMR <sup>31</sup>	300	90%	60	15,500	5,000	3	2

### Greenhouse Gas Emissions

Electricity generated by onshore wind, offshore wind, and nuclear all have similarly low carbon emissions. Solar PV emissions are higher but are still considered to be low. Open cycle gas turbines (OCGT) and combined cycle gas turbines (CCGT) have high emissions to air and are the primary contributor to the estimated 4-5 million tons of annual emissions from Ireland's electricity in 2030.

While not explicitly stated in Table 4, although CCGT with 90% carbon capture (CCS) causes lower direct emissions to atmosphere than other gas plant, its captured emissions over 60 years require permanent storage capacity for 47 million tons of CO<sub>2</sub>.

Nuclear energy has one of the lowest carbon footprints of all power generation technologies and has virtually no emissions to air once construction is complete.

### Materials

The reduction of material inputs is a central concept of sustainable development as it conserves finite resources, consumption of which is expected to more than double by 2050. As such, the metric of material throughput is important in consideration of energy efficiency as well as life-cycle carbon emissions. But more broadly, resource efficiency is a key aim in itself.

For power plant, the major material inputs, apart from fuel, are concrete, metals (e.g. aluminium, copper, steel) and technology-specific requirements, such as rare earth metals for gearless wind turbines. Materials used in the production, construction and operation of power plant also consume fossil fuel energy.

The SMR has by far the lowest materials requirement of all the low emissions technologies and most of the metals used can be recycled.

<sup>24</sup>[http://publications.jrc.ec.europa.eu/repository/bitstream/JRC119941/rms\\_for\\_wind\\_and\\_solar\\_published\\_v2.pdf](http://publications.jrc.ec.europa.eu/repository/bitstream/JRC119941/rms_for_wind_and_solar_published_v2.pdf) (for all materials-use data for Wind and Solar PV)

<sup>25</sup><https://www.energy.gov/sites/prod/files/2017/03/f34/qtr-2015-chapter10.pdf> (Iron and steel only)

<sup>26</sup>[https://www.ipcc.ch/site/assets/uploads/2018/02/ipcc\\_wg3\\_ar5\\_chapter7.pdf](https://www.ipcc.ch/site/assets/uploads/2018/02/ipcc_wg3_ar5_chapter7.pdf)

<sup>27</sup> The area between wind turbines is often used for agriculture or civic amenity purposes

<sup>28</sup><http://www.centalscotlandgreennetwork.org/resources/publications/category/71-business-case-studies?download=176:scottishpower-renewables-business-case-study-4-page> 539MW on 55km<sup>2</sup>

<sup>29</sup> Assumes the same concrete stand is used for each re-powering

<sup>30</sup><https://www.fehilytimoney.ie/sector/furryhill-kilteel-solar-farm/> 20.7MW on 31.2Ha

<sup>31</sup><https://nuclear.gewater.com/build-a-plant/products/nuclear-power-plants-overview/bwr-x-300>



## Land use

Lower land use limits land-use change and the loss of biodiversity and natural habitats. It also reduces the potential for visual impact of energy generation. While the land area required for onshore wind power is large, most of the land may simultaneously be used for agriculture or other activities. The land area required for Solar PV equipment is the largest of all technologies considered.

The land area needed to produce electricity from nuclear power plants is significantly smaller than for any other technology, thereby limiting land-use change and the loss of biodiversity and natural habitats while reducing the visual impact of energy generation. Some former nuclear power stations have been fully remediated to their original condition where they are now available for unrestricted use<sup>32</sup>, subject to normal planning laws.

## Comparison of Strategies 1 and 2

Using the data sources above, a simple comparison can be made of the extra land and materials required to develop Ireland's power system according to the 2 strategies considered elsewhere in this study. This comparison is summarised in Table 5 below.

**Strategy 1** is a simple default position, where the share of renewables is projected to expand beyond 2030, and where no new low carbon technology becomes commercially available. The resultant power plant portfolio is outlined in Table 15 in Appendix B.

**Strategy 2** investigates the impact of directly replacing fossil fuel plant with nuclear energy after 2030, while retaining the renewables and supporting technology already installed. The resultant power plant portfolio is outlined in Table 16 in Appendix B.

Table 5 Land and materials comparison of Strategies 1 and 2

	Technology	Capacity MW	Concrete & cement Tonnes	Metals Tonnes	Land use Hectares
<b>Strategy 1</b>	Wind onshore	1000	413,000	139,000	10,204
	Wind offshore	1900	461,000	264,000	N/A
	Gas OCGT	4700	304,000	37,000	94
	<b>Totals</b>		<b>1,180,000</b>	<b>440,000</b>	<b>10,298</b>
<b>Strategy 2</b>	Nuclear SMR	1800	93,000	30,000	18
	Dispatchable low carbon	900	46,500	15,000	9
	<b>Totals</b>		<b>139,500</b>	<b>45,000</b>	<b>27</b>

Results presented in Table 11 of Appendix B show that emissions from following Strategy 1 could remain at 5.3 million tons in 2040, but would fall to 0.9 million tons by including 18% nuclear energy.

The above table shows that following Strategy 2 has these relative environmental benefits by 2040:

- Almost 90% reduction in requirement for concrete and cement
- 90% reduction in requirement for iron and steel
- Over 99% reduction in land use.

This analysis shows that the environmental case for adding 18% nuclear to Ireland's power sector portfolio is compelling.

<sup>32</sup><https://www.world-nuclear.org/information-library/nuclear-fuel-cycle/nuclear-wastes/decommissioning-nuclear-facilities.aspx>

## 7. Legal Framework and Regulatory Framework

The framework legislation governing the nuclear and radiation protection sectors in Ireland is the Radiological Protection Acts 1991 to 2018<sup>33</sup>. This would apply to nuclear installations, and currently applies to radioactive sources in the medical, industrial, veterinary, dental and educational sectors.

The 1991 Act repealed the Nuclear Energy Act 1971, which had established the Nuclear Energy Board as the regulatory authority for a nuclear power station which was being considered at the time. The 1991 Act also established the Radiological Protection Institute of Ireland, which merged with the EPA in 2014, as the national expert body responsible for, inter alia, advising the Minister and the government on nuclear safety and radiological protection matters.

There are two legal barriers to developing a nuclear power programme in Ireland; nuclear power stations cannot be authorised under The Planning and Development (Strategic Infrastructure) Act 2006 and the use of nuclear fission electricity generation is not permitted under The Electricity Regulation Act 1999.

In both cases, these barriers are single lines of legislation whose removal would not impact on the rest of the acts. The National Planning Framework (NPF) identifies the requirement for “legal and regulatory frameworks to meet demands and challenges in transitioning to a low carbon society”, which would support the removal of unnecessary legal barriers to low carbon energy technologies. Furthermore, these lines of legislation should not preclude studies investigating the suitability of the technology, as demonstrated by the Oireachtas through their investigation of Carbon Capture and Storage (CCS) technologies, which are also currently not permitted in Ireland.

In addition to removing these barriers, an effective legal and regulatory framework would be required to establish the responsibilities of all organisations necessary for a successful nuclear power programme, including an independent nuclear regulator. Legislation would cover all aspects of nuclear law: nuclear safety, security, safeguards, and civil liability for nuclear damage. This is similar in many ways to the need for new or amended legislation that would be required prior to the introduction of other technologies to Ireland, such as CCS plants.

Currently, facilities and activities involving the use of radioactive sources are regulated by the Environmental Protection Agency (EPA) through the Office of Radiation Protection and Environmental Monitoring (ORM). As mentioned in Section 4 Human Resource Development, this would act as a sound basis for a dedicated nuclear regulatory body.

Nuclear regulatory bodies regulate the use of nuclear energy and materials. The specific responsibilities vary from country to country, but a regulator for Ireland would most likely perform the following functions:

- Regulate the development, production of, and use of nuclear energy to protect health, safety, and the environment;
- Regulate the production, possession, use and transport of nuclear substances, as well as equipment and information;
- Implement measures relating to international control of the development, production of, transport and use of nuclear energy and substances; and
- Disseminate scientific, technical and regulatory information.

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<sup>33</sup> As amended by Section 26 of the 1995 Energy (Miscellaneous Provisions) Act, by Section 65 of the 1998 Food Safety Authority of Ireland Act

A nuclear regulatory body would be established through legislation and be institutionally separate from the nuclear operating organisation. Certain aspects of nuclear regulation and implementation would require the involvement of other bodies, such as An Bord Pleanála, for the strategic infrastructure development planning process.

In developing a regulatory body, Ireland would benefit from the guidance of international organisations, such as the IAEA, and well-regarded nuclear regulators, such as the Canadian Nuclear Safety Commission. Recently, certain countries, such as USA and Canada, have collaborated on the licensing of nuclear reactors. Ireland could also explore this option.

## 8. Nuclear Fuel Cycle

The nuclear fuel cycle applies to uranium which has been mined, milled, undergone conversion, enrichment and been fabricated into assemblies at the front end of the fuel cycle, through to use in a reactor and its eventual reuse, reprocessing, storage or disposal at the back end of the cycle.

Ireland is highly unlikely to become directly involved in any front-end activities, as an Irish nuclear power plant would most likely simply buy fabricated fuel assemblies. After the fuel has been used, it would initially be stored in the power plant cooling pond. Some years later, the spent fuel could be transferred to dry cask storage, either on-site or to a central above-ground storage facility. Long term wet storage – as successfully implemented in Sweden – could also be an option subject to a formal evaluation of all the options.

In assessing a nuclear power programme, Ireland would also need to account for the potential development of a high level nuclear waste disposal facility. International disposal options currently being researched are anticipated to remove the need for a disposal facility in Ireland, or may simplify this process considerably.

Another potential solution for Ireland is that the plant operating organisation would contract with a fuel supplier under which spent fuel, after initial on-site storage, is returned to the supplier for further treatment or long-term storage in the country of origin.

As a result, Ireland may need only a temporary storage facility for spent fuel and the need to dispose of High-Level Waste may not arise. There would be little need to deal with Intermediate Level Waste until the reactor is being decommissioned at the end of its life. These topics are discussed further in Chapter 9.

Although Ireland may never become directly involved in the following activities, the nuclear fuel cycle is described below, and in more detail in Appendix E, as background information.

Ireland's membership of Euratom - the single European market for nuclear materials and technology—ensures a secure supply of nuclear fuel and facilitates investment, R&D, sharing of expertise, safeguard activities, and the correct disposal of nuclear waste. Uranium is delivered from geographically and geo-politically diverse regions, the largest of which - Canada - provides 28%.

Fuel is typically fabricated and supplied by the reactor vendors. Because nuclear fuel is energy-dense and relatively inexpensive, three to seven years' worth of nuclear fuel can be stored on-site to improve energy security and reduce the impact of gas price volatility.

This is a significant advantage of nuclear fuel, given that Ireland will become increasingly reliant on imported gas to support the national grid upon the closure of peat and coal plants and the depletion of Irish gas fields.

The back end of the fuel cycle includes the storage and possible recycling of spent nuclear fuel and the disposal of waste products. A 300 MW small modular reactor (SMR) would produce approximately 10 tons of spent fuel annually, much of which could be reprocessed by the fuel supplier and used again as fuel. In France, 25% of uranium needs for nuclear power are met through reprocessed waste products. The spent fuel produced by an SMR over sixty years of operation would occupy a temporary storage building no larger than a basketball arena.

Following an on-site storage, international scientific consensus is for high-level waste to be disposed of in deep geologic repositories. Many countries are planning for such facilities, including Sweden and Finland, who both have sites selected for deep geologic repositories and are operating test facilities.

## 9. Radioactive Waste Management

Ireland produces radioactive waste routinely from dental, medical, industrial, veterinary and educational sectors. Establishing the extra responsibilities and requirements for the management of waste streams involved with a nuclear program is an important first step in identifying gaps in our existing capabilities, regulatory framework and experience with radioactive waste handling, storage, transport and disposal.

The IAEA provides information<sup>34</sup> for countries with small or newly established nuclear power programmes on the challenges of, and current and potential alternatives for, managing reactor waste and spent fuel arising during operation and decommissioning of nuclear power plants.

### Low Level Waste

Low Level Waste (LLW) comprises paper, tools, clothing, etc, which contain small amounts of mostly short lived radioactivity. LLW accounts for 90% of the radioactive waste by volume produced at a nuclear power plant. It can be held in low level waste storage facilities, as is the current practice with disused radioactive sources from Irish dental, medical, industrial, veterinary and educational sectors.

The National Policy for Nuclear Safety and Radiation Protection<sup>35</sup> envisages the establishment of a National Radioactive Waste Storage Facility for material which arises from current activities, and which is now stored at a number of locations. However, the larger volume of LLW produced by a nuclear power plant may require the establishment of a facility for final disposal of LLW, which could be sited at or close to the site of the power plant.

The Office of Radiation Protection and Environmental Monitoring (ORM), a department of the EPA, is the national expert body responsible for advising the Minister for the Environment, Heritage and Local Government on nuclear safety and radiological protection matters. It is also responsible<sup>36</sup> for regulating, in particular through advance licensing, the custody, use, manufacture, transportation, disposal etc. of radioactive substances, irradiating apparatus and other sources of ionising radiation.

All activities are conducted in accordance with the IAEA guidance and best EU practice. A 2011 European directive<sup>37</sup> that allows for the sharing of repositories between two or more member states may attract member nations to use external contracts for infrastructure cost offset and commercial benefits in the future. The directive makes it legally binding by all member states to follow the IAEA safety standards for the responsible and safe management of spent fuel and radioactive waste.

The National Policy for Nuclear Safety and Radiation Protection<sup>38</sup> contains a policy objective of the “long-term goal of final disposal, possibly in coordination with a third country”.

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<sup>34</sup>[https://www-pub.iaea.org/MTCD/Publications/PDF/PUB1825\\_web.pdf](https://www-pub.iaea.org/MTCD/Publications/PDF/PUB1825_web.pdf)

<sup>35</sup><https://www.dccae.gov.ie/en-ie/environment/publications/Pages/National-Policy-Position-for-Nuclear-Safety-and-Radiation-Protection.aspx>

<sup>36</sup><https://www.oecd-nea.org/law/legislation/ireland.pdf>

<sup>37</sup><https://eur-lex.europa.eu/legal-content/EN/ALL/?uri=CELEX:32011L0070>

<sup>38</sup><https://www.dccae.gov.ie/en-ie/environment/publications/Pages/National-Policy-Position-for-Nuclear-Safety-and-Radiation-Protection.aspx>

## Intermediate Level Waste and High Level Waste

Intermediate Level Waste (ILW) comes from resins and materials from reactor decommissioning. It is more radioactive than LLW, but does not produce enough heat for this to be a factor in its disposal. There would be only very small quantities of ILW requiring management until the nuclear power plant was being decommissioned at its end of life.

High Level Waste (HLW) includes spent fuel and accounts for about 3% of the total volume of radioactive waste produced by a nuclear power plant. It is radioactive enough to produce heat which requires cooling, but its radioactivity decreases by a factor of a thousand within forty years.

Domestic management of ILW and HLW could consist of temporary storage and long-term disposal, and all activities included in these management systems – administrative and operational – should be fully evaluated prior to Ireland undertaking any nuclear programme development. As discussed in Chapter 8, international disposal options currently being researched may remove the need for a disposal facility here or may simplify this process considerably.

ILW and HLW are waste streams not dealt with currently by Irish regulations and regulators<sup>39</sup>. Additional information on various spent fuel management options is contained in Appendix E. Short term storage solutions for spent fuel are provided by the reactor manufacturer as part of the power plants facilities. Medium term storage in dry casks is provided on the international market through the leasing of certified designs or direct purchase of casks.

All costs associated with all stages of the storage and disposal regime for HLW and ILW is included in the price of nuclear electricity generation, a model unique to the industry, as costs associated with waste are not accounted for in any other electricity generation industry.

Recent international nuclear projects have involved a fuel leasing agreement, where the spent fuel is returned to the fuel vendor nation for reprocessing or longer-term storage pending final disposal or potential reuse in an advanced reactor<sup>40</sup>. An agreement of this nature may be particularly suited to an SMR programme, as the volume of waste produced would be very small.

Reprocessing of spent nuclear fuel, as occurs in France, reduces the HLW to 0.2% of the total volume of radioactive waste. Shipment to a suitable reprocessing facility via a vendor agreement is an option that Ireland could consider as a method of managing its spent nuclear fuel.

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<sup>39</sup>The IAEA Joint Convention on the Safety of Spent Fuel Management and on the Safety of Radioactive Waste Management is the legal instrument that directly addresses such issues on a global scale by establishing fundamental safety principles and creating a similar peer review process to the Convention on Nuclear Safety. Ireland ratified the Convention in 2001 and it entered into force here on 18 June 2001.

<sup>40</sup><https://www.world-nuclear-news.org/Articles/Russian-proposal-for-nuclear-fuel-leasing-and-recy>



## 10. Radiation Protection and Emergency Preparedness

The Office of Radiation Protection and Environmental Monitoring (ORM<sup>41</sup>) recognises the important role that ionising radiation plays in our economy and society and is responsible for ensuring that people and the environment in Ireland are protected from its harmful effects. The ORM has strong independent regulatory control in relation to the use of ionising radiation and has well-established arrangements in place for appropriate resourcing including financial, human, research and development, and safety leadership.

There is a strong commitment to the global safety regime through Ireland's membership and active participation in the broad range of international organisations and conventions dealing with nuclear safety and radiation protection.

The effects of high and very high doses of ionising radiation, including serious injury, cancer or death, are well known from scientific studies. Although epidemiological data provide essentially no evidence for negative health effects for low doses<sup>42</sup>, regulatory bodies (including the ORM) assume that there is a direct relationship between dose and risk all the way down to zero.

By far, the largest contribution to the average radiation exposure of an Irish adult, approximately 86%, comes from natural sources<sup>43</sup>. Man-made sources contribute approximately 14% and are dominated by the beneficial use of radiation in medicine. Doses from other man-made or artificial sources, including from their use in nuclear energy, industrial, veterinary and educational sectors, account for less than 1%.

While licenses are required for the custody, use, manufacture, importation, transportation, distribution, exportation and disposal of radioactive substances, primary responsibility for the protection of people and the environment from the harmful effects of ionising radiation rests with the licence holder of the radiation sources.

The radioactive gas emissions from nuclear power plants during normal operations are at levels that are not harmful to the public. Some modern designs of nuclear power plant virtually eliminate even these insignificant emissions to air.

The ORM has responsibilities concerning radioactive material and waste from industrial, medical and research facilities requiring licensing and regular site visits and audits to ensure compliance with regulations. Their radiation protection activities are certified according to ISO standards, providing for transparency and continuous improvement.

The ORM could potentially see a revision in its frameworks to work in collaboration with a dedicated nuclear regulatory body, or could form part of a new dedicated nuclear regulatory body.

### Emergency Preparedness

Modern nuclear power plants are designed with extremely small accident occurrence probabilities, typically orders of magnitude smaller than those required by design licensing bodies. Despite robust passive safety features being a primacy to modern reactor designs, equally robust plans for emergency situations must be ensured and confirmed well in advance of reactor operation.

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<sup>41</sup><http://www.epa.ie/about/org/orm/>

<sup>42</sup><https://www.ncbi.nlm.nih.gov/pmc/articles/PMC6149023/>

<sup>43</sup><https://www.epa.ie/radiation/radexp/>

Emergency planning involves cooperation between relevant regulatory bodies, local and national government, and the operating organisation.

Ireland's nuclear and radiological emergency plans are considered to be "well integrated in a framework for major emergency management and a national emergency coordination system following an all-hazards approach"<sup>44</sup>.

The National Emergency Plan for Nuclear accidents (NEPNA<sup>45</sup>) is designed to ensure that Ireland can respond quickly to any major accident at an overseas nuclear installation which might lead to radioactive contamination reaching Ireland. It sets out a framework for a co-ordinated national response to an event where the required response is beyond the resources or capabilities of any individual Government Department or public authority and thus requires the political and strategic involvement of Government.

The NEPNA forms a good basis for development of a similar plan relevant to a domestic nuclear energy programme. In this case, the ORM would also provide assurance of the resources needed to develop and maintain robust Emergency Preparedness and Response (EPR) capabilities and regulate the licensee's obligations under the EPR plan.

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<sup>44</sup><https://www.iaea.org/newscenter/pressreleases/iaea-mission-says-irelands-regulatory-body-effective-recommends-further-action-on-patient-protection>

<sup>45</sup><https://www.epa.ie/radiation/emerg/nuclear/theplan/>

## List of Contributors

All contributors to this Preliminary Study: *Nuclear Energy Development in Ireland* are members of 18for0, a voluntary group of professionals concerned about the credibility of current proposals to achieve net zero emissions in Ireland by 2050.



Allan Carson

A project manager and chemical engineer with over a decade of experience working within nuclear project development and licensing both in the UK and internationally



Sarah Cullen

A training manager in the nuclear sector, with a background in Irish solar farm development and energy systems engineering



Denis Duff

Chartered engineer with global experience in electrical utilities and electricity trading systems, including wind energy, gas and oil fired thermal and Combined Cycle Power Plants



Lee Gibbons

Mechanical Engineer working in the energy sector with experience in data centre energy management and molten salt nuclear reactor design



Jonathan McIntyre

Medical physicist with experience in material science, clinical engineering, imaging and radiation protection



Pat Morrissey

A GP/family doctor working in the shadow of Ireland's last coal plant. Eager to establish clean nuclear as part of Ireland's energy mix. Commercial experience as chairman of a medical services company providing out of hours care to a population of 380,000



Dermot O'Loughlin

Nuclear operations professional with many years experience working within nuclear power generation. Fellowship in nuclear / nuclear power technology from the World Nuclear University. Chartered Engineer IMechE



Norma O'Mahony

Nuclear Safety Engineer at the Olkiluoto 3 EPR construction site. Previously worked at the Wylfa ABWR project as a safety analysis engineer



Jerry Waugh

Chartered Engineer with a decade of experience in the nuclear power sector in Europe and the United States of America



Jianwei Wu

A project planner and civil engineer with 22 years experience working within various roles, including senior management. Expertise in construction management, project management and quality assurance. 10 years experience working on nuclear power plant construction

## Appendix A Technology review

This review assesses prospective nuclear power plants for Ireland on the basis of their compatibility with our grid, engineering readiness, cost to build, cost of energy and spent fuel management.

Any new power generation plant proposed for Ireland must take account of our plans to produce 70% of our electricity from renewable sources by 2030, as outlined in CAP19. To achieve this, EirGrid expects that our electricity system must develop to routinely accept non-synchronous generation supply of over 95%. It may also be necessary to operate the system with no synchronous generation occasionally, which is very unlike the current situation where at least five units must be connected at all times to ensure dynamic system stability<sup>46</sup>.

The electricity grid operating regime envisaged for 2030 and beyond will present a significant extra challenge to incorporating all low emissions dispatchable capacity that EirGrid believe will also be required to continue to reduce emissions from power generation in the decade up to 2040<sup>47</sup>.

While it may be technically possible to incorporate a large nuclear power plant in Ireland if it was operated in conjunction with sufficient dedicated interconnector and storage capacity, it is preferable that any nuclear unit deployed would be small enough to enhance the dynamic stability of the grid and to minimise system integration costs.

It is also important that low-emission dispatchable capacity would have flexibility in electrical power output to complement the variable nature of much of the power plant that will be installed in Ireland by 2030. The most important characteristics in this regard are that the power plant would be able to change load rapidly, have a low minimum load, and remain connected to the Grid, providing essential stability during significant frequency excursions.

In addition, nuclear plants can form part of hybrid power producing systems, where their output can be rapidly diverted to storage or other power conversion systems. For example, molten salt reactors can quickly divert their hot thermal salts from electricity production into thermal salt storage tanks that can be used to produce electricity when power is required. Another potential means is through the production of hydrogen or other 'Power-to-X' technology when the demand for electricity is low.

We conducted a high-level overview of the main features of both a proven, modern reactor and some small nuclear power plants that are ready for near-term deployment and whose maximum power output is around 300MW or less. The results are presented in Table 6 below.

The Westinghouse AP1000 (1150MW) is a proven reactor, designed and licensed in the USA, that has been built in China and is nearing completion in the USA. This would represent a larger than ideal share of Ireland's electricity mix from a stability and security perspective, but could operate effectively if used in conjunction with dedicated interconnection capacity.

We also assessed four small modular reactors (SMRs), all of which output 300MW or less. These may be built independently or as modules in a larger multi-unit station, with capacity added incrementally as required. An added feature of SMRs is their potential to be pre-fabricated in a factory setting and installed module by module on site, thus offering very high control of quality and short build time.

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<sup>46</sup>[http://www.eirgridgroup.com/site-](http://www.eirgridgroup.com/site-files/library/EirGrid/OperationalConstraintsUpdateVersion1_89_December_2019.pdf)

[files/library/EirGrid/OperationalConstraintsUpdateVersion1\\_89\\_December\\_2019.pdf](http://www.eirgridgroup.com/site-files/library/EirGrid/OperationalConstraintsUpdateVersion1_89_December_2019.pdf)

<sup>47</sup> p73 <http://www.eirgridgroup.com/site-files/library/EirGrid/EirGrid-TES-2019-Report.pdf>

Table 6 Technical overview of selected technology

Manufacturer	Westinghouse	NuScale	GE Hitachi	Moltex	Terrestrial
<b>Description</b>	1150 MW Pressurised Water Reactor	60 MW Pressurised Water Reactor	300 MW Boiling Water Reactor	150 MW Molten Salt Reactor	192 MW Molten Salt Reactor
<b>First build</b>	2018	Due 2029	Due 2027	Early 2030s	Early 2030s
<b>Grid compatibility</b>	Quite large May need Grid constraints and outage control Fleet unlikely	Ideal as a 6-module unit Possible fleet Simple outage planning	Ideal Possible fleet Simple outage planning	Ideal Possible fleet Simple outage planning	Ideal Possible fleet Simple outage planning
<b>Economics</b>	Good	Good	Excellent	Excellent	Excellent
<b>Capital cost USD / kW</b>	\$9,000	\$4,200 - \$8,500	\$2,000 - \$4,000	\$2,000 - \$4,000	\$2,000 - \$4,000
<b>LCOE / MWh</b>	€65 - €135	€50 - €140	€44 - €61	€40 - €65	€50 - €\$85
<b>Engineering readiness</b>	Already built on time and on budget in China Overran in USA	Well established technology Experienced suppliers US NRC design approved	Well established technology Experienced suppliers Licence and build by 2027	Less technology readiness Complex fuel supply chain Experienced engineering partners	Less technology readiness Experienced R&D partners Being licenced in Canada
<b>Spent fuel management</b>	Comparable to current light water reactors	Comparable to current light water reactors	Comparable to current light water reactors	Can be fuelled by existing spent nuclear fuel ('waste burner')	Comparable to current light water reactors + repeated reprocessing opportunity

A nuclear power plant contains a nuclear reactor and a generator. All of the reactors identified above can be coupled with generators capable of satisfying the Grid Connection Conditions required of any generator that intends to connect to the Irish grid.

Preliminary results indicate that the **NuScale** and **GE-Hitachi reactors** are the most likely to provide cost-effective, clean energy in Ireland by the early 2030s, while the Terrestrial Energy and Moltex machines could be available by the mid-2030s. The larger Westinghouse unit would also meet this need even though its economics are not quite as favourable as the others and it would probably require a dedicated interconnection capacity for system security reasons.

Further detailed research is needed to identify technically and commercially viable reactors to facilitate Ireland's electricity supply in meeting our climate targets beyond 2030. The main purpose of this research would be to:

- Develop a methodology for evaluating the wide range of innovative design principles and define criteria for identifying the most appropriate design;
- Apply that selection methodology with a two-step process objective to focus development efforts on the most appropriate design;
- Present a summary of the results to stakeholders and the general public.

## Appendix B Summary Analysis: Emissions and Economics

This appendix contains a summary of a more detailed analysis of Ireland's options for decarbonising electricity with and without nuclear energy.

### Introduction

Ireland's Climate Action Plan 2019<sup>48</sup> (CAP19) contains many measures intended to deliver 70% of our electricity from renewables and reduce annual greenhouse gas emissions to 4 - 5 million tons by 2030. CAP19 must be fully implemented for Ireland to meet our 2030 EU obligations. It also intends to provide a pathway to achieving a net zero emissions society by 2050.

CAP19 will require these changes in our power generation portfolio by 2030 compared to 2020:

- renewable electricity supply increase from 30% to 70%,
- renewable capacity increase from 4,500 MW to around 13,500 MW,
- all coal, peat and oil fired power stations to close,
- hydro pumped storage plant increase from 290 MW to 650 MW,
- battery storage plant increased to 1,700 MW, and
- interconnection increase from 500 MW to 1,700 MW.

We conducted a simple simulation of the above measures from CAP19, using industry standard data (tables below). By including associated research into the topic by EirGrid<sup>49</sup> and others, we came to these conclusions about the CAP19 plan for 2030:

- 1) Renewables**  
70% of our electricity could be delivered by renewables, as CAP19 intends.
- 2) Emissions**  
Emissions could also fall as intended, reaching 4.9 million tons by 2030. However, there is no specific policy statement on how such emissions will be further reduced after 2030 and there is no technology commercially available at scale and permitted in Ireland that can enable us to achieve that objective.
- 3) Costs**  
The average cost of producing electricity increases from €65/MWh in 2020 to €111/MWh in 2030. The capital cost of installing the infrastructure is estimated at over €23 billion.
- 4) Technical**  
EirGrid describes delivery of 70% renewable electricity as a significant challenge, because the electricity grid must be enhanced to remain stable while being supplied by over 95% non-synchronous generation for extended periods. This has never been attempted before and its impacts on stability and reliability are, as yet, uncertain.
- 5) Future pathway**  
➤ As the renewable infrastructure will have been developed to close to its optimum levels by 2030, simple expansion of such plant is unlikely to achieve significant additional emissions reduction benefits

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<sup>48</sup><https://www.dccae.gov.ie/documents/Climate%20Action%20Plan%202019.pdf>

<sup>49</sup>EirGrid assumes a step change in the uptake of electrified transport and heating, where thermal efficiency is improved due to deep retrofitting. Although uptake is significant, there is only a modest level of grid flexibility offered from consumer technologies. Renewable electricity is mainly generated by large-scale sources, but the diversity of the renewables mix increases due to reducing technology costs and auction designs.

- CAP19 established a steering group to examine the feasibility of carbon capture and storage (CCS) in Ireland, but its commerciality and availability is still uncertain
- Surplus renewable energy could be used to produce biofuels, synthetic gas, hydrogen or a 'Power-to-x' energy resource, but the commerciality and availability of these options are also far from certain as they are yet to be proven at scale
- If none of these technologies become commercially available at scale within a reasonably short timeframe, there will be no policy-compliant technology that allows us to continue beyond 2030 on a path to net zero emissions electricity.
- Nuclear energy is a proven, low-emissions technology that has not been adequately considered for its potential to assist us in reaching our environmental targets.

It is therefore appropriate to consider the potential of nuclear energy as part of Ireland's clean electricity system after 2030.

## Nuclear energy's potential for Ireland

### Metrics for success

The fundamental requirement of any energy system in a modern society is that it must be sustainable, affordable and reliable. Indeed, these three primary elements – often referred to as the 'Energy Trilemma' – are central to the UN Sustainability Development Goal SDG 7. Their achievement can be measured by assessing:

- Impact on emissions and renewables targets – compliance with EU obligations
- Impact on the cost of producing electricity – affordability for the customer
- Impact on the capital cost of the power plant – affordability for the industry
- Impact on the electricity grid – stability, reliability and security of supply.

### Assessment of the Climate Action Plan

If CAP19 is fully implemented, as it must be for Ireland to meet our EU Renewable Energy targets, Ireland's power plant portfolio<sup>50</sup> is expected to almost double between 2020 and 2030. This is detailed in the Data Tables on page 34 and summarised in Table 7 below.

Table 7 Power plant changes by 2030

Plant Type		2020	2030
Renewables	MW	4675	13585
Coal, Peat and Oil	MW	1755	0
Gas	MW	4316	4880
Others	MW	135	145
Storage	MW	290	2350
Interconnection	MW	500	1700
Nuclear	MW	0	0
<b>Total power plant</b>	<b>MW</b>	<b>11671</b>	<b>22660</b>

<sup>50</sup> We compile the economic case using data from CAP19, EirGrid, the Irish Wind Energy Association (IWEA) and industry, in that order of priority



Our calculations confirm the theoretical ability of this power plant to approximately meet the 2030 targets of 70% electricity from renewables and emissions of 4-5 million tons, as shown in Table 8.

Table 8 Electricity and Emissions changes by 2030

Electricity supplied		2020	2030
Renewables	%	39%	68%
Fossil Fuels	%	56%	18%
Interconnection and Storage	%	5%	13%
<b>Emissions</b>	<b>Mtons</b>	10.9	4.9

As electricity demand increases by one third by 2030, this will be a significant technical achievement if it can be accomplished. Table 9 shows the assumed electricity demand growth from 2020 to 2050.

Table 9 Electricity demand growth assumed

Projected electricity demand		2020	2030	2040	2050
Total electricity	TWh	32.6	43.8	48.3	52.8
Peak demand	MW	5500	6650	7550	8450

However, as all coal, peat and oil will be removed from power generation and interconnection and storage is increased substantially by 2030, these actions cannot be simply replicated to maintain emissions on an adequate low carbon pathway out to 2050.

## Strategies for decarbonisation

### Initial assumptions

We assume that CAP19 is fully implemented as planned and that all low carbon infrastructure installed by 2030 is retained and used to its best effect in an electricity grid that is capable of accepting up to 100% non-synchronous generation as required.

We assess two strategies for decarbonising electricity after 2030 to compare how well they maintain Ireland on its net zero emissions pathway.

**Strategy 1** is the current default position, in which renewables account for all of the growth in power plant using the range of technologies suggested in CAP19 for adoption in Ireland by 2030. Storage and interconnection expands as predicted by EirGrid for 2040 but natural gas capacity is retained at 2030 levels. This provides a benchmark against which to assess the alternative strategy.

**Strategy 2** is where nuclear energy directly replaces fossil fuel plant after 2030. Renewables are retained at near-2030 levels and include dispatchable renewables that are assumed to have the same characteristics as small nuclear plants. If dispatchable renewables are not commercially available when required, additional nuclear or other low carbon technology is used instead. Storage and interconnection expands as in Strategy 1

### Methodology

We begin by modelling Ireland's power plant portfolio in 2030 as envisaged in CAP19, supplemented as required by relevant projections by EirGrid in their Tomorrow's Energy Scenarios reports. The portfolio then develops to 2050 as already described for both Strategy 1 and Strategy 2, in order to meet the demand projections as outlined in Table 9 above.

Assuming that renewable plant continues to have priority dispatch on the grid, we calculate the total renewable electricity generated using renewables capacity factors as predicted by the Irish Wind Energy Association (IWEA<sup>51</sup>) and curtailment data as estimated by EirGrid. The contribution of interconnection and electricity storage to Ireland’s electricity supply remains at around 12% throughout the period from 2030 to 2050, as the increase in electricity exports and energy storage are offset by reduced electricity imports.

Biomass, landfill gas and CHP are assumed to increase slightly after 2030 in Strategy 1 but are kept at 2030 levels in Strategy 2.

The remaining electricity demand is assumed to be supplied by gas plant in Strategy 1 or by its nuclear replacement in Strategy 2, allowing us to predict capacity factors (Table 18) and curtailment levels (Table 19) for the relevant technologies.

For each year, we calculate the income each generation technology needs to remain viable based on its capacity factor and its levelised cost of electricity (LCOE) for that year. The sum of this income for all technologies can be considered as the cost of electricity generation for that year. This is the total income the power generators need to remain viable while generating the energy required each year. As it ignores windfall profits, trading profits and losses and all feed-in tariffs, the cost of electricity generation is likely to be lower than the wholesale price of electricity.

Capital costs are calculated using data from IWEA for renewables and from various industry sources for remaining power plant – see Table 17 for details of our financial assumptions. For simplicity, the entire capital cost of a power plant is assumed to be incurred in the year it is commissioned.

The direct emissions intensity of each power plant technology (see Table 21) is used to calculate the total annual emissions from each technology as well as the total power system emissions.

## Results

The two decarbonisation strategies have a common starting point in 2030, and result in power plant portfolios that are summarised in Table 10 below.

Table 10 Power plant changes from 2030, under different strategies

Plant Type		Initial	Strategy 1		Strategy 2	
		2030	2040	2050	2040	2050
Renewables	MW	13500	15440	16480	13331	13280
Coal, Peat and Oil	MW	0	0	0	0	0
<b>Gas</b>	MW	4700	4700	4700	1505	<b>0</b>
Others	MW	1170	1730	1730	1670	1670
Storage	MW	2350	3200	3200	3200	3200
Interconnection	MW	1700	2200	2200	2200	2200
<b>Nuclear</b>	MW	0	0	0	<b>1500</b>	<b>1800</b>
Total power plant	MW	23420	27270	<b>28310</b>	23406	<b>22150</b>

As shown in Table 10, Strategy 1 sees renewables, storage and interconnection capacity continue to increase, while gas plant remains at 2030 levels to provide support. The total power plant increases by a further 21% by 2050 compared to 2030.

<sup>51</sup> <https://www.iwea.com/images/files/70by30-report-final.pdf>

Strategy 2 sees the inclusion of 1800 MW of nuclear capacity, replacing fossil fuel that is eliminated by 2050. Renewables remain near their 2030 levels and include 900 MW of firm low-carbon renewables capacity, assuming it becomes commercially available; otherwise, carbon capture or additional nuclear plants can provide this capacity. Storage and interconnection increases as with Strategy 1. The total power plant required by 2050 is 22% lower with Strategy 2 than with Strategy 1.

### Impact on emissions and renewables targets

We next compared the two different strategies against the metrics already identified as essential to demonstrate compliance with the sustainable energy goal, SDG 7.

Table 11, below, shows how much electricity is generated by each of the technology groups, along with the total emissions from the power sector. Interconnection and Storage figures represent only the power supplied to Ireland’s grid, although these technologies also take power from the grid.

This table shows that each strategy results in a high level of renewables to facilitate meeting our EU renewable energy targets, but that the strategy including nuclear is much more effective at reducing emissions than the strategy where nuclear is excluded.

Table 11 Progress on Emissions and Renewables targets

Electricity supplied		Initial	Strategy 1		Strategy 2	
		2030	2040	2050	2040	2050
<b>Renewables</b>	%	<b>68%</b>	<b>71%</b>	<b>76%</b>	<b>67%</b>	<b>69%</b>
Fossils and Others	%	18%	15%	13%	2%	1%
Interconnection and Storage	%	13%	14%	11%	14%	11%
Nuclear	%	0%	0%	0%	18%	18%
<b>Emissions</b>	<b>Mtons</b>	<b>4.9</b>	<b>5.3</b>	<b>5.3</b>	<b>0.9</b>	<b>0.9</b>

Strategy 1 indicates a higher renewable penetration but much higher emissions compared to Strategy 2. The residual emissions in Strategy 2 are attributable to waste incineration (considered to be 50% renewable) and a small amount of Combined Heat and Power (CHP) plant.

The nuclear plant is operated at relatively modest capacity factors to reduce curtailment of renewables and increase their output despite a marginal fall in renewable capacity relative to 2030.

Getting electricity to net zero or net negative emissions will most likely require some form of carbon removal system that has yet to be commercially developed at scale. The direct storage of carbon dioxide gas is currently not permitted in Ireland, although CCS is currently being assessed by a steering group established by CAP19.

Overall, even though Strategy 1 has higher renewables penetration it also has much higher associated emissions than Strategy 2.

### Impact on the cost of producing electricity – affordability for the customer

It is not possible to confidently predict the wholesale or retail price of electricity so far into the future, as those prices depend on unknowns including the level of subsidy that might be in place, the levels of curtailment and constraints on the power system, the cost of imports and exports, and the likely level of profit for the plant owners.

Instead, we calculate the revenue each generation technology needs to remain viable based on its capacity factor and its levelised cost of electricity (LCOE) for that year. The sum of these revenues for all technologies can be considered as the underlying cost of power generation for that year - it is the total income the power generators need to remain viable while generating the energy required.

Dividing this income by the annual electricity demand yields the average cost of producing electricity when all power plants cover their costs. It is likely to be lower than the wholesale price of electricity as it ignores windfall profits, trading profits and losses and all feed-in tariffs.

The average cost of producing electricity in each strategy is shown in Table 12 below.

Table 12 Average cost of producing electricity

Average cost of producing electricity	2020	2030	Strategy 1		Strategy 2	
			2040	2050	2040	2050
€/MWh	65	112	104	98	97	85

Because the total installed power plant capacity increases at a much faster rate than electricity demand between 2020 and 2030, the average cost of producing electricity increases substantially, from €65/MWh in 2020 to €112/MWh in 2030. Between 2030 and 2050, Strategy 1 sees a 12% decrease in the average cost of producing electricity, while Strategy 2 shows a decrease of 24%.

Overall, Strategy 1 has higher average cost of producing electricity than Strategy 2. The cumulative cost of producing electricity from 2030 to 2050 is estimated to be over €6 billion higher in Strategy 1 than in Strategy 2.

### Impact on the capital cost of the power plant – affordability for the industry

Table 13 below shows the total capital costs per decade of the power plant required in each strategy. The costs associated with new overhead lines and other electrical infrastructure is ignored in each case but is likely to be significantly higher in Strategy 1.

Table 13 Total capital costs of power plant per decade

Capital costs	2020-2030	Strategy 1			Strategy 2		
		2030-40	2040-50	Total	2030-40	2040-50	Total
€ billion	23.3	9.5	11.8	44.5	9.4	9.5	42.1

The majority of the capital costs for each strategy are incurred before 2030 because of the large investment in renewables, interconnection and energy storage system in that decade.

Thereafter, the capital cost for Strategy 1 is over 11% higher than for Strategy 2. This is because the capital cost of the extra renewables and replacement of gas plant in Strategy 1 is higher than the cost of the nuclear and firm low carbon plant that replaces it in Strategy 2.

Overall, Strategy 1 has higher capital costs than Strategy 2.

### Impact on the electricity grid – stability, reliability and security of supply

EirGrid’s DS3 programme<sup>52</sup> is designed to increase integration of non-synchronous generation through various non-energy system services, including reserve and fast frequency response to enhance grid stability and reliability. These services are likely to be ever more important as the instantaneous System Non-Synchronous Penetration (SNSP) limit is increased from 65% to over 95% by 2030 and possibly to 100% thereafter.

It is assumed that EirGrid will continue to apply and, in some cases, establish industry best practice techniques to maintain a reliable grid in all scenarios. However, there is an increased risk associated

<sup>52</sup><http://www.eirgridgroup.com/how-the-grid-works/ds3-programme/>

with Strategy 1 due to the unprecedented nature of many of the changes that are introduced to accommodate it. Strategy 2, on the other hand, entails a more certain level of change and the nuclear generators that it includes are more proficient in providing the required system services than the generators included in Strategy 1. This topic is explored in greater detail in Appendix D.

Overall, Strategy 1 negatively impacts on grid issues while Strategy 2 impacts positively.

## **Concluding remarks**

It is clear that CAP19, along with its associated projections by EirGrid and others, has the potential to generate 70% renewable electricity and reduce annual emissions to 4-5 million tons by 2030. But it is also clear that continuing beyond 2030 with the same strategies is not conducive to achieving net zero emissions electricity, let alone net zero emissions energy, in accordance with our national policy.

Introducing nuclear energy after 2030 has real potential to quickly reduce power generation emissions to their minimum, maintain renewable penetration at high levels, and offer better stability to the grid.

In particular, the GE-Hitachi X-300 SMR used in this analysis would also significantly reduce both the average cost of producing electricity and the capital cost of the entire power plant portfolio.

**According to our analysis, including nuclear energy in our electricity policy would have only positive impacts on our economy, emissions and electricity system, and should be considered urgently and in detail.**

## Data tables used in the assessment

Table 14 CAP19 Power plant portfolio in 2020 and 2030

Plant Portfolio		2020	2030
Wind - Onshore	MW	4120	8200
Wind - Offshore	MW	30	3500
Solar PV	MW	150	1500
Coal, Peat and Oil	MW	1755	0
Gas	MW	4154	4700
Hydro	MW	240	240
Biomass/Landfill (incl CHP)	MW	190	190
Renewable Waste:	MW	80	100
Ocean	MW	0	10
Pumped storage	MW	290	650
Conventional CHP	MW	162	180
Interconnection	MW	500	1700
Battery Storage	MW	0	1700
Demand Side Units	MW	350	750
<b>Total generating plant</b>	<b>MW</b>	<b>12021</b>	<b>23420</b>
<b>Total electricity</b>	<b>TWh</b>	<b>32.6</b>	<b>43.8</b>
Renewables	%	39%	68%
Fossils	%	56%	18%
Interconnection & Storage	%	5%	13%
Annual emissions	Mt CO <sub>2</sub>	10.9	4.9
Emissions Intensity	kg/MWh	334	112
Cost of electricity (LCOE)	€/MWh	65	112

Table 15 Strategy 1 Plant portfolio and predicted results from 2020 to 2050

Plant Portfolio		2020	2030	2040	2050
Wind - Onshore	MW	4120	8200	8900	9200
Wind - Offshore	MW	30	3500	4700	5400
Solar PV	MW	150	1500	1500	1500
Coal, Peat and Oil	MW	1755	0	0	0
Gas	MW	4154	4700	4700	4700
Hydro	MW	240	240	240	240
Biomass/Landfill (incl CHP)	MW	190	190	210	210
Renewable Waste	MW	80	100	100	100
Ocean	MW	0	10	50	90
Pumped storage	MW	290	650	650	650
Conventional CHP	MW	162	180	220	220
Interconnection	MW	500	1700	2200	2200
Battery Storage	MW	0	1700	2550	2550
Demand Side Units	MW	350	750	1250	1250
<b>Total generating plant</b>	<b>MW</b>	<b>12021</b>	<b>23420</b>	<b>27270</b>	<b>28310</b>
<b>Total electricity</b>	<b>TWh</b>	<b>32.6</b>	<b>43.8</b>	<b>48.3</b>	<b>52.8</b>
Renewables	%	39%	68%	71%	76%
Fossils	%	56%	18%	15%	13%
Interconnection & Storage	%	5%	13%	14%	13%
Annual emissions	Mt CO <sub>2</sub>	10.9	4.9	5.3	5.3
Emissions Intensity	kg/MWh	334	112	109	100
Cost of electricity (LCOE)	€/MWh	65	112	104	98

Table 16 Strategy 2 Plant portfolio and predicted results from 2020 to 2050

Plant Portfolio		2020	2030	2040	2050
Wind - Onshore	MW	4120	8200	7091	7000
Wind - Offshore	MW	30	3500	3500	3500
Solar PV	MW	150	1500	1500	1500
Coal, Peat and Oil	MW	1755	0	0	0
Gas <sup>53</sup>	MW	4154	4700	1505	0
Hydro	MW	240	240	240	240
Biomass/Landfill/CHP	MW	190	190	190	190
Renewable Waste	MW	80	100	100	100
Ocean	MW	0	10	50	90
Pumped storage	MW	290	650	650	650
Nuclear	MW	0	0	1500	1800
Conventional CHP	MW	162	180	180	180
Interconnection	MW	500	1700	2200	2200
Battery Storage	MW	0	1700	2550	2550
Demand Side Units	MW	350	750	1250	1250
Dispatchable low carbon	MW	0	0	900	900
<b>Total generating plant</b>	<b>MW</b>	<b>12021</b>	<b>23420</b>	<b>23406</b>	<b>22150</b>
Total electricity	TWh	32.6	43.8	48.3	52.8
Renewables	%	39%	68%	67%	69%
Fossils	%	56%	18%	2%	1%
Interconnection and Storage	%	5%	13%	14%	11%
Nuclear	%	0%	0%	18%	18%
Annual emissions	Mt CO <sub>2</sub>	10.9	4.9	0.9	0.9
Emissions Intensity	kg/MWh	334	112	19	17
Cost of electricity (LCOE)	€/MWh	65	112	97	85

Table 17 LCOE general input assumptions

Technology	Economic life	WACC	FOM	Build time	Overnight Cost €/kW			
	Years				%	€/kWyr	Years	2020
Wind - Onshore	20	10	53	2	1529	1434	1376	1376
Wind - Offshore	20	10	105	3	3327	2949	2754	2754
Solar PV	25	10	12	1.75	882	732	650	650
Coal	20	8.7	16	6	390	390	390	390
Gas CCGT	20	8.7	32	3	653	597	552	552
Gas OCGT	20	8.7	20	3	386	349	322	322
Oil	20	8.7	32	3	700	700	700	700
Peat	20	8.7	32	3	700	700	700	700
Hydro	60	8.7	32	7	3500	3500	3500	3500
Biomass/LFG/CHP	30	8.7	119	3	3151	2500	2012	2012
Renewable Waste	40	8.7	252	3	6630	6630	6630	6630
Ocean	60	8.7	32	5	4000	3500	3125	3125
Pumped storage	60	8.7	32	6	4000	4000	4000	4000
Nuclear <sup>54</sup>	60	10 - 8.7	32	4 - 3	5250	2970	2640	2640
Conventional CHP	20	8.7	32	3	653	597	552	552
Interconnection	-	-	-	-	1429	1429	1429	1429
Battery Storage	10	11	10	3	618	380	277	277
Dispatchable low carbon	60	10 - 8.7	32	4 - 3	5250	2970	2640	2640

<sup>53</sup> \* By 2040, this is mostly gas turbines installed after 2020 to support CAP19. They operate for 20 years design life at low capacity factor and provide reserve when very low winds coincide with low availability of imports.

<sup>54</sup> \* Overnight cost used for nuclear technology from 2030 is 50% above the GE-Hitachi X-300 estimate



Table 18 Renewables Capacity Factors for new plant

Capacity Factors	2020	2025	2030	2035	2040	2045	2050
Wind - Onshore	31%	33%	35%	39%	42%	42%	42%
Wind - Offshore	40%	42%	43%	45%	47%	49%	52%
Solar PV	11%	11%	11%	11%	11%	11%	11%

Table 19 Curtailment

Renewables curtailment	2020	2025	2030	2035	2040	2045	2050
Scenario extending CAP19	5%	7%	10%	11%	12%	14%	15%
Scenario Including Nuclear	5%	7%	10%	10%	9%	9%	8%

Table 20 LCOE of the primary technologies

LCOE calculation			2020	CAP19 2030	Strategy 1 2040 2050		Strategy 2 2040 2050	
Onshore wind	Load factor	%	31%	32%	35%	42%	34%	42%
	LCOE	€/MWh	<b>92</b>	<b>83</b>	<b>69</b>	<b>58</b>	<b>72</b>	<b>57</b>
Offshore wind	Load factor	%	40%	42%	43%	45%	42%	45%
	LCOE	€/MWh	<b>165</b>	<b>131</b>	<b>113</b>	<b>105</b>	<b>115</b>	<b>107</b>
Solar PV	Load factor	%	11%	11%	11%	11%	11%	11%
	LCOE	€/MWh	<b>121</b>	<b>100</b>	<b>84</b>	<b>82</b>	<b>84</b>	<b>82</b>
Gas CCGT	Load Factor	%	44%	29%	35%	35%	0%	0%
	LCOE	€/MWh	<b>30</b>	<b>42</b>	<b>27</b>	<b>27</b>	<b>N/A</b>	<b>N/A</b>
Gas OCGT	Load Factor	%	22%	11%	17%	11%	0%	0%
	LCOE	€/MWh	<b>36</b>	<b>67</b>	<b>35</b>	<b>54</b>	<b>N/A</b>	<b>N/A</b>
Nuclear	Load Factor	%	80%	80%	0%	0%	85%	79%
	LCOE	€/MWh	<b>115</b>	<b>61</b>	<b>N/A</b>	<b>N/A</b>	<b>49</b>	<b>44</b>

Table 21 Emissions Intensity of power plant in 2020

Technology	Units	Lifecycle	Direct to air
Wind - Onshore	kg/MWh	12	0
Wind - Offshore	kg/MWh	12	0
Solar PV	kg/MWh	43	0
Coal	kg/MWh	960	960
Gas CCGT	kg/MWh	425	425
Gas Peaking plant	kg/MWh	550	550
Oil	kg/MWh	700	700
Peat	kg/MWh	1150	1150
Hydro	kg/MWh	24	0
Biomass/Landfill (incl CHP)	kg/MWh	230	230
Renewable Waste	kg/MWh	425	425
Ocean	kg/MWh	0	0
Pumped storage	kg/MWh	0	0
Nuclear	kg/MWh	12	0
Conventional CHP	kg/MWh	400	400
Dispatchable low carbon	kg/MWh	12	0

## Appendix C Enabling low carbon technology

Appendix B demonstrates that the capital cost of the infrastructure needed to decarbonise power generation in Ireland will run into the tens of billions of euro, regardless of the technology used. However, there is growing concern both here and in the EU that current market mechanisms are not best suited to reduce emissions effectively or to facilitate the investment required.

For example, Deloitte<sup>55</sup> advises that carbon targets should be based on carbon reduction and not RES share. ESRI (in a 2020 Working Paper<sup>56</sup>) finds that “...decarbonisation policy in Europe has been driven to date by a mix of specific targets for emissions reduction, energy efficiency and renewable generation. Because using multiple instruments to achieve a policy objective tends to be sub-optimal, these overlapping targets will lead to a final energy and technology portfolio that is no cheaper, and possibly more costly, than the least-cost policy that targets emissions reduction alone.

*“For example, some low carbon technologies, such as nuclear power or carbon capture and sequestration (CCS), can aid in meeting a carbon reduction target, but not a renewable generation target. Any carbon abatement solution that can be arrived at under a policy mix that includes targets for emissions, renewable energy and energy efficiency can therefore also be arrived at by a policy that targets emissions alone, but the converse is not necessarily true”.*

Recent MaREI<sup>57</sup> research found that 70% emissions reductions can be achieved for half the GDP cost by following a ‘zero CO<sub>2</sub> policy’ targeting all technologies (low carbon CCS and renewables) compared to a renewables-only programme – see their graph below. They also found that a renewables-only programme could only reduce CO<sub>2</sub> by a maximum of 88% (due to residual industrial process emissions).

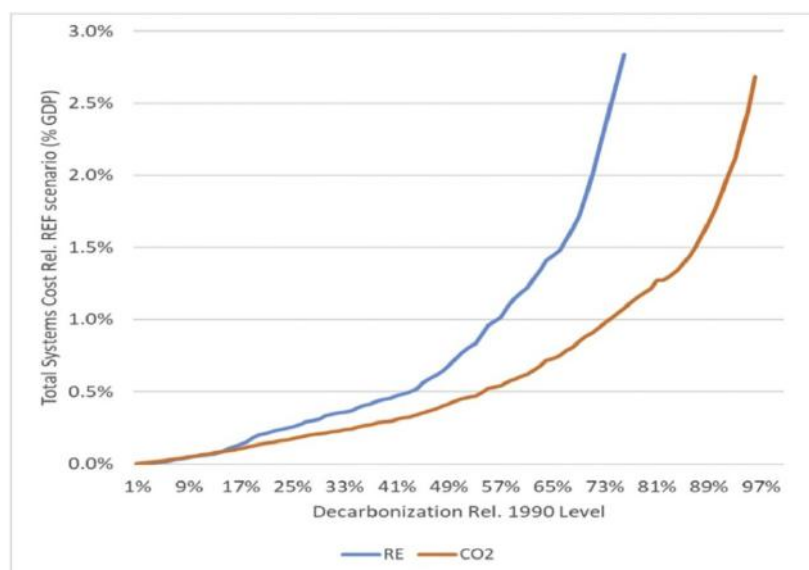


Figure 1 A Zero CO<sub>2</sub> policy is more effective and cheaper than a Renewables Only policy (MaREI)

<sup>55</sup><https://www2.deloitte.com/global/en/pages/energy-and-resources/articles/energy-market-reform-europe.html> : EU energy and climate policy measures had “numerous unexpected, or unintended impacts on energy markets and industry: an excess of intermittent sources of electricity causing disruption for grid operators, surplus electricity resulting in a price collapse on the wholesale electricity market, an electricity price increase at retail level, exit of gas from the fuels for power generation and the advent of coal as an electricity price setter”.

<sup>56</sup>[https://www.esri.ie/system/files/publications/WP657\\_1.pdf](https://www.esri.ie/system/files/publications/WP657_1.pdf) (a Working Paper undergoing Peer Review)

<sup>57</sup><https://www.sciencedirect.com/science/article/pii/S0360544220313712> “Focusing on renewable energy penetration is less cost effective in CO<sub>2</sub> mitigation compared to focusing solely on decarbonisation”

A simple illustration of unsuitable market structures hindering decarbonisation efforts is the 2020 collapse in the price of oil that prompted a demand for storage that will inevitably result in a relative increase in consumption of oil compared to cleaner alternatives.

Given the importance attached to meeting emissions reduction goals, it is vital that Ireland has market mechanisms that enable these goals. This is not the case today, where our policy includes targets for emissions, renewable energy and energy efficiency, and does not target emissions alone.

This Preliminary Study shows how nuclear energy could dramatically reduce Ireland's power generation emissions, but our market mechanisms may act as a barrier to investment in the technology even at its anticipated lower capital costs. For example, our market dispatches power plant based on lowest short run marginal cost. While this is useful for increasing renewable power generation, it is not necessarily in the best interests of emissions reduction, as outlined by ESRI, or if it reduces the production of nuclear electricity to the extent that it becomes unviable.

Ireland is facing a large increase in electrical demand. Including nuclear would also facilitate development of data centres, hydrogen production or similar energy-intensive facilities with no significant increase in power sector emissions.

Ireland should participate fully in the current EU research into how the market must develop to target emissions alone, rather than also including targets for renewable energy and energy efficiency, to ensure that market structures will enable us to meet Ireland's emissions goals.

## Appendix D Additional electrical grid information

### Inertia

#### What is Inertia?

Conventional generators on the grid behave with regard to mains frequency like carriages of a train – if one starts to go too fast or slow the others pull it into line (they are synchronous) – but most renewable power is not generated at mains frequency (they are non-synchronous) so there is a greater risk of departure in frequency which could bring the network to a stop. Nuclear plant is synchronous and would greatly improve grid stability.

Large synchronous generators provide inertia to the power system, helping to keep the grid frequency stable, particularly during sudden changes due to faults or transients. New technical solutions are needed to overcome the absence of inertia from non-synchronous generation and HVDC interconnection before current SNSP limits can be safely increased. SNSP limits enforce curtailment of non-synchronous generation, initially during periods of low electricity demand and when the weather favours wind and solar power generation, and more progressively as renewable capacity increases.

Gas fired generation is expected to form a significant portion of the generation portfolio in Ireland in the coming years, as coal and peat fired plant is retired. However, gas turbines provide less inertia to the system as the rotating mass of their turbines and generators is less than that of coal, peat and nuclear generators. The increased inertia of nuclear generators compared to gas turbines would provide greater stability to the grid at times of increased SNSP.

### System Services

EirGrid's DS3 programme<sup>58</sup> is designed to increase integration of non-synchronous generation. One of the key areas in the DS3 Programme is to obtain various non-energy system services, including reserve and fast frequency response, that generators can provide to the grid to enhance stability and reliability. Modern nuclear generators are proficient in providing these services.

### Dedicated and flexible electrical output alternatives

A nuclear plant could also contract with energy-intensive industries such as data centres and hydrogen production facilities to provide them with reliable, round the clock generation.

Hybrid SMR power plants are also being proposed. A simple example is where a station of one or more SMRs is co-located with an electrolysis plant such that the SMRs remain at full energy output, providing electricity as dispatched to the grid and diverting surplus electricity to the production of hydrogen. An alternative is to store surplus energy in thermal salt storage tanks.

### Accommodating larger plant

The largest plant in our study, at 1150 MW, would probably become the largest single infeed on the system until at least 2040 and could present grid stability challenges. A power plant of that size may only be suitable for the grid if accompanied by specific system constraint measures.

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<sup>58</sup><http://www.eirgridgroup.com/how-the-grid-works/ds3-programme/>

For example, a constraint mandating the export of excess power generation over, say, 600 MW from any single unit would limit the apparent loss of that large plant to the Irish system to no more than 600 MW, and that power could be quickly replaced by interrupting and reversing the associated interconnector flow. This constraint option would require detailed study.

This would increase the minimum reserve requirement from 525 MW, when the Celtic Interconnector is commissioned, to 600 MW.

Another alternative is that the plant would form part of a hybrid energy park containing a dedicated energy storage or energy carrier facility, including those for hydrogen production.

### Summary of anticipated changes to the Ireland’s electricity system

Table 22 below contains a summary of how the electricity system in Ireland could change between 2020 and 2040, if current policies are implemented.

Table 22 Summary of Grid assumptions following current policies

Summary	2020	2030	2040
Demand - ROI	32 TWh	43 TWh	48 TWh
Generation - ROI	12 GW	23 GW	26 GW
Renewables - ROI	37%	70%	>70%
Interconnection - ROI	800 MW	1700 MW	2200 MW
15% of capacity - ROI	1700 MW	3000 MW	3400 MW
Min generators - System	5 (ROI) + 3 (NI)	0 (ROI) + 0 (NI)	0 (ROI) + 0 (NI)
Min reserve - System	375 MW	525 MW	525 MW
SNSP limit - System	65%	>95%	100%

## Appendix E Additional spent fuel management information

For the initial ten or so years after removal from the reactor, spent fuel is held in deep tanks of water which require no input other than occasional water top ups due to evaporation.

Each tank of water is sufficiently deep that the heat from the elements is dissipated and the water temperature is generally kept below 50°C. Such facilities require minimum user input in-between fuel element changes but remain under constant supervision with appropriate infrastructure - water- and air-monitoring. The depth of water provides sufficient radiation shielding for personnel standing beside the pool. This initial stage in spent fuel management is ubiquitous in the industry and is internationally employed.

Once the fuel has cooled sufficiently and shorter lived radioactive isotopes have decayed, it can either be moved to wet cask storage, where it remains stored in water for an additional period of time, or into dry casks, which is now a more widely practised routine. The fuel may also be recycled depending on the preferences of the host country. Dry casks are multi-layered, sealed and reinforced containers, filled with an inert gas for optimal long term storage. The circulation of the gas inside the cask is sufficient to keep the elements cool at this stage.

The fuel will remain in the dry casks for a number of decades allowing the radioactivity and subsequent heating to reduce further. The spent fuel may then be moved into smaller containers, such as the KBS3 containers approved by the Swedish government, for long term storage in deep geological repositories.

It is a common misconception that the final disposal of spent nuclear fuel is a prevailing problem with no viable options and apparent evidence of this is in the fact that few countries have implemented a permanent solution. There is firm international consensus on the solution, based on natural events and rigorous testing providing evidence of efficacy. The deferment in implementation is due to the low volume of waste which poses very little risk, and the potential for future reductions in the overall volume requiring disposal. Finland is well-underway in constructing a deep geologic repository, with mature construction plans in place elsewhere.

Deep-geological repositories are considered internationally to be an economically viable and safe option for long-term spent fuel disposal, with test facilities currently in operation in Europe. They are constructed in rock formation with simple hydrogeology and tectonic history, such as argillaceous rocks and bedded salts.

Nature has provided us with evidence of the viability of this solution. Approximately 1.7 billion years ago, natural fission reactors existed due to the higher concentration of fissile isotopes of uranium. One such example is in Oklo, Gabon, where the naturally occurring fission reactor produced approximately 5 tonnes of fission products and 1.5 tonnes of plutonium. By analysing daughter nuclei of the products and near stable caesium isotopes, evidence on how far completely uncontained fission products could travel through the environment was assessed<sup>59</sup> and it was found a vast majority did not move despite water being able to freely flow through the cavern containing the natural reactor.

Materials disposed of in deep geological repositories are placed in stable rock formations with little water flow, in corrosion-resistant multiple barrier containers in stable configurations, either as glass or in the fuel pellet ceramic form. This multiple barrier approach assures isolation for geological time scales.

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<sup>59</sup> Evan E. Groopman et al. Discovery of fissionogenic Cs and Ba capture five years after Oklo reactor shutdown, *Proceedings of the National Academy of Sciences* (2018).

Deep-geological repositories can be classed depending on how economically viable it is to reclaim the spent fuel after disposal. Horizontal borehole utilizing solutions have been investigated, with a private company, Deep Isolation, holding a patent for a complete solution. Deep Isolation uses horizontal drilling technologies, utilized currently in industry, which may be then backfilled to seal the containers in the stable rock formations chosen. Deep Isolation successfully deposited a replica container and later retrieved it in early 2019. The vertical depth of the hole would typically be up to 5km, depending on the desired rock formations depth.

Some countries have planned or have begun to implement an underground mined shaft matrix of horizontal chambers, typically less than 2km deep. The infrastructure cost of this method is higher but guarantees easy access to all chambers until final sealing. The desire for retrievable containers, particularly those containing unprocessed spent fuel, is due to the only small proportion of the fuel's constituents needing permanent isolation.

Most reactor fuel is in the form of fuel elements comprising pellets of ceramic uranium dioxide sealed within thin metal tubes, generally stainless steel or zirconium alloys that are bundled together in a fuel assembly. The composition of spent fuel is approximately 96% Uranium, 1% Plutonium, with the remaining 3% being products of the fission process, most of which are stable or having an extremely long half-life and thus extremely low activity.

The fission products of particular concern have a half-life of approximately 30 years and will be less radioactive than the ore from which the uranium came in just over 500 years. Trace amounts of transuranic elements (elements with a higher atomic number than uranium, caused by the capturing of neutrons) are also present in the spent fuel.

The uranium content of the spent fuel can be recycled, being no more radioactive than the natural ore removed from the ground, with some of it being the fissile and valuable uranium-235. The plutonium content may be used in future reactors or recycled into fuels suitable for current light water reactor designs and as it contains the isotope, plutonium-240, poses no proliferation concern.

A typical SMRs entire fuel load, when spent, would contain up to 60kg of uranium-235 and 50kg of fissile plutonium with a combined energy equivalent of 400,000 tonnes of coal, potentially utilized with MOX fuel configurations or fast spectrum reactor designs. The fission products constitute the bulk of the radioactivity but are a very small volume of the fuel constituents.

The transuranic elements tend to have the longest half-lives but offer the potential to be destroyed by fast spectrum reactor designs, utilizing their energy potential, and are already reduced to smaller quantities with current reactor designs than previous generation reactors. International commitment to the Generation 4 reactor designs, many of which are based on prototypes, mean these options will likely become a feasible, routine option this century.

If fusion is to become an option, a process with heavy neutron fluxes is likely to be the first, offering a transuranic consuming potential. It is highly likely that, due to its remaining energy potential, spent fuel will be considered an asset rather than a liability in the near future.