SUSTAINABLE
ENERGY AUTHORITY
OF IRELAND

Briefing Note

SEAI expert elicitation on plausible deployment rates of variable renewable generation technologies in Ireland, 2025 – 2040

Introduction

This document should be read in preparation for the SEAI expert elicitation on plausible deployment scenarios and rates of offshore wind (OFW), onshore wind (ONW), and solar PV (SPV). It provides accompanying information on factors that may influence the deployment of these technologies in the coming years within the Republic of Ireland (ROI). It may serve as a starting point and aid for making explicit the factors and assumptions that shape your own deployment scenarios and forecasts during the interview.

Sections 1 – 9 of the brief highlights factors that affect the deployment of all three the technologies in the ROI. Sections 10 – 12 add additional points that are specific to each of the technologies separately. Overall, the brief does not assume or recommend any deployment scenarios or rates but seeks to highlight the factors or drivers that may affect deployment rates of variable renewable generation technologies in the ROI. We expect that experts will bring additional data, assumptions and causal models (formal or mental) to the discussion to construct their forecasts as part of the elicitation.

Briefing note

SEAI expert elicitation on plausible deployment rates of variable renewable generation technologies in Ireland, 2025 – 2040

Date 7 February, 2024

Report prepared by:
Frontier Economics & SEAI

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Sustainable Energy Authority of Ireland

SEAI is Ireland's national energy authority investing in, and delivering, appropriate, effective and sustainable solutions to help Ireland's transition to a clean energy future. We work with the public, businesses, communities and the Government to achieve this, through expertise, funding, educational programmes, policy advice, research and the development of new technologies.

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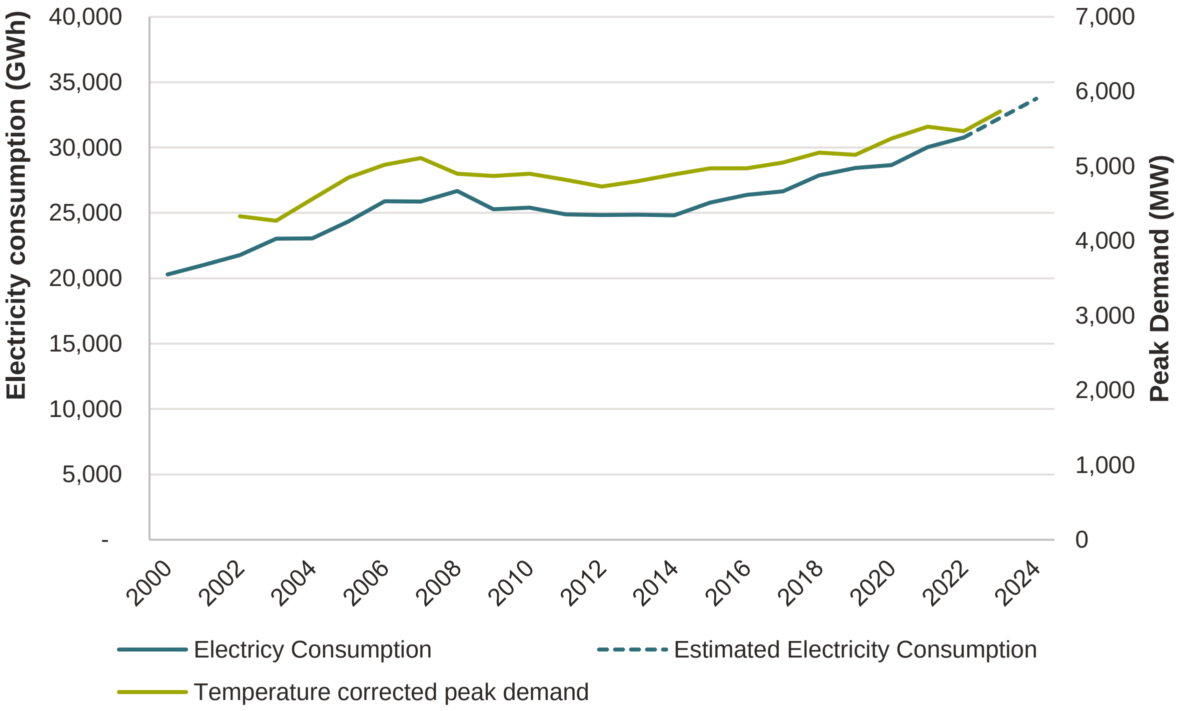
Contents

1. Historical electricity demand and supply in Ireland

This section summarises the historical electricity demand in Ireland and the sources of fuel used to satisfy this demand. Figure 1 shows the electricity demand and peak demand in Ireland from 2000 to the end of 2023.

Figure 1 - Electricity consumption



Source: *SEAI, Key Energy Statistics (Available here) and Eirgrid (January 2024), Grid Capacity Statement 2023-2032 (Available here)*

Note: *The chart assumes that the demand for 2023 and 2024 grew and will grow in line with the growth rate in GCS 2023.The Peak Demand showed is the historic, temperature-corrected peak*

Figure 2 illustrates the fuels used to meet electricity demand from 2000 to 2023. Natural gas is the most common fuel type used for electricity generation in Ireland. Electricity generated with natural gas reached its peak in 2010 (18.11 TWh, equivalent to 62.8% of the electricity generated). Since then, it has stayed between 15.5 to 16.5 TWh, and the percentage it represented of total production has decreased. In 2023, natural gas accounted for 43% (14.2 TWh) of the electricity generation[14].

Electricity generated by onshore wind power has increased substantially over the period considered. Since 2010 there has been a steady increase in electricity generation from onshore wind power, from 2.8 TWh in 2010 to 11.6 TWh in 2023. Proportionally, wind has increased from generating 10% of electricity to 35% of electricity in 2023, at an average annual growth rate of approximately 12%. As shown in Figure 3, installed wind capacity has increased substantially over the past decades, from 117 MW in 2000, to 4.7 GW in September 2023.[1] 2017 holds the record for most installed capacity in a year at 507 MW. However, the pace of adding wind capacity has slowed in recent years, from 450 MW in 2019 to a low of 9 MW in 2021. In 2023, 185 MW of onshore wind was installed.[2]

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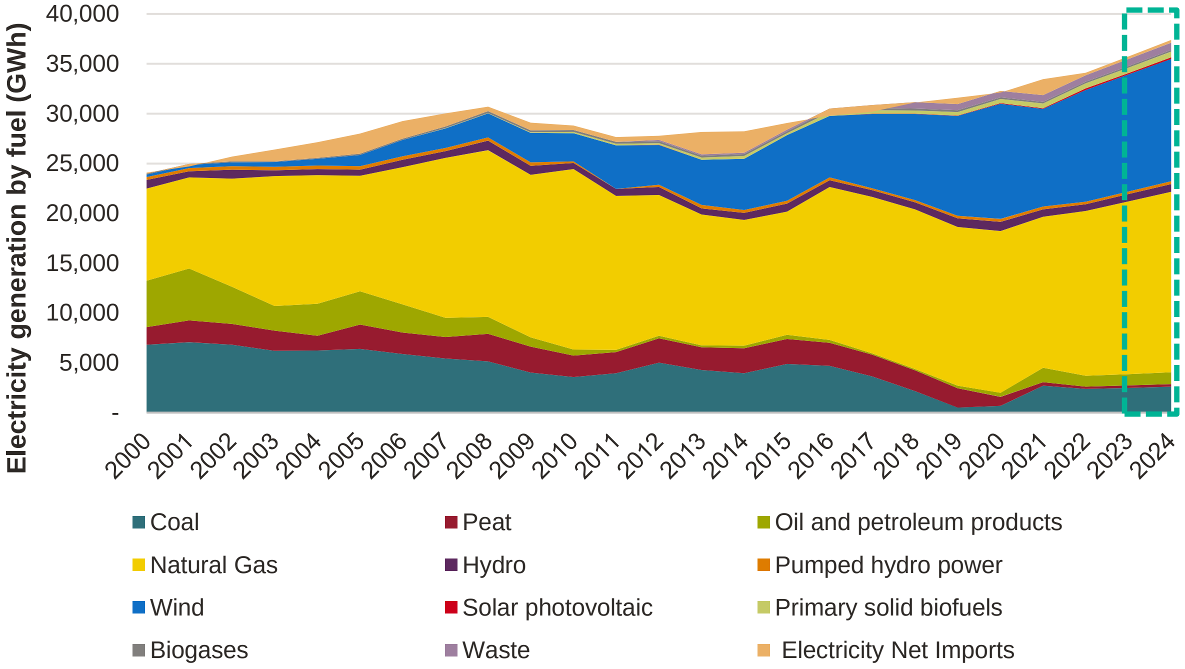
[1] Arklow Bank Phase 1 (25 MW), constructed in 2005 as a demonstration project, is Ireland's first and only offshore wind farm. Its generation is not reported separately.

[2] This figure excludes DSO data for Q4 2023.

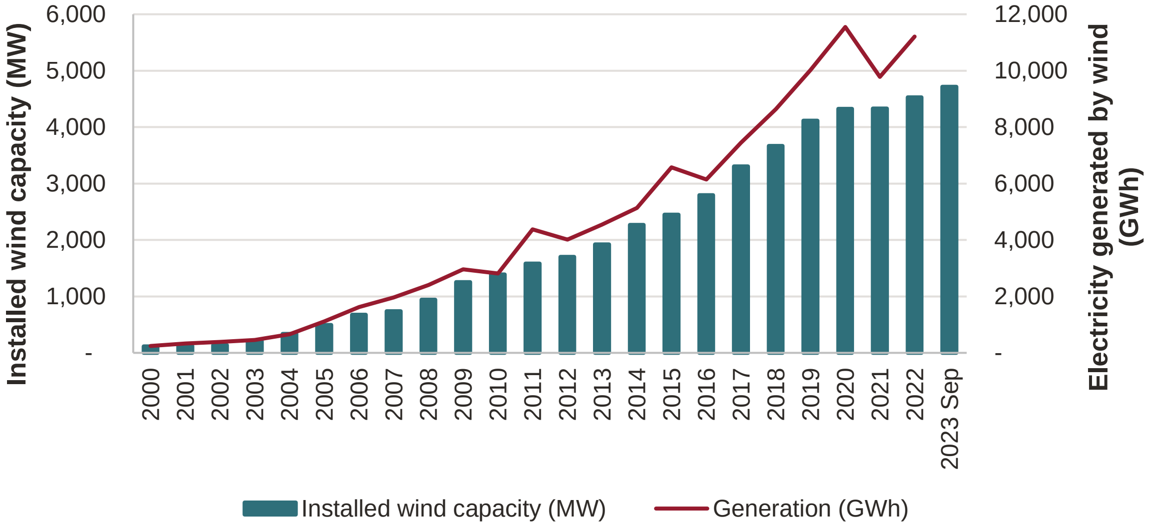
Figure 2 - Electricity generation by fuel



Source: Eurostat, Dataset nrg_bal_peh (Available here), CSO, Fuel used in electricity production (Available here)

Note: Data for 2023 and 2024 are calculated based on the assumption that electricity generation has and will continue to grow in accordance with the GCS 2023 growth rate and that the percentage breakdown of fuels remains consistent with that observed in 2022.We note that the total in this chart is slightly above the electricity consumption in the figure above. This is likely due to transmission and distribution losses, as well as own electricity use.

Figure 3 - Installed wind capacity and electricity generated by wind



Source: Eurostat, Eirgrid

Solar's contribution to electricity supply can be divided between small scale solar, mostly on rooftops, and utility-scale solar farms. The small-scale sector has increased strongly with recent government incentives, from around 0.01 – 0.1 % of supply. Utility scale solar projects have recently added significantly to national supply. In 2023, solar PV generated 372 GWh (1%) of electricity. Table 1 below synthesises the data available on solar installed capacity in Ireland. By the end of 2023, ROI has approximately 744 MW of installed solar capacity, with at least half of it (384 MW) connected in 2023.

Table 1- Installed solar capacity

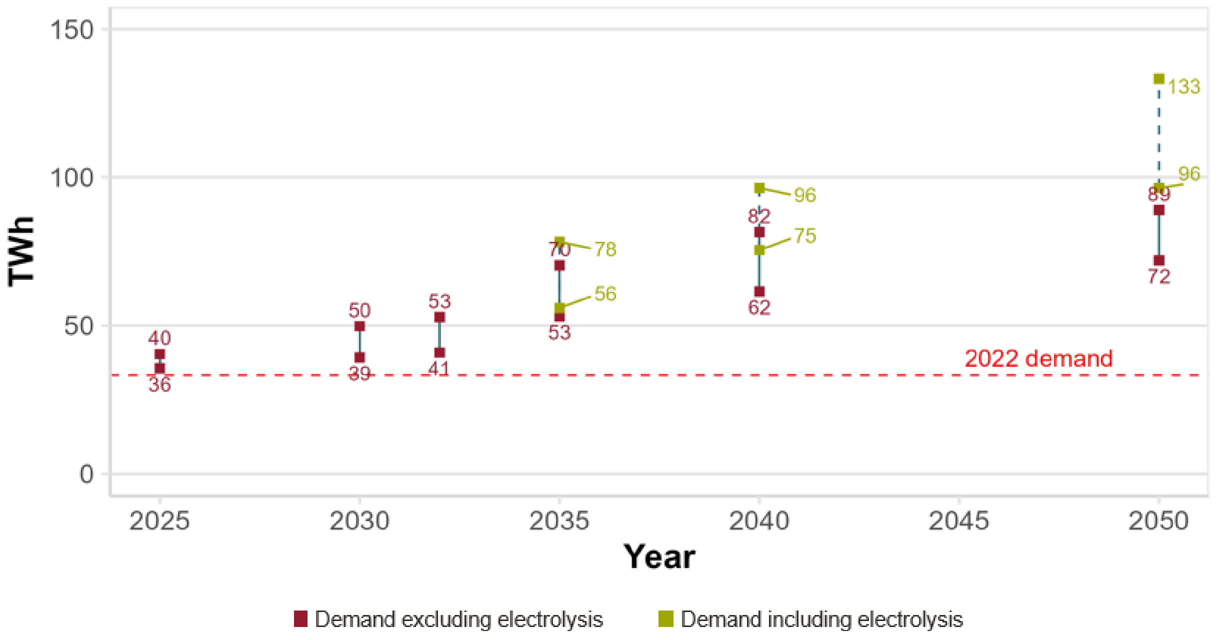
Type of solar	MW	Comment
Transmission-connected	369.0	• All plant connected in 2023 • 4 projects, between 60 to 110 MW
Distribution connected	67.1	• 51.7 MW connected in 2022, 15.4 in 2023 • 17 projects, of which 4 (40 MW) above the 5 MW size. 5 projects (25.5 MW) are between 1 and 5 MW.
Mini-generation	5.0	• Mini-generation projects typically have a capacity between 17kVA and 50kVA. Usually installed by businesses and farms for consumption of their self-generated electricity
Micro-generation	208.0	• Solar PV installed on household roofs
Auto-production	95.0	• No export to the grid
Total capacity	**744.1**	

Source: *Eirgrid (January 2024), System and Renewable Data Summary Report, Available here; ISEI (June 2023), Scale of Solar, Available here*

2. Projections of Irish electricity demand up to 2050

Figure 4 and Figure 5 summarise the different projections of electricity demand and peak demand by showing the range of the forecasts. Annex B presents electricity demand and peak demand forecasts for each source separately and summarises the underlying assumptions.

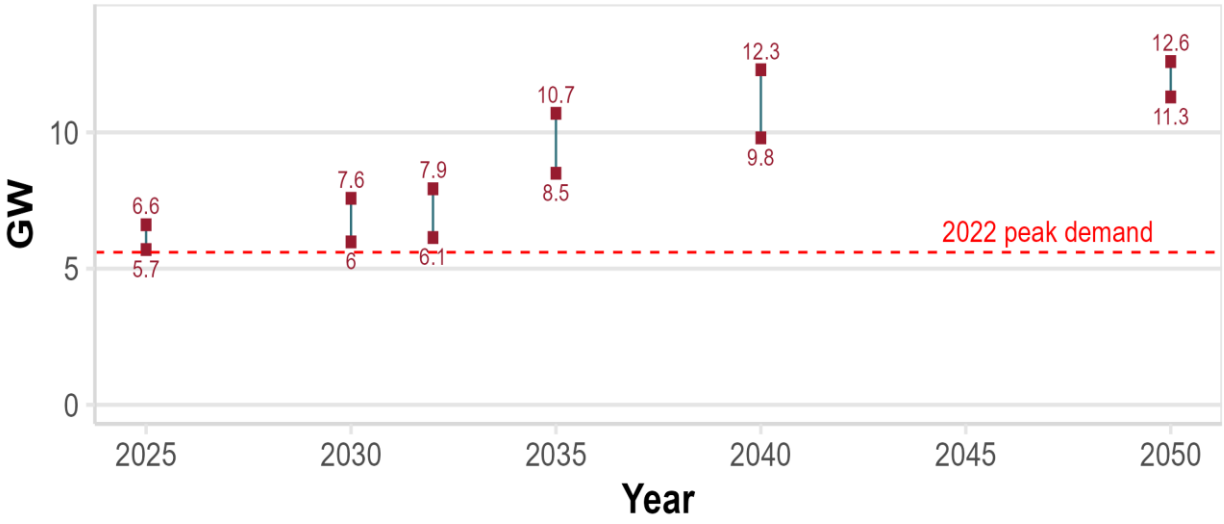
Figure 4 - Electricity demand forecast range



Source: *Eirgrid GCS 2023, Eirgrid TES 2023, SEAI Heat Study, and SEAI National Projections*

Note: *This chart displays the ranges in electricity demand forecasts for GCS 2023, TES 2023, SEAI Heat Study, and SEAI National Projections. The points in red represent the minimum and maximum aggregate electricity demand. The points in green and* *the dotted line show the range including the demand for electrolysis as per TES 2023.[3] Note that EirGrid states that this demand may be satisfied by off-grid plants.*

Figure 5 - Electricity peak demand forecast range



Source: *Eirgrid GCS 2023, Eirgrid TES 2023*

Note: *This chart displays the ranges in peak electricity demand forecasts for the sources considered (GCS 2023, TES 2023). Note that TES 23 does not report peak demand considering the additional load for green hydrogen production.*

Peak demand is expected to increase at a slightly lower rate than total demand due to the expected increase in demand flexibility. The CAP has established targets for demand flexibility, aiming for 15-20% by 2025 and 20-30% by 2030. The TES 2023 scenarios foresee a need for 20‑50% demand flexibility by 2050.

Several public consultations have been launched to date relating to demand-side flexibility, including the CRU's consultation on National Energy demand[4], ESB Networks' consultation on Demand Flexibility Product Proposal[15], and Eirgrid's consultation on Long Duration Energy Storage[13],[4]. In its document, the CRU recognises the urgency for Ireland to progress on demand flexibility, and focuses on near-term actions. According to the CRU, the greatest potential in the near term lies in procuring flexibility services (explicit flexibility) from LEUs and storage.[5] ESB Networks' and Eirgrid's consultations align with this view. In particular, ESB Networks proposes to procure demand flexibility products in locations where there is a high system need. It anticipates of procuring 100 MW in the first round, and up to 500 MW by 2025. Similarly, Eirgrid aims to launch its procurement scheme for long energy duration storage in January 2025.

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[3] Eirgrid considers electrolysis demand separately, as this load could be supplied by non-grid-connected generators and therefore should not be considered as part of the electricity load.

[4] We note that the SOs have already implemented various programmes. With DS3, Eirgrid procures services that provide flexibility. ESBN has recently launched programmes as "Beat the Peak Business" and "Is this a good time?"

[5] Generally speaking, demand flexibility could be provided by different technologies/customers (domestic customers, business and storage providers) and incentivised in different ways (differentiated tariffs, dedicated procurement contracts, and clauses in connection contracts).

3. Grid capacity

Decarbonising the Irish power sector requires a significant programme of works to expand and reinforce the transmission and distribution grid. Eirgrid describes the grid investment required to meet current renewable electricity targets[6] as "simply the most ambitious programme of works ever undertaken on the transmission system in Ireland"[9]. It require significant and timely capital expenditure and human resources from the TSO and DSO, as well as depending on the alignment of several other factors. These include timely planning decisions (including granting of licences for site investigation); the availability of sufficient outages and the efficient utilisation of outage windows by multiple parties to deliver required grid infrastructure; availability of the road network for routing of underground cable infrastructure; and the availability of suitable land for strategic network investments[10].

Significant investment in Ireland's electricity grid is required to accommodate additional generation, especially renewables, and to meet expected demand growth. Eirgrid estimates that investment of €3.4 billion is required in transmission capex by 2030 [10]. This includes both connecting generation and reinforcing the network to accommodate additional load. In comparison, the transmission system and asset owners spent, on average, €152 million per annum on total regulatory capex in the five years to 2022. In other words, annual capex will need to nearly triple for the rest of the decade to enable the 2030 RES-E target.

System operators have previously undertaken programmes of work to support the rapid deployment of renewables, although not all planned capex has always been delivered. For example, the previous price control period for the transmission system operator (TSO) and asset owner (TAO) ran from 2016-2020. The regulator had allowed for €1,024 million of capex, but €823 million was spent during the period[3]. The key issues affecting project delivery during this period were identified as land access and planning issues, in particular social opposition to large scale 400kV projects[3].Planning issues are discussed in more detail below.

Eirgrid has identified several risks to delivery of the necessary grid investment[10]. These include a shortage of materials (e.g. HV cable); security of supply constraints or other system conditions restricting outage windows; a shortage of human resources (including contractors and sub-contractors) to support a growing pipeline of projects to 2030; and delays on land acquisition and land access[11].

One proposal that is currently being piloted to facilitate increased volumes of renewables connecting to the network is "Renewable Hubs". Renewable Hubs would be advanced substations where network capacity will be created in advance of an expected pipeline of projects (e.g. onshore wind in the pilot scheme). If successful, this could reduce the time taken for relevant clusters of renewable projects to connect to the grid.

4. Grid connection

This section discusses the onshore wind and solar grid connection policies and grid development plans. Offshore connection policy is discussed separately in Section 10 (p. 19).

The connection pathway for onshore wind and solar projects is via the CRU's Enduring Connection Policy (ECP) approach. Projects with planning permission are able to apply for grid connection in batches during

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[6] The Climate Action Plan 2023 (and the draft for 2024) targets for 2023 are 9 GW of solar, 8 GW of onshore wind, and 5 GW of offshore wind.

specific time windows. Table 2 shows the total connection capacity for wind and solar offered on ECP agreements that are not operational or have a RESS offer.

Table 2: Current ECP agreements (not operational or in RESS) for Solar as of October 2022. ECP2.4 figures include hybrid projects with storage.

	ECP 1 (MW)	ECP 2.1 (MW)	ECP 2.2 (MW)	ECP 2.3 (MW) (A)	ECP 2.4 (MW) (A)	Total ECP (MW)
Solar	60	544	1,079	1,835	1,653	**5,171**
Wind	83	432	340	422	406	**1,682**

The CRU is currently consulting on a new grid connection policy. The recast Renewable Energy Directive requires that the permit granting process (including planning permission and grid permitting) for onshore renewable projects shall not exceed two years for projects. The current permit-granting processes in Ireland do not adhere to these timelines[5]. The timelines for grid connection permitting alone (excluding planning) can be more than two years[5]. This new policy consultation has been driven primarily from delays in onshore wind applications, but the new policy would also likely be relevant for solar.

5. Grid management

As the penetration of variable renewables increases, existing and new system services will be required to ensure system stability. Without these system services, an increasing proportion of renewable electricity will be dispatched down.[7] Over the past decade, Eirgrid has successfully increased the System Non-Synchronous Penetration (SNSP) on the Irish grid from 50% to 75%, addressing one of the sources of dispatch down[10].

Figure 6 shows the amount of wind dispatch-down in Ireland for the period 2016‐2023. About 56% of the wind dispatched down was caused by local network constraints, while the remainder was due to system-wide reasons. In 2023, 37 GWh of solar PV, equivalent to 9.3% of the available volume, was dispatched down.[8]

Figure 6 - Historical level of wind constraint and curtailment

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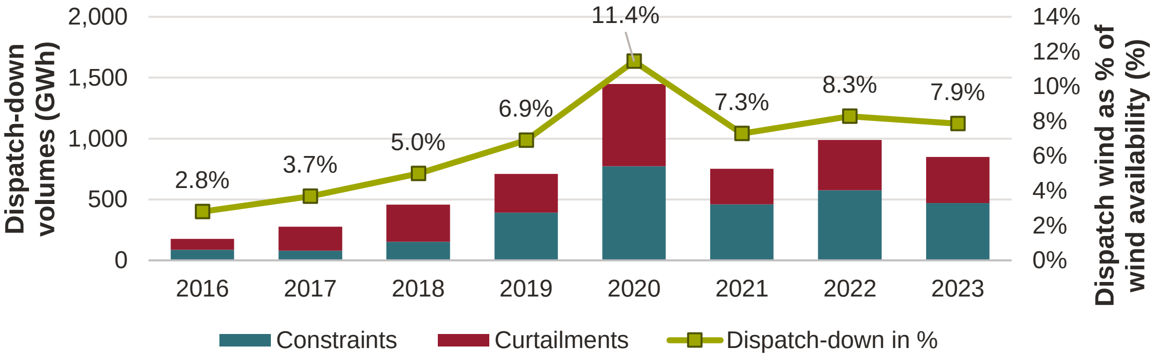
[7] Dispatch-down of renewable energy refers to the amount of renewable energy that is available but cannot be used by the system. There are typically three reasons why renewable generation is dispatched down: curtailment (operational limits of the system), constraint (local network limitations), oversupply (total available generation exceed system demand plus interconnection export flows).

[8] Eirgrid reports dispatch-down volumes and percentages specifically for solar from 2023.



Source: Eirgrid (2023), DD Summary Spreadsheet. Available here

To reach an 80% RES-E target, the Irish system needs to operate at a SNSP close to 100%. This will require various forms of flexibility, including new regulatory and market practices and technologies to minimize dispatch down of renewables[9]. The CAP 2023 set a target of keeping dispatch-down below 7% by 2030[19]. However, a recent independent estimate finds that dispatch-down of renewables could reach at least 16% by 2030 (in a scenario where the ROI reaches its 2030 RES-E targets), even if various forms of flexibility measures were successfully introduced, including synchronous condensers, medium term storage, and demand response[38]. Annex C includes Eirgrid's forecasts for dispatch-down.

RES generators may receive compensation for some or all of the electricity subject to dispatch-down, mitigating the financial risks associated with dispatch-down. For instance, successful projects in the RESS 3 and ORESS auctions will be compensated at the strike price for availability not converted to generation, whether due to oversupply or curtailment.[24] However, there is a risk that such schemes will distort the market signal for developers to co-invest in storage[38]. RES generators also have the potential to recover some of the lost revenue associated with dispatch-down by redirecting that electricity towards hydrogen production. As the temporal characteristics of dispatch-down may not match the minimum load factor requirement of electrolysers, the economic viability of the latter remains uncertain.

6. Market conditions that may affect Irish deployment of VRE

This section briefly covers market factors such as required investment, labour and skills for decarbonising the Irish power sector and technology cost trajectories.

Required investment

A rapid increase in renewable generation in Ireland will require a step change in the required investment. Table summarises a recent estimate of the additional investment required in renewable generation to meet the 2030 renewable electricity targets[6]. No publicly available reliable estimates exist for historic investment in renewable generation in Ireland, but over the last *15 years* approximately 5.4 GW of wind and solar PV have been installed, which is about a quarter of the total installed capacity required to meet 2030 renewable electricity targets, giving a very rough quantum of the step-change in investment.

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[9] As, for example, the reduction of the minimum number of conventional units, synchronous condensers, grid-forming and other emergent technologies. Source: Eirgrid (2022), Operational Policy Roadmap 2023-2030. Available here

Table 3: Scale of required investment to meet 2030 RES-E targets

	Gap to 2030 target	Required investment
Offshore wind	5 GW	€15 billion
Onshore wind	4 GW	€5 billion
Solar	6 GW	€4 billion
Back-up capacity		€1 billion
Grid		€14 billion
Storage		€4 billion
Total renewable generation		**€43 billion**

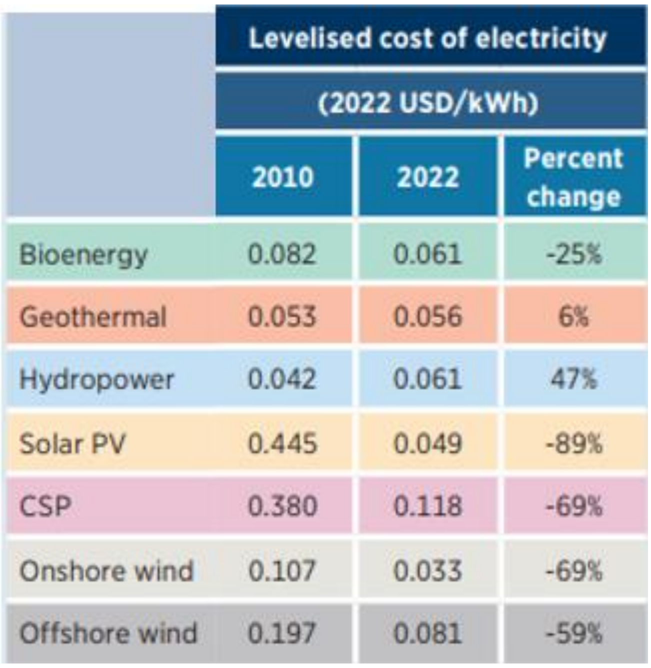
Source: *Davy (November 2023), Investing in Tomorrow: Shaping a Net-Zero Future. Available here*

Cost differentials between technologies

Cost differentials in levelised cost of energy (LCOE) can be one of the factors that influence both government support for technology-specific policies and market demand for renewable generation as a means of decarbonisation (as compared to other policies), and particular VRE technologies as contributors to a RES-E target. These trends also influence corporate demand for renewable electricity (e.g. through CPPAs).

Figure 7 below shows changes in LCOE by technology for 2010 and 2022. The comparatively cost of energy from fossil fuel has been a key driver of the deployment of renewables. Since 2010 the global weighted-average LCOE of onshore wind has decreased from being 95% higher than the lowest fossil fuel-fired electricity to being 52% lower than the cheapest fossil fuel-fired solutions. Over the same period, solar PV went from being 710% more expensive than the cheapest fossil fuel-fired solution to costing 29% less than the cheapest fossil fuel-fired solution.

Figure 7 - LCOE by technology



	Levelised cost of electricity (2022 USD/kWh)		
	2010	2022	Percent change
Bioenergy	0.082	0.061	-25%
Geothermal	0.053	0.056	6%
Hydropower	0.042	0.061	47%
Solar PV	0.445	0.049	-89%
CSP	0.380	0.118	-69%
Onshore wind	0.107	0.033	-69%
Offshore wind	0.197	0.081	-59%

Source: *IRENA, Flexible Power Generation Costs in 2022, Available here*

However, although the global LCOE has shown a remarkable decrease in the costs of onshore wind, offshore wind and solar PV, different markets have moved in different directions. Recently solar PV costs increased 34% in France and Germany, and 51% in Greece, driven by rising PV module and commodity prices at the end of 2021 and into 2022. Some of this variability represents the normal variation in individual project costs, but it is likely that commodity and labour cost inflation had a significant impact on some markets. The IEA estimates that electricity generation costs from new utility-scale onshore wind and solar PV plants are likely to remain 10-15% above pre Covid-19 values in most markets outside China in 2024. This is due to commodity and freight prices, and increases in developers' financing costs due to rising interest rates.[25] Furthermore, LCOE's for projects in Ireland may differ from international averages because of multiple local factors, including land leasing costs, local authority rates and development levies, and grid costs.

In the ROI (and shifting from LCOE to auction prices), since 2020, the combined weighted average strike price for onshore wind and solar PV increased significantly in successive RESS auctions, from €74 /MWh (RESS-1, 2020), to €98/MWh (RESS-2, 2022) and €100 / MWh (RESS-3, 2023). In 2023, offshore wind came in at €86 /MWh (ORESS, 2023), lower than the average combined strike price across solar PV and onshore wind in the same year. The aforementioned prices may also be strongly influenced by the auction terms and conditions and how these allocate risks.

Routes to market

The government supports onshore wind and solar PV via the Renewable Energy Support Scheme (RESS).[17] In order to qualify to compete in RESS, developers must have planning permission and a grid connection offer or agreement. The Programme for Government commits to holding RESS auctions at frequent intervals. To date, there have been three RESS auctions, details of which are summarised in Table 4 below. The next auction (RESS-4) is scheduled for Q4 2024. The current final scheduled auction is RESS 5 in 2025, but it is expected that RESS will be extended beyond this timeframe.

Table 4 - RESS 1, 2, and 3 auction outcomesTable 4

	RESS 1	RESS 2	RESS 3
Successful onshore wind projects	19	14	3
Volumes – capacity	479 MW	414 MW	148 MW
Successful solar projects	63	66	20
Volumes – capacity (solar)	769 MW	1,534 MW	498 MW
Price[10]	€74.08/MWh	€97.87/MWh	€100.47 MWh

Source – Eirgrid (June 2023), ORESS 1 Final auction results. Available here

RESS is not the only route to market for onshore wind. A key alternative route to market is a corporate power purchase agreement (CPPA).[18] CPPAs are used in Ireland (and elsewhere) by large corporate users, such as data centres. In Ireland these have typically been onshore wind (and more recently solar).

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[10] i.e. Weighted Average Strike Price of Successful Offers including solar PV and wind power.

Offshore wind power generation in Ireland is supported via the Offshore Renewable Electricity Support Scheme (ORESS). The first ORESS auction (ORESS 1) was held in 2023.[11] Six projects qualified to participate in the auction, and four of those projects received CfD offers (Table 5).[12] The auction awarded a total capacity of 3.1 GW at a weighted average price was €86.05 per MWh. [12]

Table 5 - Successful ORESS 1 projects

Successful applicant	Project	Offer quantity
Kish Offshore and Bray Offshore Wind Limited	Dublin Array	824 MW
Fuinneamh Sceirde Teoranta	Sceirde Rocks Offshore Wind Farm	450 MW
North Irish sea Array Windfarm Limited	North Irish Sea Array (NISA)	500 MW
Codling Wind Park Limited	Codling Wind Park	1,300 MW

Source: Eirgrid, ORESS 1 Final Auction Results

To date, none of the ORESS 1 winners have received planning permission and it is possible that one or more projects may face judicial review.[12] The ORESS1 projects must start generating electricity by 31st December 2031, though extensions are possible if a project falls under the judicial review clause (clause 7.3) of the terms and conditions.

In 2023, the government issued a policy statement for future ORESS auctions. The next ORESS auction (ORESS 2.1) is provisionally scheduled for February – June 2025. Currently, government proposes to procure up to 900 MW from this auction. Importantly, the auction will be spatially restricted to projects within a state-designated DMAP off Ireland's south coast. This area has been chosen as it aligns with existing available onshore grid capacity identified by EirGrid.[22] The DMAP has not yet been published and the auction process will only proceed once the Oireachtas approves the DMAP under the MAP Act. Government also anticipates the possibility of a judicial review of the DMAP (included in the aforementioned scheduled date). Government envisages that subsequent 'Phase 2' auctions (after ORESS 2.1) will exclusively procure offshore wind capacity from a single auction winner within individual DMAPs.[21]

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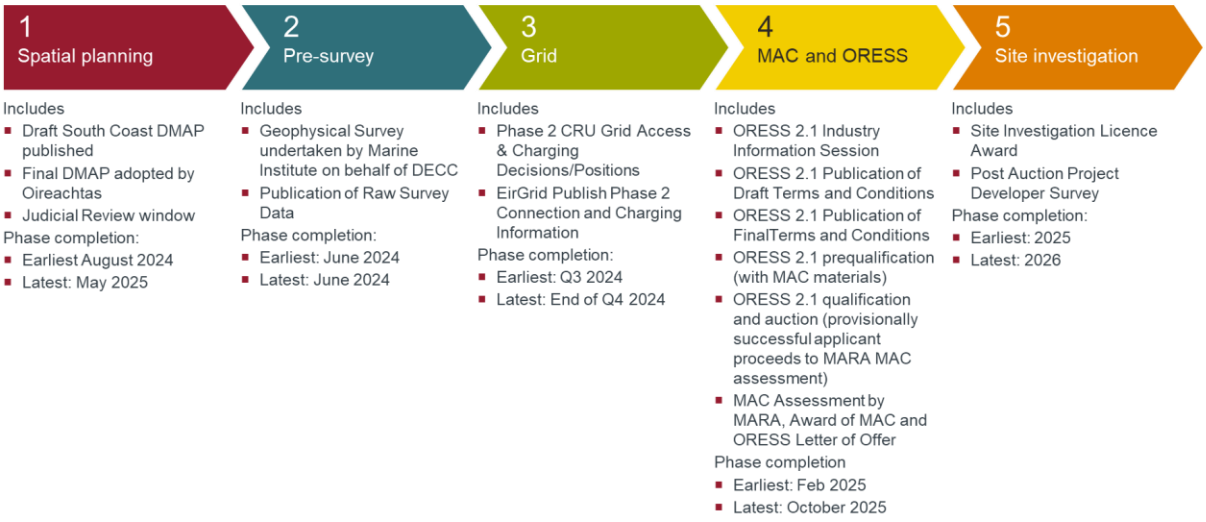
[11] In early 2022, six offshore wind projects, comprising nearly 4GW, that had already had a longer history of development (i.e. had either obtained planning consent, or a grid connection offer, or had conducted significant development under a foreshore licence) were fast tracked for ORESS. Five of these projects are in the Irish Sea, the Sceirde Rocks project is off the Galway coast.

[12] To participate in the ORESS 1 auction, developers needed a MAC, but did not need planning permission.

Figure 8 - Summary of ORESS 2.1 indicative roadmap



1 Spatial planning

Includes
- Draft South Coast DMAP published
- Final DMAP adopted by Oireachtas
- Judicial Review window

Phase completion:
- Earliest August 2024
- Latest: May 2025

2 Pre-survey

Includes
- Geophysical Survey undertaken by Marine Institute on behalf of DECC
- Publication of Raw Survey Data

Phase completion:
- Earliest: June 2024
- Latest: June 2024

3 Grid

Includes
- Phase 2 CRU Grid Access & Charging Decisions/Positions
- EirGrid Publish Phase 2 Connection and Charging Information

Phase completion:
- Earliest: Q3 2024
- Latest: End of Q4 2024

4 MAC and ORESS

Includes
- ORESS 2.1 Industry Information Session
- ORESS 2.1 Publication of Draft Terms and Conditions
- ORESS 2.1 Publication of FinalTerms and Conditions
- ORESS 2.1 prequalification (with MAC materials)
- ORESS 2.1 qualification and auction (provisionally successful applicant proceeds to MARA MAC assessment)
- MAC Assessment by MARA, Award of MAC and ORESS Letter of Offer

Phase completion
- Earliest: Feb 2025
- Latest: October 2025

5 Site investigation

Includes
- Site Investigation Licence Award
- Post Auction Project Developer Survey

Phase completion:
- Earliest: 2025
- Latest: 2026

Source: Government of Ireland, ORESS 2.1 Indicative Roadmap. Available here

Finally, government has also published the intentions for 'Phase 3' ORESS auctions. It is envisaged that an initial 2 GW of floating offshore wind capacity will be procured off Ireland's South and West coasts, and may include projects available for green hydrogen production and other non-grid uses. Longer term, the government proposes developing an 'Enduring Regime' for offshore wind that will increase state involvement in the development of Ireland's offshore renewable energy sector, including through designation of maritime zones for future offshore projects, timing future development, and determining the optimum offshore renewable energy technology mix.

In addition to the ORESS, corporate power purchase agreements (CPPAs) present another route to market.[20] No offshore wind farm has yet made use of a CPPA to access the Irish market. The requirements for CCPA-supported offshore wind projects to receive gird connection offers is currently unclear. In future, it is possible that offshore wind projects in Irish waters may follow the approach of "revenue stacking" where developers contract a certain proportion of their output under renewable subsidy schemes (similar to ORESS), and a certain proportion of their output under a CPPA and/or a merchant operation.

Irish labour market, skills needed for deployment of VRE generation in Ireland

A skilled labour force is a key enabler for transitioning the economy to net zero. Some of the required skills will be common across technologies, while other skills will differ by technology deployed. In order to reach national RES-E targets, a significant increase in the supply of a range of existing skills/occupations as well as a change in the skills mix is required. [28]

Figure 9 shows the modelled labour demand expected from offshore wind, onshore wind and grid-scale solar over the 2020-2030 period based on meeting renewables targets.[13]

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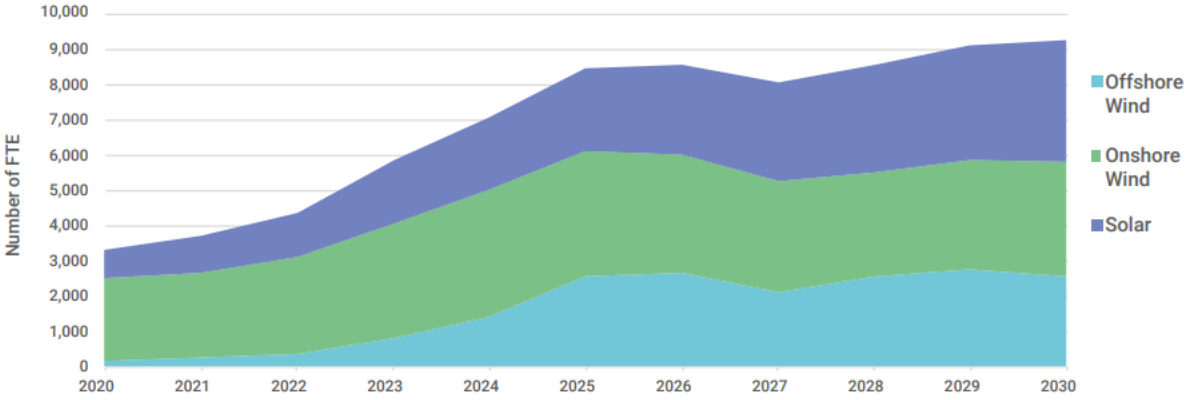
[13] It is based on the modelled cumulative installed capacity of offshore wind, onshore wind and solar energy: an additional 5GW of new offshore wind, 4GW of new onshore wind, and 2.9GW of new grid-scale solar energy by 2030. Increases in small-scale residential solar installations were captured separately within another model for retro-fits. Labour requirements are expressed in terms of 'Full-Time Equivalents' (FTE), which approximates the number of full-time workers that would be required to meet the labour demand.

Figure 9 - Modelled labour demand from offshore wind, onshore wind, and grid-scale solar energy, 2021-2030



Source: Skillnet Ireland, [https://skillsireland.ie/all-publications/2021/5119-dete-egfsn-skills-for-zero-carbon-web .pdf](https://skillsireland.ie/all-publications/2021/5119-dete-egfsn-skills-for-zero-carbon-web%20.pdf),

Labour supply allocated to offshore wind, onshore wind and grid-scale solar would have to triple from approximately 3,500 FTE per year in 2020 to over 9,000 FTE per annum in 2030. As onshore wind is a comparatively mature industry in Ireland, most of this growth in labour demand is expected to come from offshore wind and solar, with growth in onshore wind more moderate. Grid-scale solar PV has the largest growth in FTE labour demand. This is because solar is the most labour-intensive of the three sectors relative to installed capacity, reflecting the small scale of most solar farms in comparison to wind.

Error! Reference source not found. Figure 10 shows this FTE labour demand in terms of the main occupational groups. By 2030, the main occupational groups are expected to be construction and installation occupations (approx. 3,200 FTE), technicians and technical professionals including maintenance technicians (1,900 FTE), and engineering professionals (1,300 FTE). An existing overall shortage in construction occupations may constrain activity in the renewable energy sector.[14] [37] [29] Furthermore, a particular acute shortage in electrical trades may emerge because of government policies to support multiple areas of the energy sector, including the deployment of heat pumps, EV's, domestic solar PV, wind and solar farms, and grid infrastructure. Such a deficit might not be addressed by short term retraining.

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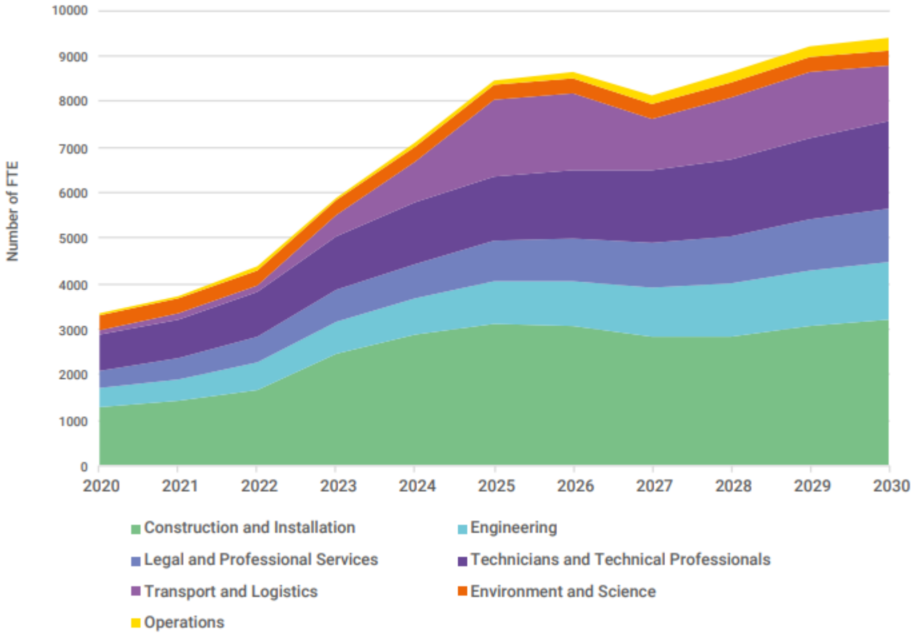
[14] Upskilling in construction occupations is especially challenging given the pipeline of work that was suspended during COVID-19 workplace closures. The National Skills Bulletin 2022 identifies significant implications for construction-related skills from the transition to a zero-carbon economy. While a small number of relatively new occupations (e.g. wind turbine technician, retrofit coordinator) are likely to grow in size, the most significant impact will be changes in the skills mix of a range of existing occupations (e.g. civil engineers, plumbers, roofers, glaziers, etc) as well as an increased demand for some existing ones.

Figure 10 - Modelled labour demand from renewable energy by broad occupational group, 2021-2030



Source – Skillnet Ireland, https://skillsireland.ie/all-publications/2021/5119-dete-egfsn-skills-for-zero-carbon-web_.pdf,

For offshore wind, it is estimated that the required upskilling is greater than what the Irish market can provide in time to reach the current target. [8]

In addition to the increase in volume and specialisation for skills in the renewable sector, there are also concerns over a lack of capacity in the National Parks and Wildlife Service An Bord Pleanala. In 2022 the organisation issued a public apology for not meeting statutory time frames for decisions on “a large number ” of planning cases. Planning applications for onshore wind farms are supposed to be decided by An Bord Pleanála within 18 weeks but, on average, it is taking over a year. This is largely due to a lack of capacity at the board level and specialist planners to handle the case load.. [30]

7. Planning consent and the planning process

Planning has been identified by wind industry stakeholders as the greatest barrier to the development of renewable projects in Ireland.[39] As of November 2023, it had been more than a year since the last onshore wind farm was granted planning permission. [6] This is driven by a combination of factors including An Bord Pleanála timelines and Judicial Reviews. Annex G provides a diagram of the planning process in Ireland.

Planning requirements for onshore wind is currently being reviewed. The Planning and Development 2023 Bill was recently published which includes an intention to restructure An Bord Pleanála, impose strict time periods for planning decisions; and reform the judicial review procedure. The government is also expected to publish revised Wind Energy Development Guidelines for onshore wind in Q4 2024 which will include updated guidelines for setback distances and noise.

8. Supply chain

We discuss the supply chain for onshore wind and solar PV in this section. Specific supply chain points for offshore wind are included in section 10.

Onshore wind Supply chain

Many high-value niches in the onshore wind supply chain are being captured by Irish companies.[33] Irish companies could capture around half of the investment in onshore wind energy, particularly during the planning, installation and quality-assurance stages. Most professional and engineering services are expected to be locally sourced, although some technical specialists are likely to be drawn in from neighbouring countries.

Due to the lack of a heavy manufacturing base in Ireland, 13% of total investment in onshore wind is expected to be associated with manufactured imports. In general, the areas of the supply chain that are less well positioned to capture investment are those where there is no significant manufacturing base in Ireland or where the small Irish market size inhibits early growth. Those identified as offering potential for the future relate to equipment repairs, where manufacturers may set up local service centres if the market is large enough to sustain them, and the manufacture of smaller components such as controls, gearboxes, transformers and generators.

In addition, there are opportunities for companies that have developed and refined their business model in the Irish wind energy sector to expand their business to other markets. Examples of companies that have done this are wind-farm development companies such as Airtricity and Mainstream Renewables, meteorological monitoring company Wind Measurement International, and specialist ICT companies such as ServusNet, BrightWind and EnergyPro. The provision of ICT based services to the international wind energy sector is well matched to exploiting Ireland's strong competences in ICT.

Solar Supply chain

In general, the areas of the supply chain considered to be poorly positioned to capture investment are those where there is no significant manufacturing base in Ireland, which includes solar panels. [8] The are a few niches, largely in R&D, where ROI could capture value from a growing international PV market in the future.[34]

9. Social acceptance

Two independent studies recently noted widespread support for offshore wind amongst Irish coastal communities. [2] [31] Most coastal residents would prefer government to reach its offshore wind energy target for 2030 and do not think visibility of offshore wind will affect their enjoyment of coastal activities. However, coastal resident (on average) prefer offshore wind farms to be further from the shore (at least 15km). A few networked opposition groups are actively advocating against some of the Phase 1 projects or for a general setback distance for all offshore wind projects. Whilst these groups present views from a small minority, it is anticipated that judicial reviews will be lodged for some of the Phase 1 projects given their proximity to the coastline, concerns over procedural injustice, and/or contestation over the conservation status of some of the east coast sand banks. Government also anticipates judicial review of forthcoming DMAPs. This may delay deployment of some Phase 1 projects and/or the scheduling of future ORESS auctions under 'Phase 2' of the government's offshore energy programme.

A strong majority of the Irish public residing in rural areas have positive attitudes towards onshore wind, regardless of how close they are to wind projects. [35]

65% of people who live next to (less than 1km from) a new wind farm or far away (more than 10km) believe that Ireland has too few wind farms and that more should be built. This number falls to 52% for those who live near new wind farms (1 – 5km). Approximately eight out of ten rural residents think Ireland has too few solar PV farms, regardless of their proximity to new solar PV projects. About one in eight people who live in rural areas have a negative attitude towards onshore wind farms in general. Only 4% of rural residents have a negative attitude towards solar PV farms in general. Those who have such attitudes are much more likely to take action(s) regarding a local wind/solar farm.

However, one in three people who live near a new wind farm project and one in five people living near a new solar PV project (1 – 5km) in Ireland do not believe they can have a say in the planning process, and a slightly larger proportion believe that developers and/or the planning authorities do not take account of the opinions of communities near projects. Most people residing in rural areas do not think the planning process in Ireland is fair and transparent, regardless of their proximity to new wind or solar farm projects.

There is currently no reliable, publicly available data on the trends in judicial reviews lodged against wind or solar farms' planning consent.

10. Offshore wind

As of 2024, there is only one 25 MW demonstration project operational in Irish waters. Since the early 2000s, a few industrial and policymakers have (at various points in time) advocated for its deployment. There were, however, significant technical, legislative, regulatory and economic complexities in deploying this technology in the Irish context, which extended the timeline for deployment well beyond what some actors had expected.[32] However, by 2019, a consensus had been established between state agencies, system operators, the regulator and Irish generation market that the technology would be a necessary part of the required generation mix to meet a national 70% RES-E target.

Existing policy measures to enable offshore wind energy

This section summarises existing policy measures, including targets and policy coordination, marine planning and consenting, and grid connection policies and plans.

Targets & policy coordination

Since 2019, successive governments issued increasingly ambitious targets for offshore wind power deployment by 2030 and 2050. [21] These targets serve as a necessary and import signal of intent to other actors and serve to calibrate related policies towards target attainment. However, it cannot be assumed that they will be met. The government has established a cross-Departmental Offshore Wind Delivery Taskforce to implement a singular, system-wide strategy and road map for all the activities required to meet the medium-term targets and provide oversight and reporting on delivery. Key areas of this plan are summarised below.

Marine planning and consenting legislation and policies

In recent years, several significant updates to the legal framework for marine planning and consenting have sought to facilitate the deployment of offshore wind power.

- The National Marine Planning Framework (NMPF) provides an overarching framework that sets a direction for managing Irish seas and objectives for progressing offshore wind power deployment alongside other maritime sectors. [7]
- The Maritime Area Planning (MAP) Act 2021 provides the legal underpinning to the new marine planning system, and provides further clarity to developers on the offshore wind development management system for projects in Ireland's maritime area.
- In accordance with the MAP Act 2021, the Maritime Area Regulatory Authority (MARA) was established in 2023. MARA has responsibility for assessing applications for maritime area consents (MACs), which will be required before offshore wind project developers can make a planning application.
- Furthermore, the MAP Act sets out the process for establishing Designated Maritime Area Plans (DMAPs) that will determine the spatial zones where offshore renewable energy projects can be developed as the planning regime shifts from the historical 'developer led' approach to a 'plan-led' spatial planning approach. [23]
- In addition to MACs, offshore wind projects also need to obtain planning consent from An Bord Pleanala.

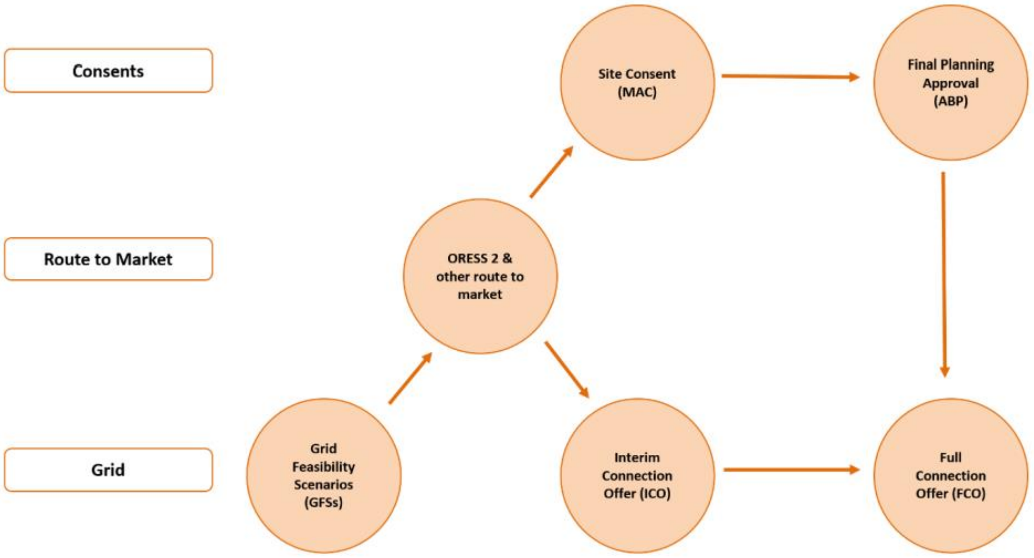
Grid connection policies and grid development plans

The ability for offshore wind projects to secure grid connection is driven by availability of capacity on the grid. Grid capacity can be split into existing grid capacity and future grid capacity (provided for by investment in the grid, such as through reinforcement projects).

ORESS 1 project developers are required to build their own offshore grid transmission infrastructure to connect their projects to the grid, ownership of which will then be transferred to EirGrid. The first wave of offshore wind projects will rely on existing grid capacity. All ORESS 1 projects have a valid Grid Connection Assessments, and therefore are expected to be able to connect to the grid. For ORESS 2.1, the gid connection policy is yet to be finalised, but the CRU's proposed decision is that Eirgrid will issue Grid Feasibility Scenarios that will align existing grid capacity with the DMAP (discussed previously); and provide some expectation that a grid connection would be forthcoming.

However, to receive a gid connection offer, the regulator proposes that projects must be in possession of a MAC, a route to market (e.g. successful ORESS bid); and final planning consent. The CRU's proposed approach to grid connection for 'Phase 2' projects is summarised in Figure 11. Eirgrid has a €3.3 billion capex programme, which is expected to enable further grid capacity in the coming years. Future DMAPs, and hence future offshore wind developments, are expected to align with that grid development.

Figure 11 - CRU's proposed grid connection pathway for ORESS 2



Source: CRU

Pipeline of project in Irish waters

In 2022, Wind Energy Ireland (WEI) estimated that there was a pipeline of projects totalling 28 GW competing for 2030 delivery. This included 16 projects totalling 13 GW off the east coast, 10 projects totalling 10 GW off the south coast, and 6 projects totalling 5GW off the west coast. The majority of projects currently publicly declared on the Atlantic coast are focused on access to the Moneypoint grid connection, which is anticipated to become available from 2025. [8]

Currently there are at least seven floating offshore wind farm projects in the Atlantic Region in the very early stages of planning. Future installed floating offshore capacity may be related to upgrades in grid connection availability, or potentially production of Green Hydrogen as a vector fuel. Combined fixed and floating offshore wind projects are also planned off the Sligo and Donegal coasts in the North-West region and are at an early stage of project definition and planning.

International factors

The Irish supply chain for bottom-fixed offshore wind is immature and deployment in Ireland is likely to remain dependent on international supply chains for the foreseeable future. [42] [1] [33] Only with an aggressive approach to ensure local content could it capture a limited proportion of the total value of a windfarm project. This would be largely from providing technical surveying services (during the project development and consent phase) and from vessel provision, vessel services & associated equipment supply during the operation and maintenance stage. [1] There is currently no signal from the Irish government that it is considering introducing local content requirements.

A shortage of specialised offshore vessels in particular presents a risk to deployment of offshore wind energy in Ireland in the short-term.[15] The availability of specialised vessels required for the transport of turbine elements, and the installation and maintenance of offshore wind farms is currently a bottleneck in the international supply chain.[8] [1] By 2025, it is expected that the demand for installation and cable laying vessels will outstrip the supply. [41]

The current macro-economic environment across advanced economies also present a risk to offshore wind deployment, at least in the next five years. [26] Since 2022, central banks have increase base interest rates whilst inflation has remained relative high. Investment costs in offshore wind is 20% higher today than a few years ago. In 2023, developers cancelled or postponed 15 GW of offshore wind projects in the United States and the United Kingdom. For some developers, pricing for previously awarded capacity does not reflect the increased costs facing project development today, which reduces project bankability. Policies in some jurisdictions have been relatively slow to adjust to the new macroeconomic environment which has left several auctions in advanced economies undersubscribed, particularly in Europe.

Green hydrogen

It is possible that the production of green hydrogen may become a driver for increased offshore wind deployment in Ireland. Government analysis indicate that hydrogen could be produced from grid-connected electrolysis from surplus renewables prior to 2030 if the 80% RES-E target is met. During the 2030s the government also envisages some offshore wind capacity dedicated exclusively to green hydrogen production (off-grid electrolysers). [16]

For hydrogen to be a valuable fuel (and hence drive greater deployment of renewables), many other developments need to happen in other aspects of the hydrogen supply chain, including transportation, storage, and demand. Initially, hydrogen is likely to be transported by truck or used onsite. Blending hydrogen into the gas transmission system is also a challenging mitigation measure. [17] Hydrogen pipelines

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[15] Bottom-fixed offshore wind requires specialist heavy-lifting and cable installation vessels whereas floating offshore wind may require less sophisticated, lower cost vessels for installing the turbine units and floating substations – specialist vessels are likely needed for installing mooring systems and dynamic cables. Various other vessels are used for surveys, equipment swaps, and crew access. Due to the metocean conditions in the Atlantic it is unlikely access to the platforms will be provided through traditional Crew Transfer Vessels (CTV). Service operation vessels (SOV) will provide a more appropriate weather window for personnel access to effect maintenance.

[16] The National Hydrogen Strategy echoed these targets

[17] Hydrogen-blending yields a convex (sub optimal) carbon reduction due to its lower volumetric energy density.

(local, and then national) will need to be developed to enable production, storage and usage at scale. The National Hydrogen Strategy envisages that small-scale storage applications are most likely until 2033, after which large-scale storage (and transport) will be developed. However, large-scale hydrogen storage sites may conflict with CO_2 storage, e.g., the Kinsale Area gas fields. The national strategy envisages that demand for hydrogen will grow in the 2030, starting with heavy-duty transport, then industry and power generation (2030 - 2035), and followed by aviation and maritime end-users (estimated 2035 - 2040).

Grid-connected electrolysers[18] presents several pros and cons. Hydrogen can be considered green if produced during periods of dispatch down [16]. However, using exclusively curtailed electricity may lead to low run hours, resulting in a high Levelized Cost of Hydrogen (LCOH). Furthermore, there is no constant or guaranteed production of hydrogen, posing potential challenges depending on demand and storage options. Moreover, these electrolysers add an additional load to an already pressured grid. To address this, Eirgrid may need to develop a grid connection policy for prioritisation, and not all electrolysers will be easily connected.

Off-grid electrolysers, running on offshore wind power plant (or other renewables) don't put additional strain on the electricity grid, but the only source of revenue for the dedicated RES plant and electrolysers will be the sale of hydrogen, as no electricity and system services are provided. Moreover, the production of hydrogen relies solely on the RES provided by the dedicated plant. Therefore, this business model is highly dependent on hydrogen demand and prices. For these electrolysers to be profitable, they must be located in area with high renewable production potential, feasible storage at large (geological) scale, and substantial demand. [19]

Selected examples from other jurisdictions

There is no historical deployment of offshore wind in Ireland from which to extrapolate indicative future deployment rates. Annex F includes historical data from other European jurisdictions for comparison.

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[18] Grid-connected electrolysers can operate under various business models, but the focus here is on the curtailment model. That is, electrolysers run during periods of high wind to reduce dispatch-down in the system, aligning with DECC's vision for the near future.

[19] According to the National Hydrogen Strategy (roadmap in Annex D), it is likely that many of these initial clusters could develop in the vicinity of commercial ports given their role in enabling offshore wind and typical proximity to potential large end users. The Strategy recognises that "Further work is needed to determine the optimal locations of these regional clusters. […] . A decision on the locations of these early hydrogen clusters should be progressed in the early stages of implementation of this strategy".

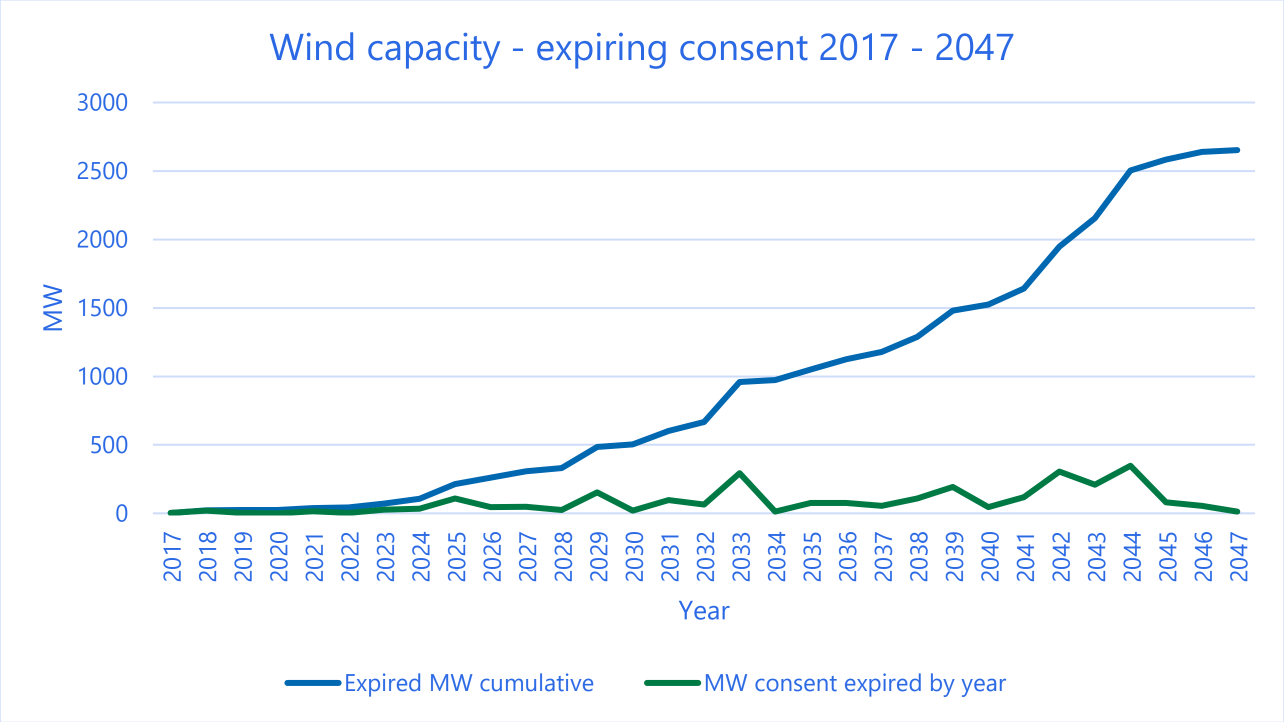
11. Onshore wind

In Section 1 (p. 5) we summarise the historical deployment of onshore wind power. This section elaborates on additional factors, specific to this technology, that may affect future deployment rates, including, expiration of planning consent for the older fleet, existing policy measures to enable onshore wind, national and international market conditions that may affect Irish deployment, social acceptance, supply chain, and selected examples from other jurisdictions.

Expiration of planning consent on older fleet

Onshore wind has been deployed in Ireland since the 1990s. At some point the older fleet of Irish onshore wind farms will reach the end of their operational or planning consent life. These sites will have to be repowered or have a life-extension, failing which the capacity will have to be decommissioned. Figure 12 indicates that an increasing capacity will have to be replaced and/or reconsented. From 2026 to 2030, approximately 290 MW will expire. From 2031 to 2040, operational planning consent for just over 1 GW will expire.

Figure 12 - Wind capacity - expiring consent, 2017 - 2047



Source: SEAI data (2022).

Existing policy measures to enable onshore wind

Targets

The government has targets in place to increase onshore wind deployment by 2030. Under Ireland's Climate Action Plan, there is a target for 9 GW of onshore wind capacity by 2030.

Approach to policy coordination

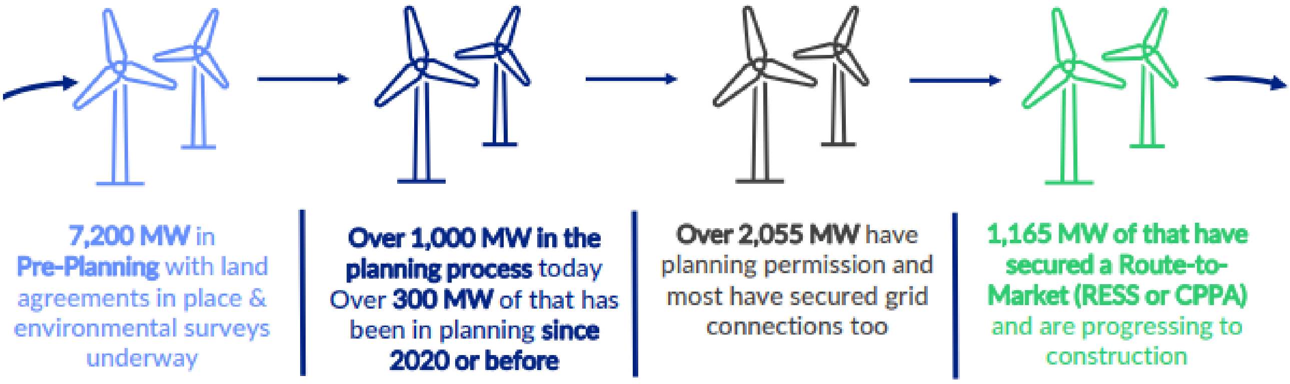
Climate Action Plan 2023 included an action to establish an Accelerating Renewable Electricity Taskforce, to focus on the development of onshore renewable generation. The programme of work for this taskforce is expected in Q2 2024. It is expected that this taskforce’s work will include addressing planning and grid-related constraints to further onshore wind deployment.

National and international market conditions that may affect Irish deployment

Current pipeline – onshore wind

Approximately 8,200 MW of onshore wind capacity is either in pre-planning or in the planning process, of which over 2 GW has planning permission as shown in Figure 13. The stacked timelines of the planning application, grid connection, RESS, financial close, and project execution implies that pipeline delivery is weighted towards the end of the 2020's. This pipeline should be read alongside the figures for wind capacity that has a route to market (refer to Table 4 p. 13) or have received grid connection offers under ECP (Table 2 p. 10) to estimate deployment rates up to 2030.

Figure 13 - Onshore wind pipeline - Ireland



Source: Wind Energy Ireland (2022), Delivering Energy Independence for Ireland. Available here

Onshore wind deployment rates in other jurisdictions

There is a multi-decadal historical precedent for the deployment of onshore wind power in the Republic of Ireland (refer to Figure 2 p.7). However, it may also be useful to refer to deployment rates in other jurisdictions in contemplating plausible future scenarios for the ROI. Annex E provides examples from other European jurisdictions for comparison.

12. Solar

In Section 1 (p. 5) we summarise the (recent) historical deployment of solar PV generation in the ROI.

The additional factors that are specific to solar and that may affect future deployment rates are contained in the above sections. We cover the current routes to market for solar PV in Section 6 (p. 11), grid connection policy in Section 4 (p. 9), planning consent in Section 7 (p. 22), social acceptance in Section 9 (p. 24), and supply chain in Section 8 (p. 23).

One omission of this brief is due consideration of the drivers of rooftop solar PV (micro generation) in ROI. We aim to correct this in a future iteration.

Selected examples from other jurisdictions

Given the lack of historical deployment of solar PV in Ireland, we consider its historical deployment in other jurisdictions. Annex H provides examples from European jurisdictions.

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Rialtas na hÉireann
Government of Ireland

Sustainable Energy Authority of Ireland
Three Park
Place Hatch
Street Upper
Dublin 2
Ireland
D02 FX65

w: www.seai.ie
e: info@seai.ie
t: 01 8082100

The value of using expert elicitations to informing decarbonisation pathways and target setting

An expert elicitation is an exercise in *forecasting*. It is a method for establishing the *likelihood* of certain outcomes by asking experts for a range of estimates. In the case of long-term climate mitigation scenarios for the power sector, expert elicitations can forecast the likelihood that power generation technologies will be deployed (how much by when). It is an especially useful forecasting method in contexts of deep uncertainty where time, resource and/or data constraints do not permit more complex assessments.

Forecasts based on the subjective judgement of experts can internalise a large set of risks and opportunities that may constrain technology deployment over the long-term. It accounts for uncertainty by pooling the diverse views of experts (who may disagree strongly) and offering a probabilistic range for technology deployment. Expert elicitation forecasts have also been used as input to energy system models, to validate model solutions for decarbonisation against solutions considered plausible by a group of subject/sectorial experts.

In the case of the SEAI expert elicitation, we selected thirty experts based on tangible evidence of their expertise/knowledge of the Irish power sector, either demonstrated through publications (in the case of academic or other researchers) or due to their extensive professional career and reputation within the Irish power sector. We sought a balanced set of views, selecting individuals from state agencies (n = 6), electricity and gas system operators (n=3), academic institutions (n=8), and industry (n=13). Experts participated anonymously and did not necessarily represent the position of their institutions. Therefore, each pooled forecast should be interpreted as a plausible range for generation technology buildout that internalises the widest possible set of drivers/conditions affecting deployment up to 2040 in the most extreme manifestations that experts could conceive. That includes both best- and worst-case extremes across a range of experts with different (and often conflicting) views of what the future may look like.

The expert elicitation results have informed additional scenarios produced with the SEAI National Energy Modelling Framework, to supplement those produced for the EPA's 2023-2050 Greenhouse Gas Emissions Projections. The forecasts have been integrated into 'delayed achievement' scenarios for onshore wind, offshore wind, and solar PV generation. These scenarios may be used to quantify the emissions gap between what is required to meet energy carbon budgets and what are deemed plausible outcomes should credible risks to deployment targets occur.

The difference between the SEAI forecasts and current carbon budget solutions highlight areas in need of further study. These are areas where there may be substantial risks to achieving the technology deployment to comply with the budgets and where there may be a need to explore other decarbonisation pathways in parallel to mitigating risks to existing deployment pathways.

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Briefing Note

SEAI expert elicitation on plausible deployment rates of hydrogen, ammonia and CCS in the Irish power sector, 2025 – 2040

Introduction

This document should be read in preparation for the SEAI expert elicitation on plausible deployment scenarios of hydrogen and ammonia power generation and generation with CCS. It provides accompanying information on factors that may influence the deployment of these technologies in the coming years within the Republic of Ireland (ROI). It may serve as a starting point and aid for making explicit the factors and assumptions that shape your own deployment scenarios and forecasts during the interview.

Sections 1 – 3 of the brief highlights factors that affect the deployment of both technologies in the ROI. Sections 4-5 add additional points that are specific to each of the technologies separately. Overall, the brief does not assume or recommend any deployment scenarios or rates but seeks to highlight the factors or drivers that may affect deployment rates in the ROI. We expect that experts will bring additional data, assumptions and causal models (formal or mental) to the discussion to construct their forecasts as part of the elicitation.

Briefing note

Expert elicitation on the plausible deployment rates of hydrogen, ammonia and CCS in the Irish power sector 2025 - 2040

26 April 2024

Sustainable Energy Authority of Ireland
SEAI is Ireland's national energy authority investing in, and delivering, appropriate, effective and sustainable solutions to help Ireland's transition to a clean energy future. We work with the public, businesses, communities and the Government to achieve this, through expertise, funding, educational programmes, policy advice, research and the development of new technologies.

SEAI is funded by the Government of Ireland through the Department of the Environment, Climate and Communications.

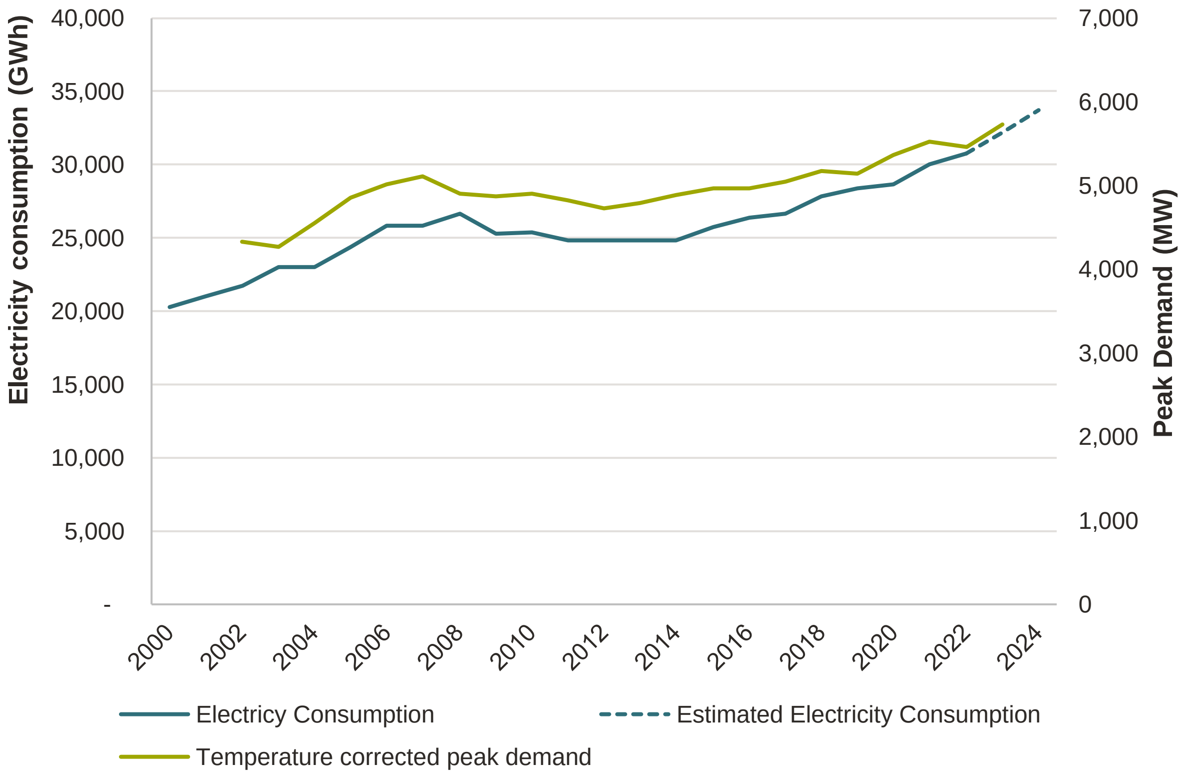
Contents

1. Historical electricity demand/supply in Ireland

This section summarises the historical electricity demand in Ireland and the sources of fuel used to satisfy this demand. Figure 1 shows the electricity demand and peak demand in Ireland from 2000 to the end of 2023. Figure 2 illustrates the fuels used to meet electricity demand from 2000 to 2023.

Natural gas is the most common fuel type used for electricity generation in Ireland. Electricity generated with natural gas reached its peak in 2010 (18.1 TWh, equivalent to 63% of the electricity generated). Since then, it has stayed between 15.5 TWh to 16.5 TWh, and the percentage it represented of total production has decreased. In 2023, natural gas accounted for 43% (14.2 TWh) of electricity generation. Electricity generated by onshore wind power has increased substantially over the period considered. Since 2010 there has been a steady increase in electricity generation from onshore wind power, from 2.8 TWh in 2010 to 11.6 TWh in 2023. Proportionally, wind has increased from generating 10% of electricity to 35% of electricity in 2023, at an average annual growth rate of approximately 12%.

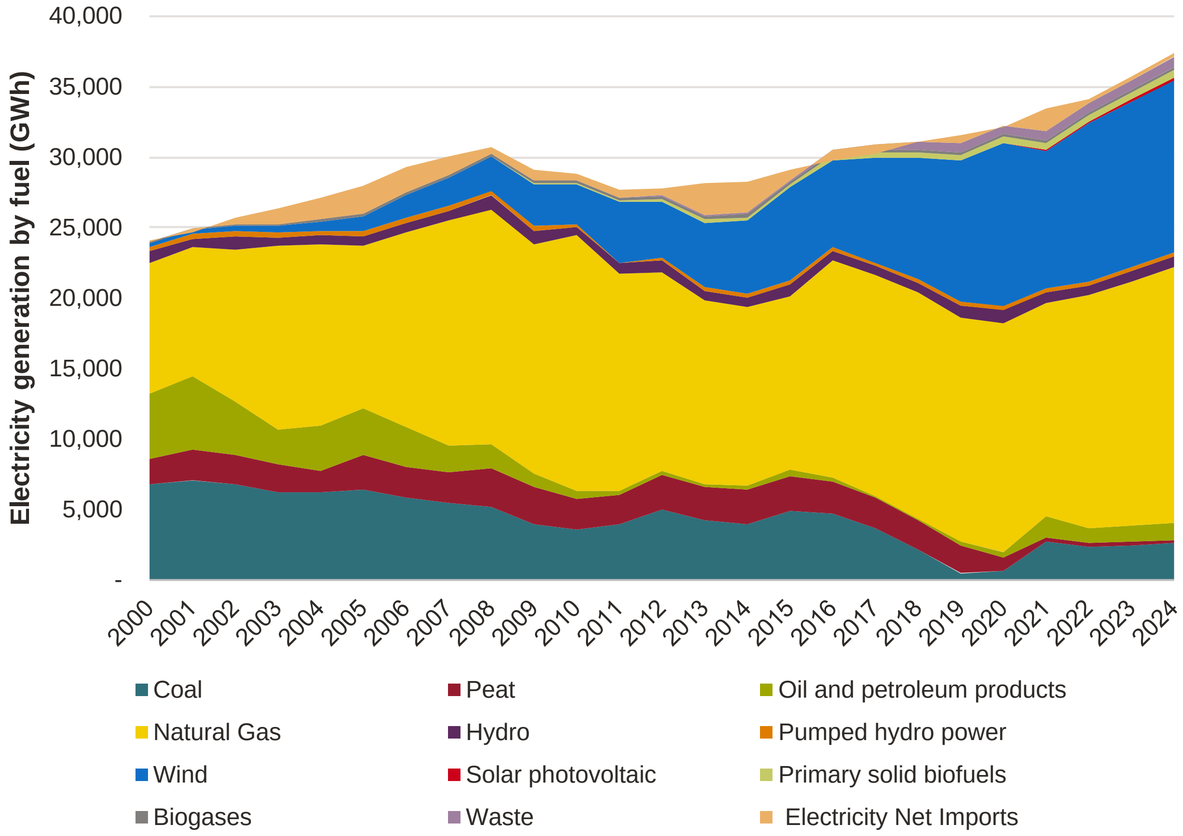
Figure 1 - Electricity consumption



Source: *SEAI, Key Energy Statistics (Available here) and Eirgrid (January 2024), Grid Capacity Statement 2023-2032 (Available here)*

Note: *The chart assumes that the demand for 2023 and 2024 grew and will grow in line with the growth rate in GCS 2023.The Peak Demand showed is the historic, temperature-corrected peak*

Figure 2 - Electricity generation by fuel



Source: Eurostat, Dataset nrg_bal_peh (Available here), CSO, Fuel used in electricity production (Available here)

Note: Data for 2023 and 2024 are calculated based on the assumption that electricity generation has and will continue to grow in accordance with the GCS 2023 growth rate and that the percentage breakdown of fuels remains consistent with that observed in 2022.We note that the total in this chart is slightly above the electricity consumption in the figure above. This is likely due to transmission and distribution losses, as well as own electricity use.

2. Projections of future Irish electricity demand

Figure 3 and Figure 4 summarise the range of projections of electricity demand and peak demand from several sources. Annex A presents a breakdown of individual demand projections by source and summarises the underlying assumptions.

Peak electricity demand is expected to increase at a slightly lower rate than total demand due to the expected increase in demand flexibility. The Climate Action Plan (CAP) has established targets for demand flexibility, aiming for 15-20% by 2025 and 20-30% by 2030. Eirgrid's Tomorrow's Energy Scenarios (TES) 2023 foresee a need for 20-50% demand flexibility by 2050.

Several public consultations have been launched relating to demand-side flexibility, including the Commission for Regulating Utilities (CRU) consultation on National Energy demand, ESB Networks' consultation on Demand Flexibility Product Proposal, and Eirgrid's consultation on Long Duration Energy Storage.[1] The CRU recognises the urgency for Ireland to progress on demand flexibility, and focuses on near-term actions. According to the CRU, the greatest potential in the near term lies in procuring flexibility services (explicit flexibility) from Large Energy Users

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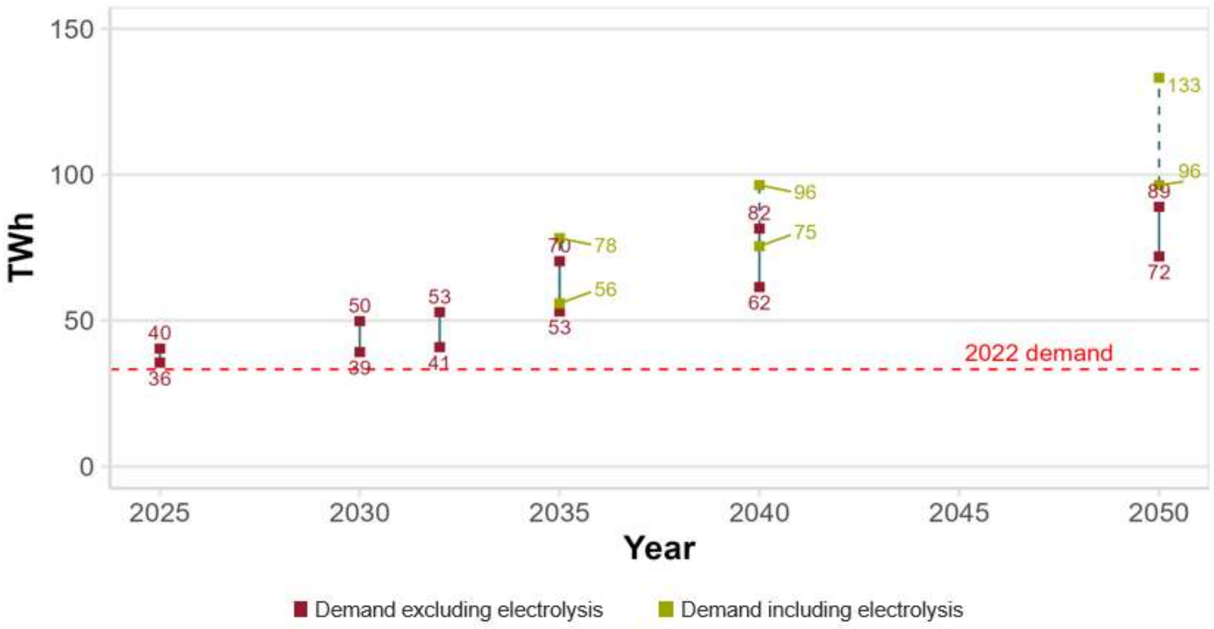
[1] We note that the SOs have already implemented various programmes. With DS3, Eirgrid procures services that provide flexibility. ESBN has recently launched programmes as "Beat the Peak Business" and "Is this a good time?"

(LEUs) and storage.[2] ESB Networks' and Eirgrid's consultations align with this view. ESB Networks proposes to procure demand flexibility products in locations where there is a high system need. It anticipates procuring 100 MW in the first round, and up to 500 MW by 2025. Similarly, Eirgrid aims to launch its procurement scheme for long energy duration storage in January 2025.

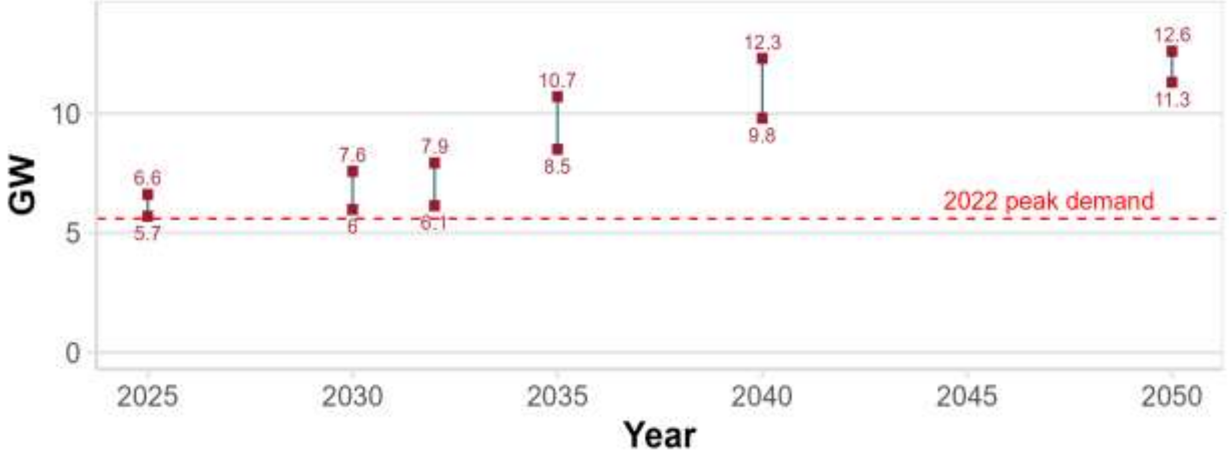
Figure 3 - Electricity demand forecast range



Source: *Eirgrid GCS 2023, Eirgrid TES 2023, SEAI Heat Study, and SEAI National Projections*

Note: *This chart displays the ranges in electricity demand forecasts for GCS 2023, TES 2023, SEAI Heat Study, and SEAI National Projections.[3] Note that electrolysis demand may be satisfied by off-grid plants.*

Figure 4 - Electricity peak demand forecast range



Source: *Eirgrid GCS 2023, Eirgrid TES 2023*

Note: *This chart displays the ranges in peak electricity demand forecasts for the sources considered (GCS 2023, TES 2023). Note that TES 23 does not report peak demand considering the additional load for green hydrogen production.*

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[2] Generally speaking, demand flexibility could be provided by different technologies/customers (domestic customers, business and storage providers) and incentivised in different ways (differentiated tariffs, dedicated procurement contracts, and clauses in connection contracts).

[3] Eirgrid considers electrolysis demand separately, as this load could be supplied by non-grid-connected generators and therefore should not be considered as part of the electricity load.

3. Drivers of the size and utilisation of Ireland's thermal fleet

The deployment of generation capacity with hydrogen or CCS is sensitive to the evolving size, composition and utilisation of Ireland's thermal generation fleet. The thermal fleet will be impacted by the demand scenarios outlined in the section above, but also by supply-side drivers. These include:

- Deployment of variable renewable power generation, storage, and demand-side response.
- System rules and constraints, including system stability and new technologies to provide system services; congestion; and markets and rules (e.g. the capacity market)

Variable renewable energy deployment

The government has set ambitious targets for the energy sector in the Climate Action Plan 2024.[4] These include target for 2030 of 80% of electricity generation from renewable sources; 9 GW of onshore wind generation; 5 GW of offshore wind generation; and 8 GW of solar PV generation capacity. These targets serve as important signals of political intent, but it cannot be assumed that they will be met within the period. Figure 5 presents SEAI's median deployment scenario for onshore wind, offshore wind and solar PV based on the pooled opinion of experts.

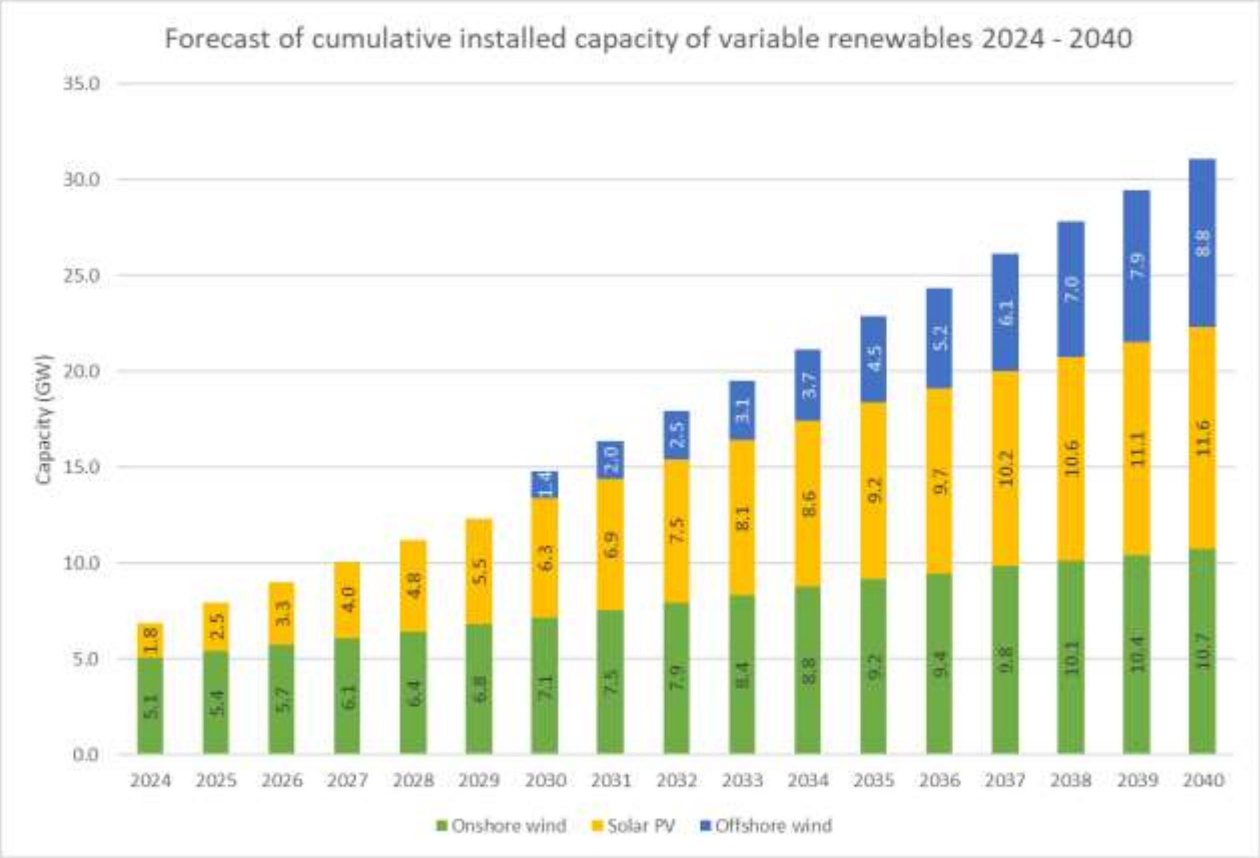

Figure 5: Forecast of deployment of variable renewables in Ireland based on median scenario of SEAI expert elicitation (2023)

Deployment of storage

While Ireland is targeting high level of renewable generation penetration, dispatchable generation will be required when renewable generation is low and/or demand is high. Short and long duration storage could meet some of the demand for dispatchable power, affecting the thermal fleet size and utilisation. Much of this new storage capacity is expected to be from batteries. Battery storage currently earns two revenue streams in the Single Electricity Market (SEM), namely capacity market revenue; and DS3 system services revenue. Eirgid forecasts a 57% growth in storage capacity in Ireland over the coming decade based on storage awarded contracts in the capacity auctions. (Figure 6).

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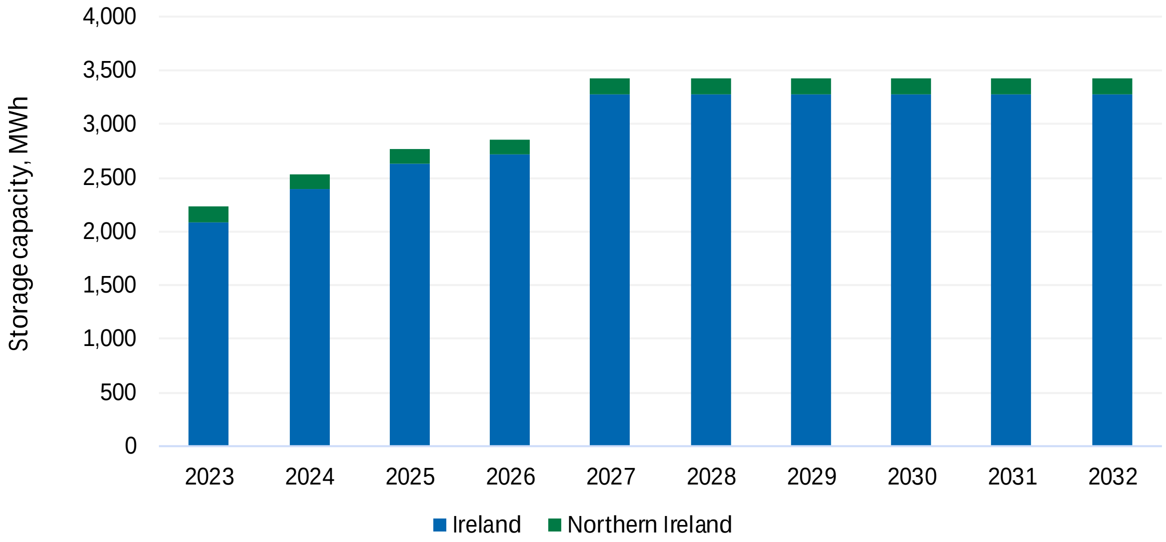
[4] Government of Ireland (2023) Climate Action Plan 2024. Available here

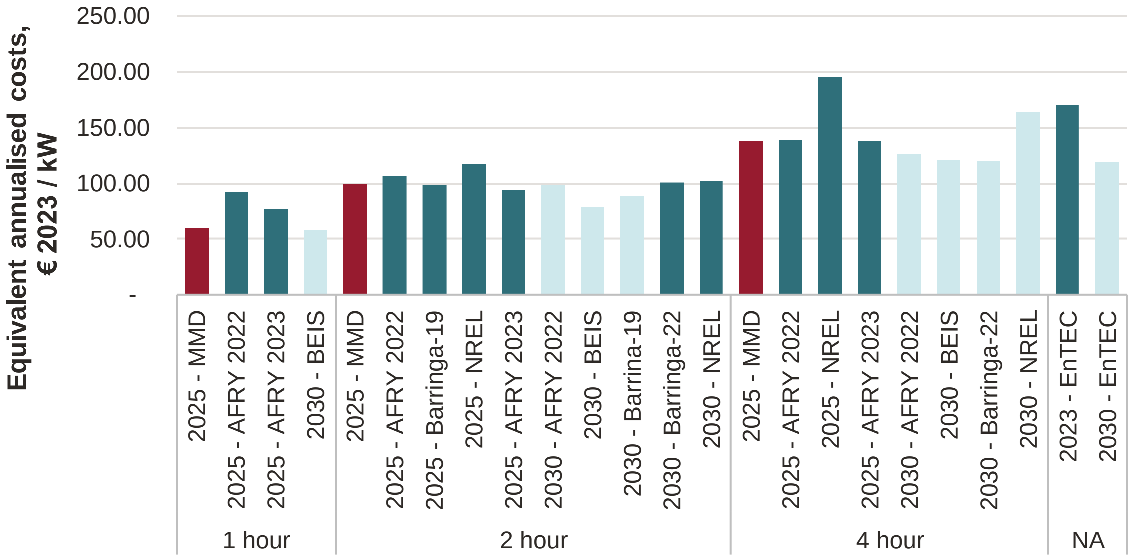
Figure 6: Total energy storage capacity assumed in studies (MWh) for Ireland and Northern Ireland



Source: EirGrid Ten-year Generation Capacity Statement, 2023-2032

Most battery storage in Ireland to date has been short duration (1 hour). This is primarily due to the cost differences between battery types and the lack of financial incentives for longer duration storage. The main mechanism through which battery storage has been procured has been the Eirgrid DS3 system services procurement. This has incentivised the provision of fast acting system services but not energy arbitrage. However, the cost of battery storage is expected to fall significantly in the coming years, with longer term storage becoming more cost competitive (Figure 7 and Figure 8). Statkraft has recently announced its plans to build Ireland's first grid-connected 4-hour battery.[5]

Figure 7: Annualised costs for different battery durations



Source: DESNZ (2020) Storage cost and technical assumptions for electricity storage technologies. Available here
Note: Costs are annualised over a 15-year asset life and assuming an 8% WACC.

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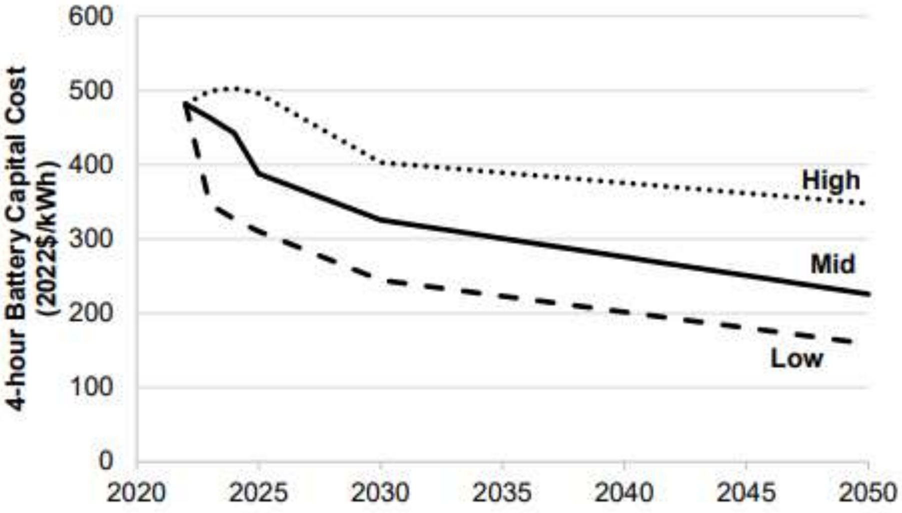
[5] Statkraft (2023) Statkraft to build Ireland's first 4-hour battery energy storage system. Available here

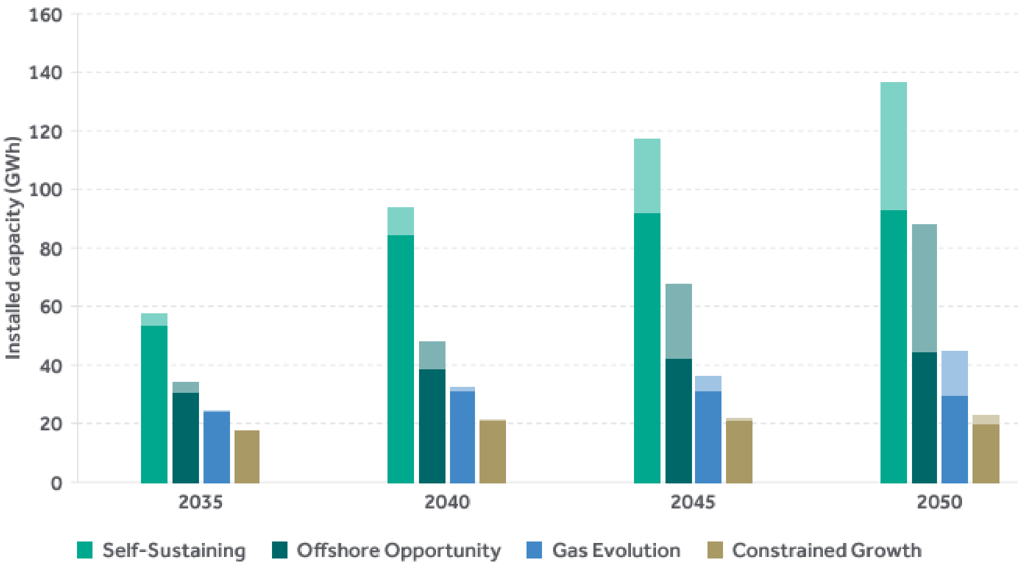
Figure 8: Battery cost projections for 4-hour lithium-ion systems



Source: NREL. Available here

The all-island projected capacity of battery storage may increase significantly between 2023 and 2040. This may occur if (1) the large-scale battery storage projects proceed, (2) there is significant uptake of Vehicle to Grid[6] and (3) battery costs continue to decline, making them more competitive.[7] Eirgrid's Tomorrow's Energy Scenarios (2023) forecasts levels of storage out to 2050 under different scenarios, including pumped hydro, batteries, and V2G (Figure 9).

Figure 9: Forecast Installed Storage Capacity



Source: EirGrid Tomorrow's Energy Scenarios 2023. Available here

Note: Lighter colour denotes vehicle to grid. Includes battery storage, vehicle to grid, and pumped hydro energy storage.

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[6] EirGrid projects the total number of EVs to be approximately 1.2m in 2030 and over 3m in 2040 in both the self-sustaining and offshore opportunity scenarios. 2040 consumption rates are assumed to be 15.48 kWh/100km. EirGrid assume that the 2050 hourly demand shift potential under these scenarios for V2G is 1,180 MW.

[7] EirGrid Tomorrow's Energy Scenarios 2023.

Demand-side management

The flexibility of demand sources could play a material role in how Ireland will meet future peaks in electricity demand. The Climate Action Plan 2024 is targeting 20-30% of available demand side flexibility by 2030. The CRU's demand strategy identifies three key areas where demand side response may be material.

- **Smart meters**: By 2030 smart meters can help reduce peak electricity demand by 8% for domestic users.[8]
- **Flexibility programmes**: ESB Networks is targeting scenarios to provide for 15-20% Flexible System Demand.[9]
- **New connections**: New large-user connections may be required to provide demand side flexibility to get grid connection offers.

System stability and deployment of new technologies to provide system services

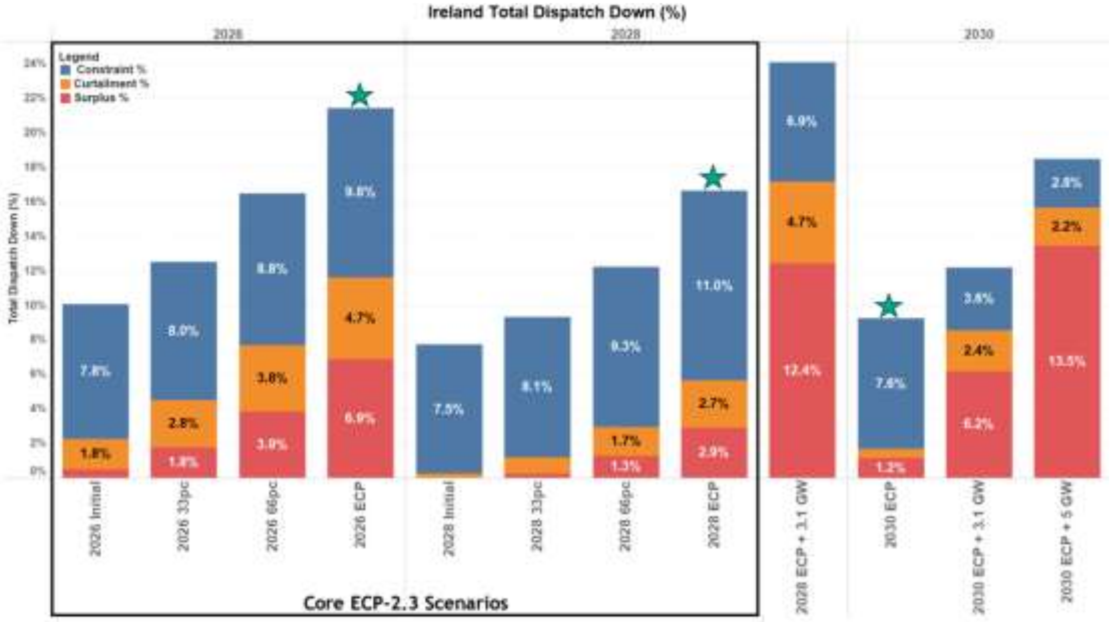
Major increases in the requirements for system services are being driven by the growth of wind and solar and the small size of Irish market. EirGrid is targeting a 95% system non-synchronous penetration (SNSP) by 2030 to support the 80% RES-E target. EirGrid has also set an interim target of 85% SNSP by 2025. The Greenlink and Celtic interconnectors coming online in 2025 and 2026, respectively, will support higher SNSP limits.

The increased SNSP limit will allow more renewables on the system at any one time, but system services will still be required from a range of technologies. No estimates are currently published for the demand for system services once SNSP reaches 95%, but it is expected that the additional required volumes will be significant. Those services will be provided by a combination of flexible dispatchable generation, storage and demand side flexibility.

Congestion

Flexible generation will also be critical to dealing with system congestion in the 2025-2040 period. Figure 10 presents the dispatch down scenarios from the latest grid connection policy.

Figure 10: Solar and wind constraint, curtailment and surplus



Source: *EirGrid (2023) Enduring Connection Policy 2.3. Available here*

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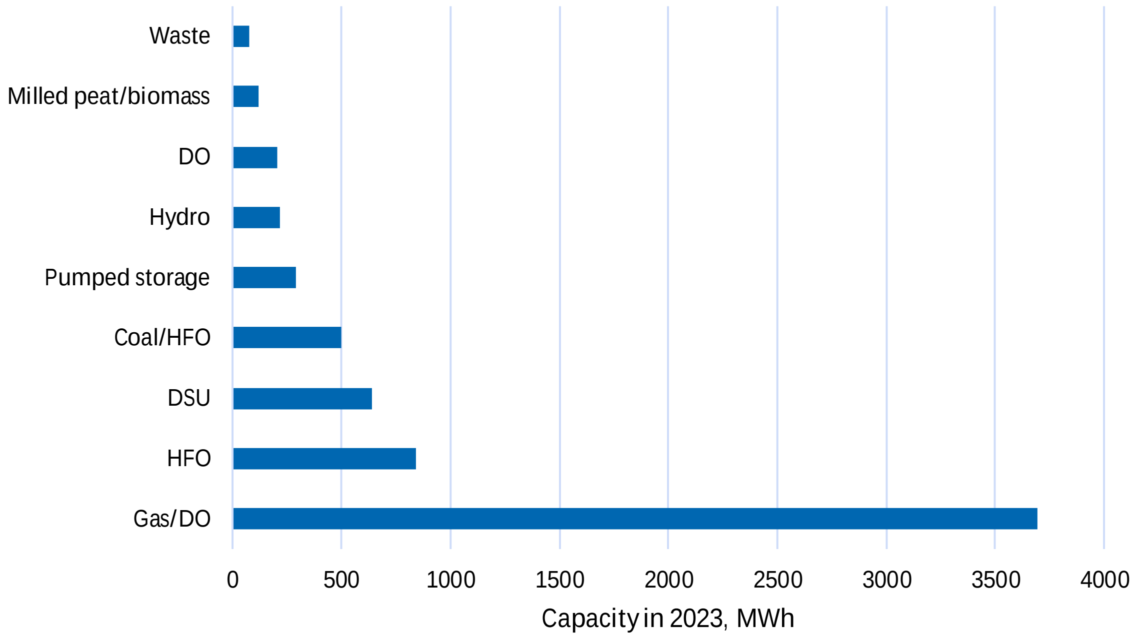
[8] EirGrid (2024) Ten-Year Generation Capacity Statement 2023-2032. Available here

[9] CRU (2023) CRU publishes a new energy demand strategy. Available here

Thermal fleet forecast

Figure 11summarises the capacity of dispatchable generation in Ireland by fuel type. Evidently, gas is responsible for delivering the largest share of capacity to the Irish energy system by far.

Figure 11: Summary of registered capacity of dispatchable generation in Ireland, 2023



Source: EirGrid (2024) Ten-Year Generation Capacity Statement 2023-2032. Available here

Ireland's commitment to net zero incorporates the enforcement of EU Directive 2010/75/EU which regulates pollutant emissions from industrial installations. Some older generators have signalled their intention to decommission due to the increasing restrictions of these regulations (Table 1). However, the recent energy crisis has postponed these dates in some cases due to risks of energy security.[10]

Table 1 – Capacities and closure dates for conventional power generators

Plant	Capacity (MW)	Modelled closure
Aghada	90	2023
Tarbert	592	2021/2022
Moneypoint	750	2024
Edenderry	118	2030

Source: EirGrid (2024) Ten-Year Generation Capacity Statement 2023-2032. Available here

Due to closures and decommissioning of peat and coal power plants, forecasting the capacity of the thermal fleet in Ireland is largely tied to the forecast of natural gas capacity. The only coal-fuelled plant in Ireland (Moneypoint) is due to transition to an oil-fired plan after which to a green energy hub. The first phase involved constructing a synchronous compensator that provides services to the grid which would have otherwise been supplied by thermal fired power stations. Later phases include the construction of an offshore wind farm with 1.4 GW capacity,

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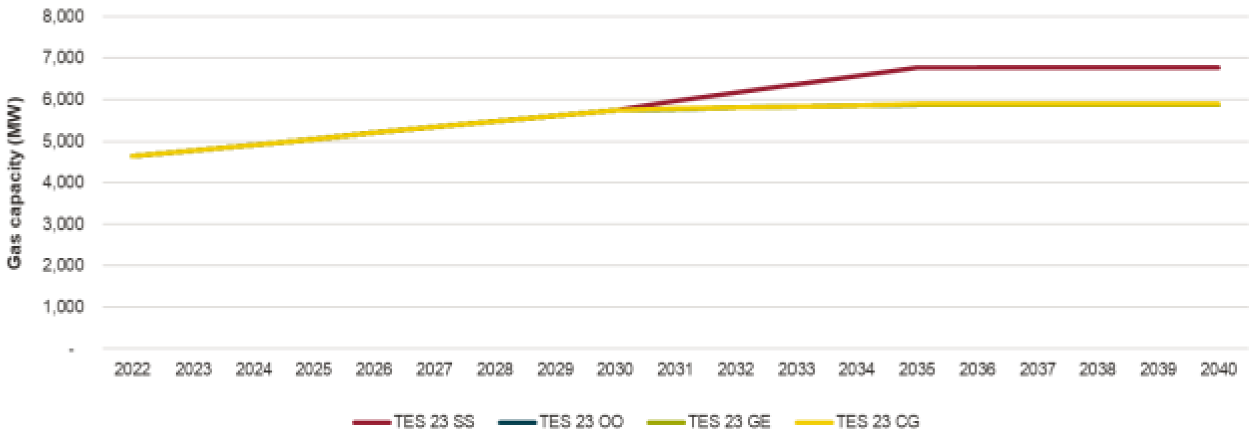
[10] Irish Independent (2022) Tarbert Island and Moneypoint to remain operating for 'years to come'. Available here

developing the site to become a centre for construction and assembly of floating wind turbines, and eventually the production of green hydrogen.[11]
The Tarbert plant uses oil as its input and is also scheduled for closure. Of Ireland's three peat plants, Lanesboro (Lough Ree) and West Offaly Power Station (Shannonbridge) both closed in 2020, while Edenderry's peat unit is transitioning to 100% biomass in 2024 and scheduled for closure in 2030 and its oil units are switching to gas.

Eirgrid forecasts gas capacity to plateau and remain stable at between 6 – 7GW for most of the 2030s and up to 2040 (Figure 12). The most significant reduction in gas capacity is forecasted in Eirgrid's 'gas evolution' scenario which sees hydrogen supplanting gas in the power sector after 2040. In Eirgrid's 'constrained growth' scenario, it is assumed that zero hydrogen capacity is added to the system prior to 2040 due to the economic unfeasibility of hydrogen technology. However, in its other scenarios larger and faster demand growth leads to just over 2 GW of hydrogen generation capacity.

Figure 12: Forecasts of gas capacity under EirGrid TES 23 Scenarios



Source: Frontier Economics analysis of EirGrid Tomorrow's Energy Scenarios 2023

4. Green hydrogen for power generation: back-up dispatchable generation

Hydrogen-fired power generation could provide flexible back-up dispatchable generation in the future, and play an important role in helping Ireland achieve its carbon emissions targets. However, there are great uncertainties on future costs and the necessary infrastructure, skills and supply chains for this. This chapter summarises the factors driving/constraining future hydrogen power generation in the Irish power sector. When considering the potential deployment of green hydrogen power generation in Ireland, the full hydrogen value chain needs to be considered, including production, transformation, transport, storage and end use.

Hydrogen development in Ireland

Currently, Whitegate refinery is the only significant domestic producer and user of hydrogen in Ireland. Here, hydrogen is used to produce gasoline, diesel, and Hydrotreated Vegetable Oil (HVO) fuel.[12]

In 2023 the government set out its vision of the development of hydrogen in Ireland in the first National Hydrogen Strategy (NHS). It outlines a pathway to producing, distributing and storing hydrogen, for different end uses. Figure 13 shows the projected hydrogen demand figures in 2050 under high and low demand scenarios in the NHS. Since 2021, consecutive Climate Action Plans also included a target of 2 GW of offshore wind connected to electrolysers by 2030. However, the Irish wind industry does not believe the 2GW/2030 target is plausible, due to the exorbitant cost of producing hydrogen from offshore wind power.[13] Traditional least-cost approaches to energy system planning, as has broadly been followed in Ireland, will likely not result in the coupling of green hydrogen and

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[11] ESB (2024) Green Atlantic at Moneypoint. Available here

[12] https://www.irvingoil.com/en-CA/press-room/irving-oil-launches-sustainable-energy-product-for-irish-customers

[13] Wind Energy Ireland (2022) Hydrogen and wind energy: the role of green hydrogen in Ireland's energy transition. Available here

offshore wind energy; rather, targeted policy will be required. Significant financial support will be critical to kickstarting the industry, either by bringing hydrogen costs in line with natural gas prices, or by paying the cost difference to consumers directly.[14]

Early development of hydrogen demand and supply in Ireland

Increasing demand for hydrogen in the short to medium term may be influential in establishing a strong market for large scale hydrogen production and usage to be economically viable and technically feasible. Blending of hydrogen into the existing natural gas network and growing the market for bio and e-fuels present such opportunities.

As a precursor to use in the power sector, it is anticipated that hydrogen will first be used in long-haul transportation, maritime shipping, and industry.[15] A key uncertainty is therefore the extent to which this precursor market for hydrogen is established in Ireland and supplied by Irish production of hydrogen. The Whitegate refinery could increase its production of hydrogen for biofuels such as HVO and fatty acid methyl esters, which can compete directly with fossil fuels. In 2022 the owner of the refinery, Irving Oil, signed a MoU with the Simply Blue Group to explore opportunities to develop a 'renewable energy hub' that would integrate floating offshore wind generation (of the coast of Cork) with green hydrogen and e-fuel production.[16] However, given the noted electricity cost differential, it remains unclear if floating wind could compete with the LCOE from onshore wind and solar, even over the long-term.

The initial transition from natural gas to hydrogen could also involve a degree of blending into the current gas network. A feasibility study by Gas Networks Ireland (GNI) found that the existing gas distribution system and half the transmission pipeline network is suitable for 100% hydrogen, but additional study is required to determine the suitability of equipment such as valves, meters and compressors.

The Irish Academy of Engineering identify potential challenges to blending hydrogen into the natural gas network.[17] Due to its smaller molecule size, hydrogen may leak from containers and fittings that are suitable for natural gas. It is also more reactive than natural gas, leading to higher rates of hydrogen embrittlement of steel pipes. Pipeline stresses could potentially be minimised if flows and pressures of hydrogen are held stable. However, this is not consistent with envisaged variability in hydrogen production that arises due to unpredictability in renewables generation capacity.

There are also challenges that end users must overcome for blending to be feasible. It is estimated that a 20% blend is the most that existing end users will be able to accept without requiring equipment modifications.[18] Some end users may need a constant blend of hydrogen, thus requiring significant storage of blends at potentially different mix levels. Finally, the EU hydrogen and Decarbonised Gas Market Package also requires members to be capable of accepting hydrogen blends at interconnection points, increasing the necessity for an internationally-agreed approach to blending rates that represents the needs of end users.[19]

Although hydrogen exports are a key demand component outlined in the NHS, the IAE deem it likely that Ireland will import hydrogen in the future. Firstly, Ireland's renewable electricity generation is a lot less stable and predictable, which makes hydrogen production more difficult. Second, Ireland's pre-tax electricity prices are among the highest in Europe, placing Ireland at an immediate cost disadvantage. Third, Ireland is less likely to have centres of demand in industry and transport at the same scale as other countries, making it more likely that imports will be cheaper than domestic production.[20] A strong priority would need to be given to energy security in order to justify state support for more expensive production in Ireland.

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[14] Aurora, available here

[15] https://www.gevernova.com/content/dam/gepower-new/global/en_US/downloads/gas-new-site/future-of-energy/hydrogen-overview.pdf

[16] https://www.irvingoil.com/en-US/press-room/irving-oil-and-simply-blue-group-announce-plans-explore-renewable-energy-hub-cork

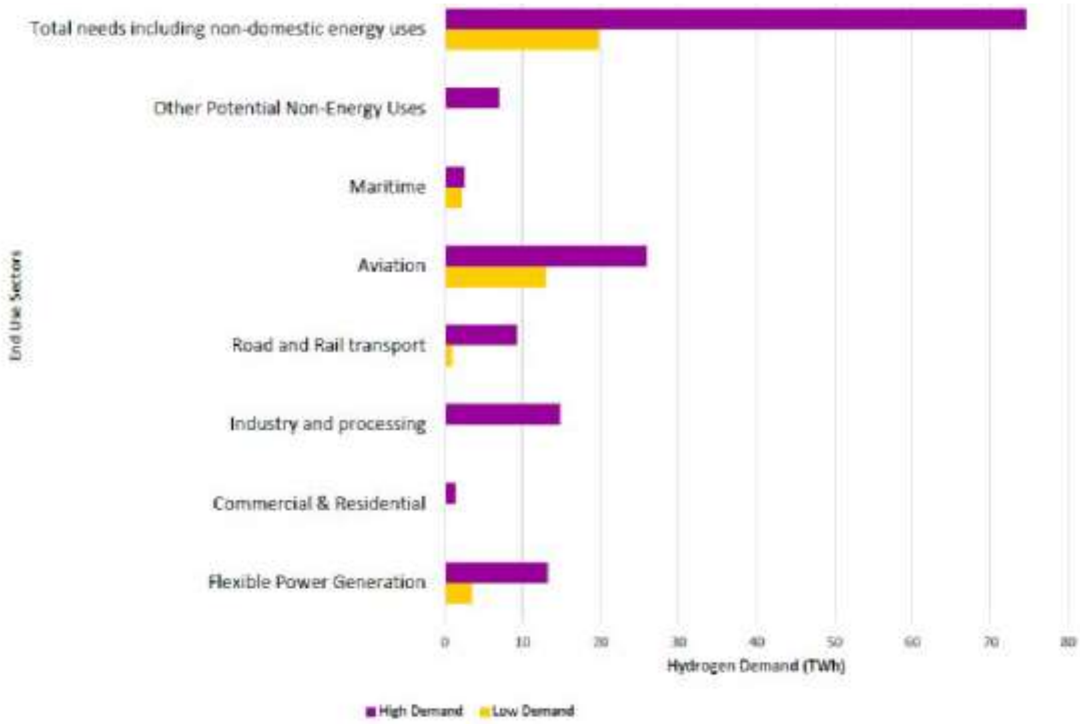
[17] IAE (2023) A commentary on the medium term prospects of Ireland's hydrogen economy. Available here

[18] GNI (2022) Injecting green hydrogen blends into Ireland's gas network. Available here.

[19] European Council (2023) Gas package: member states set their position on future gas and hydrogen market. Available here

[20] IAE (2023) A commentary on the medium term prospects of Ireland's hydrogen economy. Available here

Figure 13: Projected hydrogen demand in 2050



Source: *Government of Ireland (2023) National Hydrogen Strategy. Available here*

Hydrogen production

Hydrogen production is a vital input into hydrogen-fired power generation. Assuming the use of electrolysers, the two most significant cost components of hydrogen are the price of renewable electricity and the capital costs of electrolysers. It is also possible to supply power to electrolysers from the electricity grid. This is discussed in Annex B.

However, the costs of hydrogen production are uncertain. The Hydrogen Council predicts that the costs of renewable hydrogen could fall as low as 2.5c – 4.5c/kWh (or €0.82-1.46/kg) by 2050. However, the lowest estimate by the European Hydrogen Observatory of LCOH is much higher, at €3.41/kg and Aurora research calculates a LCOH of €3.50/kg in 2030 under optimal conditions.[21]

The cost of producing hydrogen varies not just across assumptions of electrolyser technology and grid connection, but also fuel type. Figure 14 shows the current levelised cost range estimates of hydrogen using natural gas and coal (with and without CCS), versus low carbon electricity.

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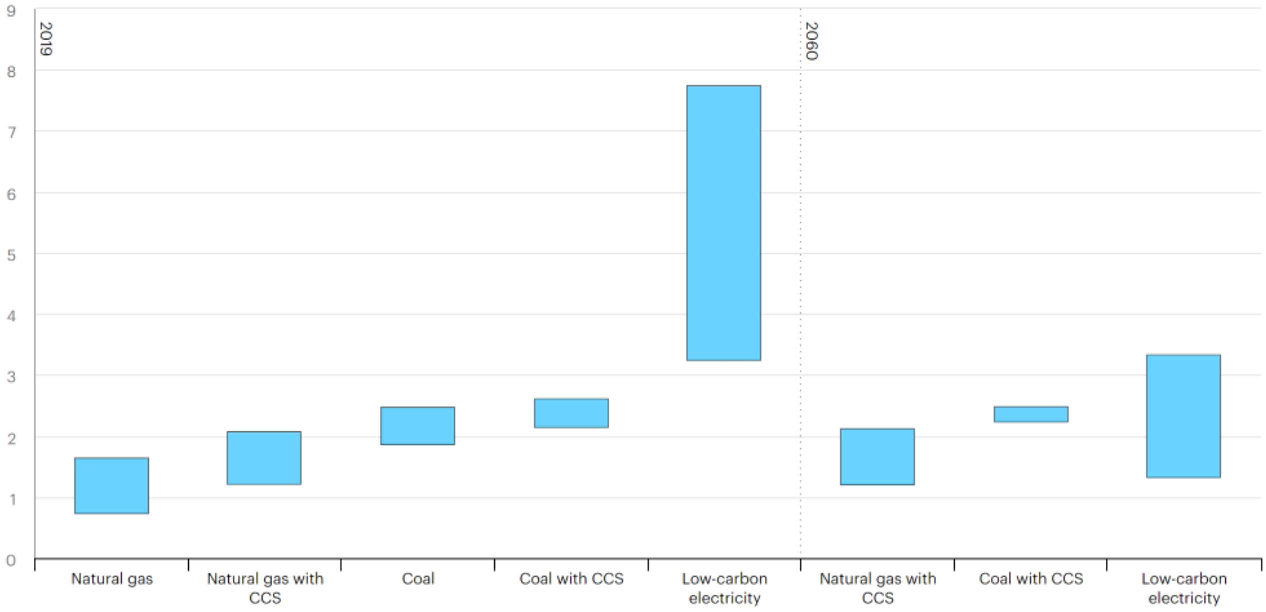
[21] A 100 MW electrolyser connected to 150 MW of onshore wind and 20 MW solar generation, not connected to the transmission system, located in Connaught. Available here

Figure 14: Low and high LCOH estimates, $/kg



Source: *IEA (2020) Global average levelised cost of hydrogen production by energy source and technology, 2019 and 2015. Available here*

Power generation - Projections of LCOE from H2 plant

Most existing gas turbines can handle hydrogen shares of 3-5%, with even fewer capable of operating under varying blends. Research is still ongoing to develop pure hydrogen power turbines, and EU Turbines (the association of gas and steam turbine manufacturers) are confident that turbines will soon be able to run entirely on hydrogen, with promising signs from Mitsubishi that they could develop such turbines by 2025.[22]

The role of hydrogen for power generation is still uncertain, given that this use is still a nascent technology. As such, uncertainty exists on the costs of generation using hydrogen and indeed on the cost of hydrogen production itself. Table 2 presents the main cost assumptions for 100% hydrogen-fired CCGTs in the United Kingdom, as estimated by DESNZ. These estimates do not yet include retrofitted hydrogen turbines.

Table 2: Main cost assumptions for 100% hydrogen-fired CCGTs

Cost item	2025	2030	2035	2040
Total pre-development (£m)	20	20	20	20
Total construction (£m)	830	830	830	740
Fixed O&M (£/MW/year)	15,500	15,500	15,500	14,000
Variable O&M (£/MWh)	2	2	2	2
Load factor (net of availability)	93%	93%	93%	93%
Operating period	25	25	25	25

Source – DESNZ : Electricity Generation Costs 2023 available here

DESNZ also produces LCOE for various peaking technologies, that enable a comparison on a £/Kw basis. Figure 17 below shows the peaking technologies of reciprocating diesel and gas, OCGT and Hydrogen CCGT 1 GW, assumed to run 500 hours per year, and unabated gas CCGT at normal load factors, all assumed to be commissioned in 2025.

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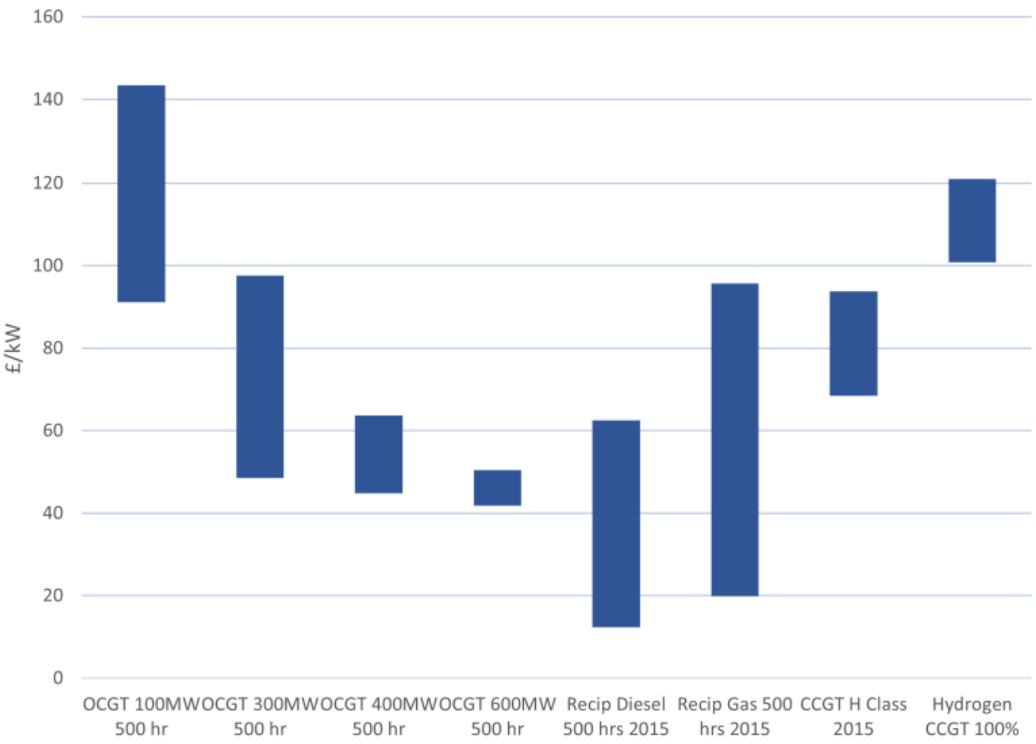
[22] Nature (2024) Turbines driven purely by hydrogen in the pipeline. Available here

Little detail is available on how those hydrogen CCGT costs may decline over time. A hydrogen-fuelled CCGT of this capacity might burn the equivalent of 1.15 TWh of hydrogen over 500 hours of operation.[23] Producing this quantity of hydrogen from renewables in Ireland and storing it would arguably not be feasible for a CCGT turbine of this size. Some argue that much smaller turbines (200 MW) would be needed to calibrate to renewables generation and storage at meaningful scale.[24] The IAE makes an initial estimate that with current technology back-up electricity produced using green hydrogen could cost between €377 and €516 per MWh in Ireland. That is, using the average accepted bid price of €86 per MWh on the Irish Offshore-RESS auction with Proton Exchange Membrane technology for electrolysis.[25]

Figure 15: Peaking technologies annual costs



Source – DESNZ Electricity generation costs 2023

Note - £/kW per annum presented for construction and fixed operating costs, with technology-specific discount rates. 2025 commissioning dates

Hydrogen converted to ammonia for power generation

Hydrogen has a share of less than 0.2% in the global electricity generation mix, and most of this share is in the form of ammonia converted from hydrogen.[26] Synthetic fuels (such as ammonia) produced using hydrogen possess technical qualities which make them more suitable to various end-use applications such as aviation and industry. Co-firing of ammonia in coal-fired power plants is still at demonstration stage, and has been demonstrated in trials in Japan and China. Further, the direct use of 100% ammonia was successfully demonstrated in a 2 MW gas turbine at IHI Yokohama works in Japan.

Although converting hydrogen to ammonia and shipping it as fuel is technically feasible, it has not been attempted at a large scale. Given that the transport and storage technology of ammonia have already been proven, ammonia is the most likely solution in Ireland capable of achieving high flow rates of hydrogen. Its liquification temperature is

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[23] Based on the assumption of a gas turbine with a capacity of 575 MW burning 40 tonnes per hour of H2 and an assumption of 1kg of H2 with an energy value of about 33.3 kWh. Source – Turbo Machinery International : https://www.turbomachinerymag.com/view/hydrogen-turbines

[24] Gulen, Zachary (2022) Feasibility of Achieving 62% Combined Cycle Efficiency With a 200 MW Gas Turbine. Available here.

[25] IAE (2023) A commentary on the medium term prospects of Ireland's hydrogen economy. Available here

[26] IEA – Global Hydrogen Review, 2023

-33 degrees Celsius and has the potential to be stored in offshore LNG facilities. It has other problems due to its toxicity, which led it to be withdrawn from some end-use applications such as refrigeration systems. [27]

Transport and storage

The NHS outlines transport alternatives for hydrogen in Ireland. These include:

- compressed tankers – well suited to decentralised small-scale applications, with their relatively low capital cost compared to pipelines making them an attractive option for small hydrogen volumes;
- pipelines – would allow the highest volume, lowest cost in the long term, but which lacks a regulatory framework and which is risky for investors; and
- synthetic carriers – in the form of ammonia, e-methanol and e-kerosene represent an alternative to hydrogen liquefication and is suitable to aviation and to shipping, unlike gaseous hydrogen.

Hydrogen storage will help to balance fluctuations in supply from variable renewable generation and seasonal changes in demand in the same way as gas at present. The most viable options for hydrogen storage are:

- compressed tankers – a suitable option for decentralised small-scale applications, offering quick and flexible deployment;[28]
- line packs – of limited use except in emergency situations given hydrogen's low density[29];
- geological storage solutions in salt caverns or depleted oil and gas fields – a potential long-term option given the potential number of caverns and the relatively low cost; and
- hydrogen derived carrier storage – once converted to a synthetic fuel, but suffers from substantial conversion loss and is less economically viable.

Considering geological storage options requires balancing several factors including density, capacity, discharge time, leakage, chemical reactions, and seismic risks.[30] Salt caverns are considered a suitable option for initial development as they have the shortest response times and lowest risk of losses from chemical reactions and leakage. Depleted gas fields are a potential option for scaling up storage as they have an abundance of available data for subsurface characterisation and existing infrastructure could be repurposed to convert a production site into a storage facility.

In Ireland, salt deposits tends to be restricted to offshore Permian and Triassic sedimentary basins along the east, south and north-west coasts, where existing borehole and seismic data can facilitate the future characterisation of these salt deposits for potential geological storage of hydrogen. A recent study identified 6,000 potential caverns in the two sea basins which are located at the optimum depth and thickness for hydrogen storage. Assuming 1% of these were viable storage options, these could deliver 60 TWh of cumulative hydrogen storage, which would be enough to meet the indicative 90-day hydrogen storage needs for 2050 demand estimates in Ireland. [31]

There are no subsurface basins with halite salt onshore in the Republic, although there exists one in Northern Ireland, Islandmagee. The Islandmagee project is currently in early-stage construction and aims to developseven underground caverns capable of storing up to 500 mcm of natural gas in Permian salt beds. The salt caverns are at a depth of approximately 1400m below Larne Lough. It is estimated that it will have a withdrawal capability of 22m cubic meters of gas per day for 14 days,[32] which could create around 0.21 TWh of useable energy per day.[33]

In the Republic of Ireland, one example of the potential for depleted gas field storage is the Kestrel Project. ESB, dCarbonX and Bord Gais Energy are proposing to redevelop the decommissioned gas reservoirs in the offshore Kinsale area for large-scale hydrogen storage. ESB and BGE operate significant electrical generation capacity at their nearby onshore Aghada and Whitegate gas-fired power stations. English and English estimate the total energy

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[27] IAE (2023) A commentary on the medium term prospects of Ireland's hydrogen economy. Available here

[28] Volume depends on tank type and pressure capabilities. A typical hydrogen car tank capacity is around 4-6kg of hydrogen weighing around 100kg (see Hyfindr (2023) Hydrogen Tank I – IV. Available here).

[29] As a comparison, Ireland's natural gas pipelines transported just under 60,000 GWh of natural gas in 2019 (see GNI (2020) Systems Performance, Available here)

[30] English and English (2022) Overview of hydrogen and geo-storage potential in Ireland. Available here

[31] SLR (2024) Hydrogen Salt Storage Assessment (HYSS). Available here

[32] Islandmagee Storage (2020) Environmental Statement Non-technical Summary. Available here

[33] SEAI conversion factors, available here

storage capacity for the Kinsale Head and Corrib gas fields at circa 134 TWh and 75 TWh respectively, of which half is working gas capacity of 67 TWh and 38 TWh respectively assuming a cushion gas requirement of 50%.[34] The Irish Academy of Engineering estimates the scale of investment required to produce the "cushion gas" to restore the pressures required for high volume delivery to be many multiples the price paid for the natural gas produced from those fields.

The volume of required storage for electricity generation will depend on assumptions on running profiles of plants.[35] Recovering the hydrogen from geological storage at flow rates required for electricity generation presents a further challenge. The Irish Academy of Engineering estimates that 4 GW of hydrogen back-up dispatchable power generation would require 18 times the peak flow rate from the SW Kinsale reservoir when it was used to store natural gas, and 6.6 times the peak flow rate from the Corrib Field (in 2017).

Regulatory and legislative planning issues

Regulation is required across multiple stages of the hydrogen supply chain, including production, transport, storage and end use. Due to its relative infancy as an industry, the current regulation is inadequate to facilitate the safe and efficient scaling up of hydrogen.

There is no specific occupational health and safety legislation at the European or national level specific to hydrogen. The current regulatory regime for natural gas implemented by the CRU does cover the safety of blends of hydrogen of up to 20%, however future legislation will be needed for pure hydrogen transport.[36] While the HSA regulates the transport and storage of dangerous goods, requirements under COMAH legislation are only relevant where the maximum anticipated quantity of hydrogen is greater than 5 tonnes. This will have implications for potential end users such as hydrogen refuelling stations, which will fall under this threshold. COMAH would also cover large scale storage of ammonia due to its poisonous nature. Storage of ammonia would require significant sterilisation zones around the chosen site.

The EU is currently developing the Hydrogen and Decarbonised Gas Market Package with the aim of developing a framework which enables the deployment of renewable gas and establishes rules on hydrogen infrastructure development. Most rules proposed align with the regulatory regime that underpins today's integrated natural gas market in Europe.[37]

International examples of hydrogen power generation and production

Most projects for hydrogen powered electricity generation are currently under development.

- Several utilities in North America, Europe and the Asia-Pacific region are exploring the possibility to co-fire hydrogen with natural gas in combined-cycle or open-cycle gas turbines. For example, the Saltend project aims to refurbish 1,200 MW natural gas-fired combined heat and power plant for 30% hydrogen co-firing share by 2027.[38]
- Other demonstration projects have been announced which focus on increasing their hydrogen co-firing share, including Hanwha Impact in Korea, a 15% hydrogen co-firing share gas turbine in Austria tested by Wienenergy and commercial partners including Siemens, and a 38% hydrogen co-firing share achieved by Constellation's Hillabee Generating Station.
- In Asia, several projects have been announced to explore the use of ammonia in coal-fired power plants.[39]

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[34] English and English (2022) Overview of Hydrogen and Geostorage Potential in Ireland. Available here

[35] For instance, if we assume a 60 Hz J+ class turbine of 300 MW burns circa 30 tonnes of hydrogen per hour and running for 500 hours per year, this would result in around 0.345 TWh equivalent of hydrogen. Assuming a hydrogen energy value conversion factor of 33.3 kWh per kg/H2a PEM electrolyser requires around 55 kWh per kg of hydrogen, thus requiring 2.2 GW of green power. However, the total dispatch down of wind energy in Ireland was only 988 GWh in 2022. More information at Carbon commentary (2021) Some rules of thumb for the hydrogen economy. Available here. Turbomachinery international (2023) Hydrogen turbines. Available here.

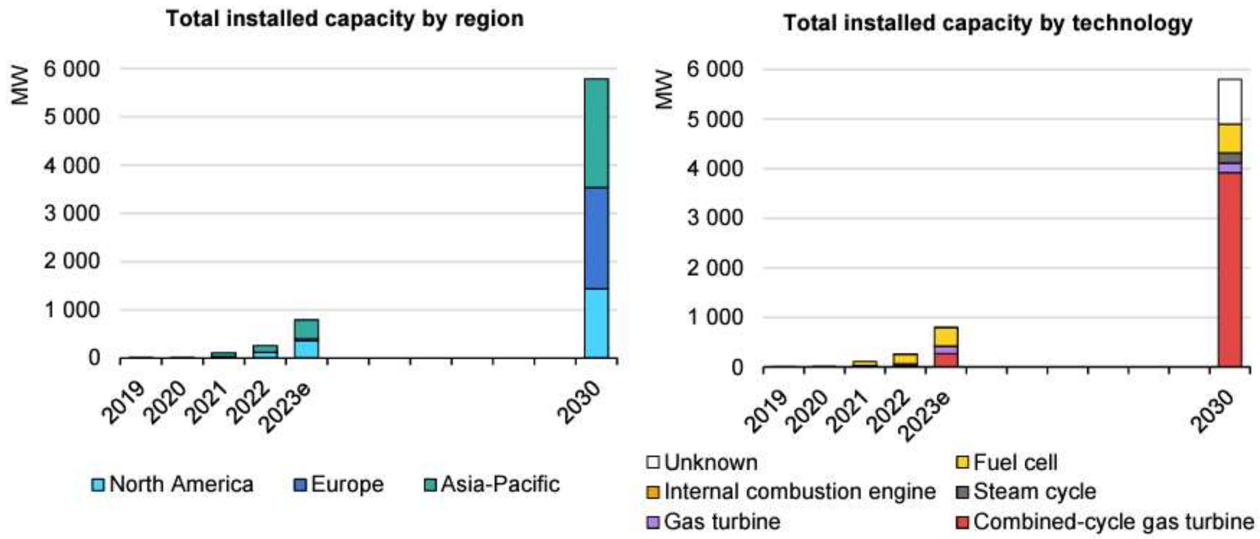
[36] Gas Networks Ireland, Hydrogen and Ireland's national gas network. Available here

[37] Government of Ireland (2023) National Hydrogen strategy. Available here

[38] Hydrogen shares are on a volumetric basis.

[39] IEA – Global Hydrogen Review, 2023

Figure 16: Power generation capacity using hydrogen and ammonia by region, historical and announced projects, 2019-2030



Source: IEA (2023) Global hydrogen review 2023. Available here

Around 70% of projects are linked to hydrogen use in open-cycle or combined-cycle gas turbines, while the use of hydrogen in fuel cells accounts for 10% and the co-firing of ammonia in coal-fired power plants for 3% of the capacity of announced projects. Regionally, these projects are principally located in the Asia-Pacific region (39%), Europe (36%) and North America (25%) (Figure 16).

In addition, several utilities announced plans to build new gas power plants or to upgrade existing gas power plants to be "H2-ready", i.e. able to co-fire a share of hydrogen. [40] The hydrogen share of the H2-ready announced capacity would correspond to 3 400 MW. Existing gas-fired power plants can handle from 10% to 100% hydrogen, depending on the gas turbine design. The hydrogen-fired capacity from existing gas turbines could amount to more than 70 GW globally.[41]

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[40] There is disagreement on what exactly it means to be hydrogen-ready. For instance, EU Turbines identifies different readiness categories for a given share of hydrogen between 10% - 100%, depending on technical adaptions and related investments required (see EU Turbines (2024) H2-Ready Definition. Available here). The Siemens definition is much narrower, and refers to plants that are prepared for immediate conversion to 100% hydrogen (see Siemens Energy (2022) Ten fundamentals to hydrogen readiness. Available here). For the purposes of our discussion, we are referring to plants that can co-fire a share of hydrogen.

[41] IEA – Global Hydrogen Review, 2023. Available here

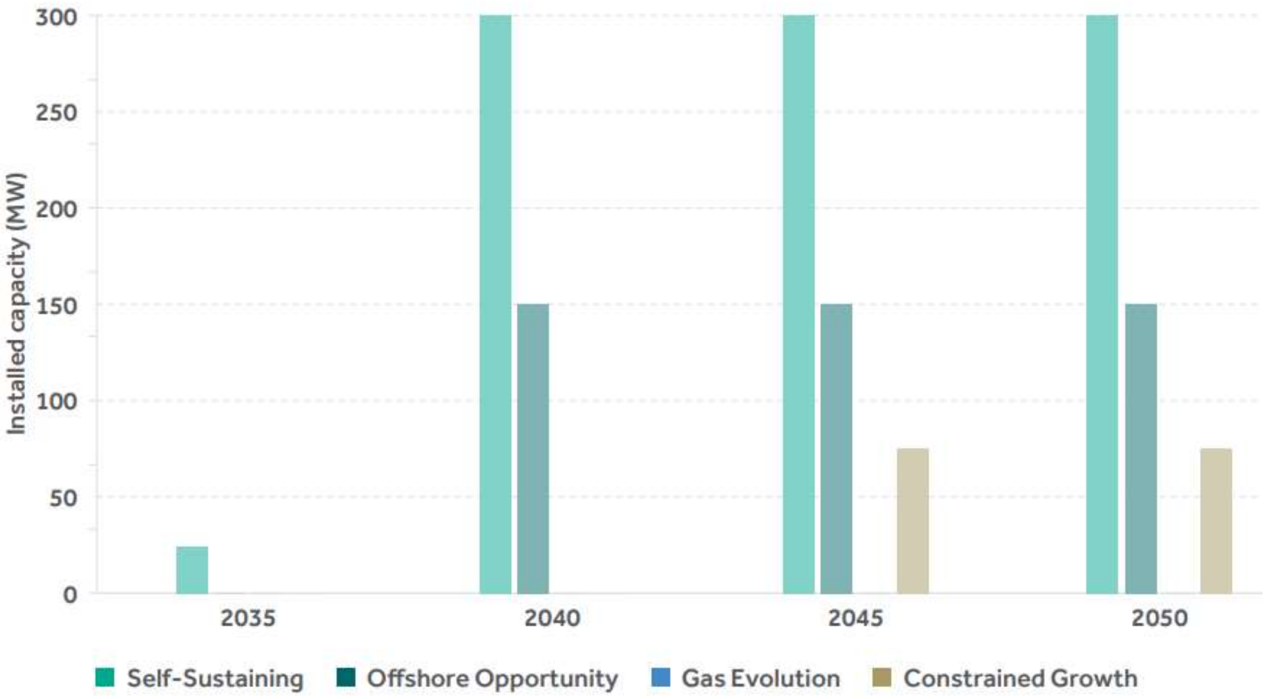
5. Carbon capture and storage from gas and bio-energy plant

In this section we summarise the drivers of deployment of CCS in the Irish power sector (on gas and bioenergy plant). These include advances in CCS in other jurisdictions, LCOE for CCS power generation, technical barriers to CCS uptake, and CCS potential in the Irish context.

Currently, CCS is not a commercially viable technology in Ireland and the speed of its development in the future is uncertain. However, policy and long-term scenario planning envisage a significant role for CCS in decarbonising the Irish energy sector. This is envisaged to include retrofitting existing power plants, and waste-to-energy facilities with carbon capture capabilities, as well as building out necessary transport and storage infrastructure.[42]

The presence of negative emission technologies such as Bio-Energy with CCS (BECCS) can be important in a future power system as it allows some unabated power generation to run while the system overall achieves zero net emissions. When constrained to meet ambitious net zero targets in the power sector, Eirgrid's scenarios indicate a preference for BECCS over biomass by 2040. Eirgrid's most recent modelling assumes that biomass with CCS will become available between 2033 and 2045 forming a significant part of a least-cost generation mix by 2040 for one out of four scenarios (Figure 17).[43] High-level scenarios from SEAI also indicate the negative emissions contributions of several potential gas-CCS (up to five sites) and BECCS generation sites in Ireland (Figure 18).

Figure 17: Biomass and BECCs capacity under different long-term power sector decarbonization scenarios



Source – Eirgird Tommorow's Energy Scenarios 2023 Consultation Report

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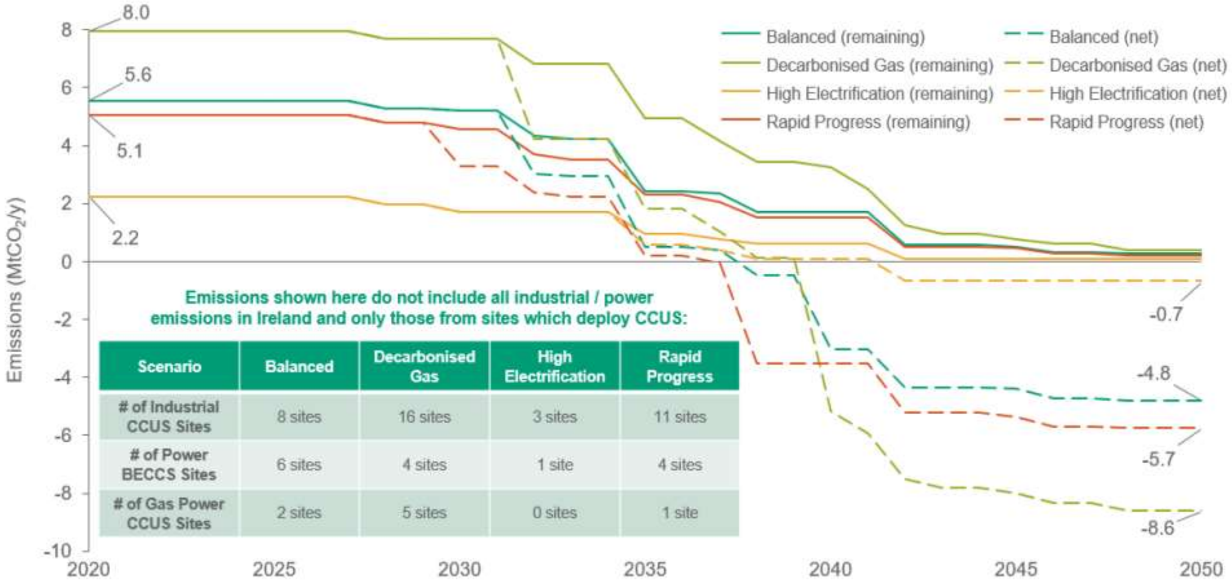
[42] Government of Ireland (2023) Climate Action Plan 2024. Available here

[43] Eirgird Tommorow's Energy Scenarios 2023 Consultation Report

Figure 18: Remaining and net emissions from all industrial and power sites abated by CCUS or BECCS



Emissions shown here do not include all industrial / power emissions in Ireland and only those from sites which deploy CCUS:

Scenario	Balanced	Decarbonised Gas	High Electrification	Rapid Progress
# of Industrial CCUS Sites	8 sites	16 sites	3 sites	11 sites
# of Power BECCS Sites	6 sites	4 sites	1 site	4 sites
# of Gas Power CCUS Sites	2 sites	5 sites	0 sites	1 site

Source – SEAI (2022) Carbon Capture Utilisation and Storage (CCUS). Available here

Other jurisdictions with CCS power generation and storage

The future availability and deployment rate of CCS in the Irish power sector is highly dependent on the outcome of RD&D activities in other jurisdictions, including the performance of pilot and demonstration projects elsewhere in the world. Internationally, the CCS industry is at an early stage, although it is developing rapidly. Approximately 40 commercial facilities are in operation applying CCS processes with a further 500 projects in development.[44] CCS projects are now operating or under development in 25 countries around the world, with the United States and Europe (UK, Norway, Netherlands) [45] accounting for three-quarters of the projects in development[46]. Other countries such as Australia and Canada have also been described as first-movers.[47] Some of these are described in Table 3 below.

Support for CCUS is also growing in Canada and Australia. Canada has announced an investment tax credit for CCUS and CAD 319 million in funding to support CCUS RD&D. In Australia, AUD 250 million in funding has been announced for CCUS hubs alongside the inclusion of CCUS under the Emissions Reduction Fund valued at around AUD 20/tCO2).

Projections of LCOEs for plants with CCS

Cost reductions are a challenge and are crucial for the wide-scale deployment of CCS.[48] The UK's Department for Business, Energy & Industrial Strategy outlines the predicted LCOE across multiple fuel types and scenarios in its Electricity Generation Costs 2020 report.[49] Figure 19 presents the levelised cost estimates for CCGT + CCS Post Combustion and Biomass CCS projects commissioned in 2025, 2030 and 2040. The cost of biomass projects is expected to be more than double that of CCGT across all years, despite having a greater reduction in total real costs by 2040.

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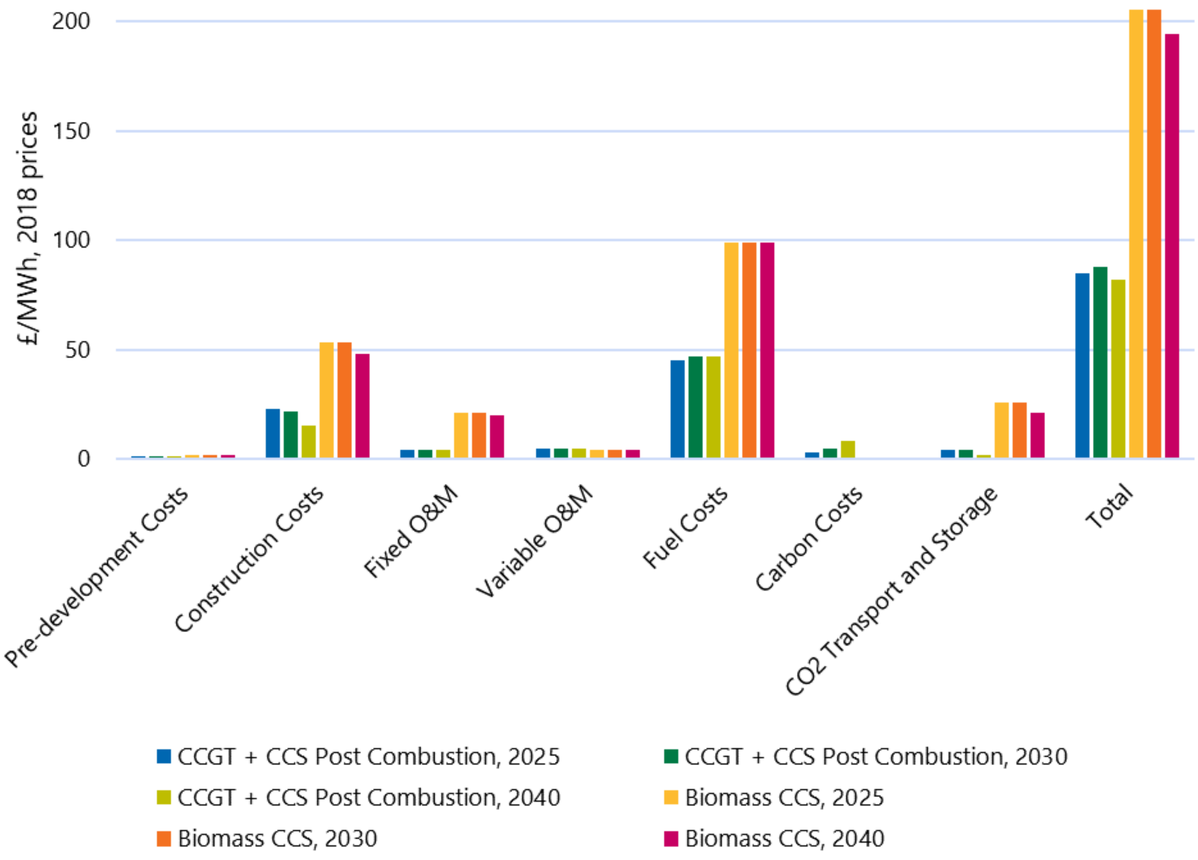
[44] IEA https://www.iea.org/energy-system/carbon-capture-utilisation-and-storage
[45] IEA (2021) Carbon capture in 2021 : Off and running or another false start? Available here
[46] IEA (2021) Carbon capture in 2021 : Off and running or another false start? Available here
[47] Energy Focus (2023) Five countries leading the way in carbon capture and storage. Available here
[48] Diego et al, "Making gas-CCS a commercial reality: The challenges of scaling up (2017). Available here
[49] The updated 2023 report from DESNZ does not update its cost estimates for power generation with CCUS

Table 3 – Overview of CCS projects in development

Country	Project name	Investment	Target capture
Norway	Northern Lights offshore storage hub	1.8 bn USD	1.5 Mt pa from 2024
Netherlands	Porthos CCUS hub	2 bn EUR (max)	
UK	Net Zero Teeside – full chain CCS[48]	1 bn GBP	4 Mt pa from 2027
UK	Drax – BECCs pilot[49] - part of proposed Zero Carbon Humber CCUS hub	31.7 bn GBP[50]	1.3 tonne/day from 2027
USA	Houston Ship Channel CCS	100 bn USD	100 Mtpa by 2040
USA	Direct Air Capture – Permian Basin	1.3 bn USD	0.5 – 1.0Mt pa in 2024
USA	Next Decade[51] - CCS in LNG supply chain	18.4 bn USD	Up to 5 m Mt
Japan	Tomakomai CCS Demo project (2016–19)	300m USD[52]	0.1 Mtpa – 0.3 Mtpa

Source – Frontier Economics

Figure 19: Levelised cost estimates for projects commissioning in 2025, 2030 and 2040.



Source – Department for Business, Energy and Industrial Strategy (2020) Electricity generation costs 2020. Available here.

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[50] Ember (2021) Understanding the cost of the Drax BECCS plant to UK consumers. Available here

[51] https://nextdecade.gcs-web.com/static-files/03effa09-1b7f-4245-95a9-cc88d74f75e4

[52] Reuters (2018) Available here

Technical barriers to CCS power generation deployment

There are some key risks and uncertainties for CCS development, including site performance risks (effective capacity and injectivity), containment risks (effective CO2 containment in the storage phase), public perception risks, and market failure risks (relating to the expected revenue stream and demand).

Post-combustion technology is the most mature technology option for CCS from CCGT plant, with the option to integrate the provision of necessary steam from the main CCGT plant or to build separate auxiliary boilers with electricity supplied from the grid connection.[53] Site-specific space constraints may pose a significant challenge to the integration of a new capture plant with an existing power plant. Furthermore, the addition of a capture plant to a CCGT plant is typically estimated to incur an efficiency penalty of around 8% points

The SEAI has identified infrastructure development[54] as a key constraint for adopting CCUS at both industrial and power sites, and particularly for more dispersed sites. It is unlikely that the development of onshore transport options will be the constraining factor for deployment of CCUS in Ireland; while permitting onshore pipelines can be a long process, trailers can be available in reasonable lead times (i.e. less than 4 years). Rather, the technology readiness of carbon capture and the availability of downstream transport and storage infrastructure at a site will be the key constraints for adoption of CCUS abatement. Previous studies have estimated lead times for CO2 shipping infrastructure to be around 5 to 7 years.[55]

The spatial distribution of the source emitters is also an important consideration as the more closely 'clustered' the sites are, the lower the overall cost of the CO2 transportation and shipping. Large point carbon source emitters would need reassurance about the viable downstream CO2 transport and storage options before investing in CO2 capture. Potential storage sites in Ireland are discussed further below.

Legal and regulatory issues

The Climate Action Plan 2024 sets an action to develop a clear framework to assist long-term decisions on CCS. The EU Directive 2009/31/EC on Geological Storage of CO2 requires that EU Member States ensure that all operators of combustion plants of 300 MW or more demonstrate that suitable storage sites are available, and transport facilities and retrofit for CO2 capture are technically and economically feasible. This minimum size of 300MW also corresponds to examples in Australia and in the UK.[56][57]

In relation to Irish legislation, the capture element of a CCS project could largely be regulated under existing planning and environmental law.[58] In relation to storage, the following two Statutory Instruments (S.I.) transpose Directive 2009/31/EC into Irish legislation. These are currently the only two Irish regulations specifically relating to carbon capture and storage.

- European Communities (Geological Storage of Carbon Dioxide) Regulations, S.I. No. 575 of 2011.125.
- European Communities (Geological Storage of Carbon Dioxide) (Amendment) Regulations, S.I. No. 279 of 2014.126.

Through these regulations, Ireland is one of several countries that have applied restrictions on CO2 storage. Article 4 of the S.I. No. 575 of 2011, Selection of Storage Sites, prohibits storage of CO2 in amounts greater than 100,000 tonnes. However, the explanatory note accompanying S.I. No. 575 of 2011 recognises the potential value of CCS and states that the restriction will be kept under active review. For a CCS project in Ireland to progress, the regulation would need to be amended or revoked and the full permitting requirements of the CCS Directive would need to be transposed into Irish law. Ultimately this would require a framework of consents for the storage of CO2 in Ireland to be developed and implemented.

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[53] Poppa et al in Energy Procedia 4, "Carbon Capture Considerations for Combined Cycle Gas Turbine" (2011)

[54] SEAI (2022) Carbon Capture Utilisation and Storage (CCUS). Available here

[55] Ibid, cited from Element Energy, 'Deep Decarbonisation Pathways for UK Industry', p. 80. A report for the Climate Change Committee, November 2020. Available here

[56] Aurecon (2022) Costs and Technical Parameter Review. Available here

[57] Poppa et al in Energy Procedia 4, "Carbon Capture Considerations for Combined Cycle Gas Turbine"

[58] Ervia (2020) Carbon Capture and Storage for Ireland: Initial Assessment. Available here

There is no specific legislation or consenting regime in place to regulate the construction or operation of a pipeline transporting CO2 in Ireland. A regime similar to that currently in place for gas pipelines under the Gas Act (1976)127, as amended, could be introduced for CO2 pipelines.

Bio-energy supply chains in Ireland and potential constraints on BECCS

BECCS involves the combination of bioenergy production with CCS. There are several potential supply chain problems that could affect BECCS implementation, including biomass availability, land use and competition, sufficiently large storage and transport, and transportation infrastructure as discussed above.

There are currently some indicative pathways for the deployment of negative emissions technologies in Ireland.[59] In the short to medium term (5–15 years), the most promising option appears to be afforestation, owing to its simplicity and technical maturity,. Afforestation can be a short-term CO2 removal "triage" measure with a clear strategic objective for the removed carbon to be transferred to secure, long-term geological storage as soon as possible, most probably through early deployment of BECCS. In the longer term, BECCS (combined with indigenous bioenergy crop cultivation) appear to offer the best prospect of large-scale indigenous CO2 removal providing a technical potential of 400–600 MtCO2 by 2100. However, the technical potential is premised on extremely ambitious, early, rapid and sustained deployment of BECCS infrastructure (including CO2 geo-storage), rapid and sustained land use change to bioenergy cultivation and, ultimately, large-scale land use reallocation. A more conservative estimate would be less than 200MtCO2.

Transport and storage of CO2 in Ireland

Ireland has limited accessible domestic CO2 storage sites. Moreover, these CO2 storage sites are also possible hydrogen storage sites, as described in the section above. The greatest potential exists offshore in saline aquifers but the most accessible storage is in the depleted gas fields of Kinsale Head and Corrib gas field. Islandmagee in Northern Ireland is a secondary potential site.

Table 4 – Principal gas storage sites

Gas field	Capacity (CO2)	Comment
Kinsale	321 Mt	Decommissioned gas site, potential option for carbon or H2
Corrib	44 Mt[60]	Gas site, in operation for the next 10-15 years.
Islandmagee	500 mcm – gas capacity[61]	A salt gas storage project. Development timeline is unclear

Kinsale gas field has been identified as an attractive target for CCS because the overall capacity and injectivity appear to be satisfactory, but its potential remains to be proven for large scale CCS. It has a carbon storage capacity of 321 Mt, the equivalent of up to 40 years of CO2 emissions from the top 10 point-source emitters in Ireland.[62]

Kinsale gas field could receive carbon from power plants and industry in the Cork area. 1.5 to 2.5 Mt of CO2 per annum could be captured this way (i.e. up to a quarter of Irish annual gas related emissions).[63] The SEAI cited an estimate of €12/tCO2 storage cost for Kinsale.[64] The offshore pipeline required from Cork could cost an estimated additional €2/tCO2. In comparison, the Northern Lights Project, a Norwegian CCS project with a targeted scale of 5 Mt pa CO2 captured by 2030, has a targeted combined cost range of €30-55/tCO2 for transport and storage by 2030.[65]

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[59] McMullin et al, (2020) IE-NETs: Investigating the Potential for Negative Emissions Technologies (NETs) in Ireland, EPA research paper. Available here

[60] English and English (2022) Carbon capture and storage potential in Ireland – returning carbon whence it came

[61] Islandmagee Energy (2024) Islandmagee gas storage project. Available here

[62] English and English (2022) Carbon capture and storage potential in Ireland – returning carbon whence it came

[63] Ervia (2020) Carbon Capture and Storage for Ireland: Initial Assessment. Available here. Ervia (2022) has commissioned a pre-FEED study to evaluate the infrastructure necessary for the compressing and transport of liquid CO2 at Cork harbour for subsequent export to the Northern Lights project, here.

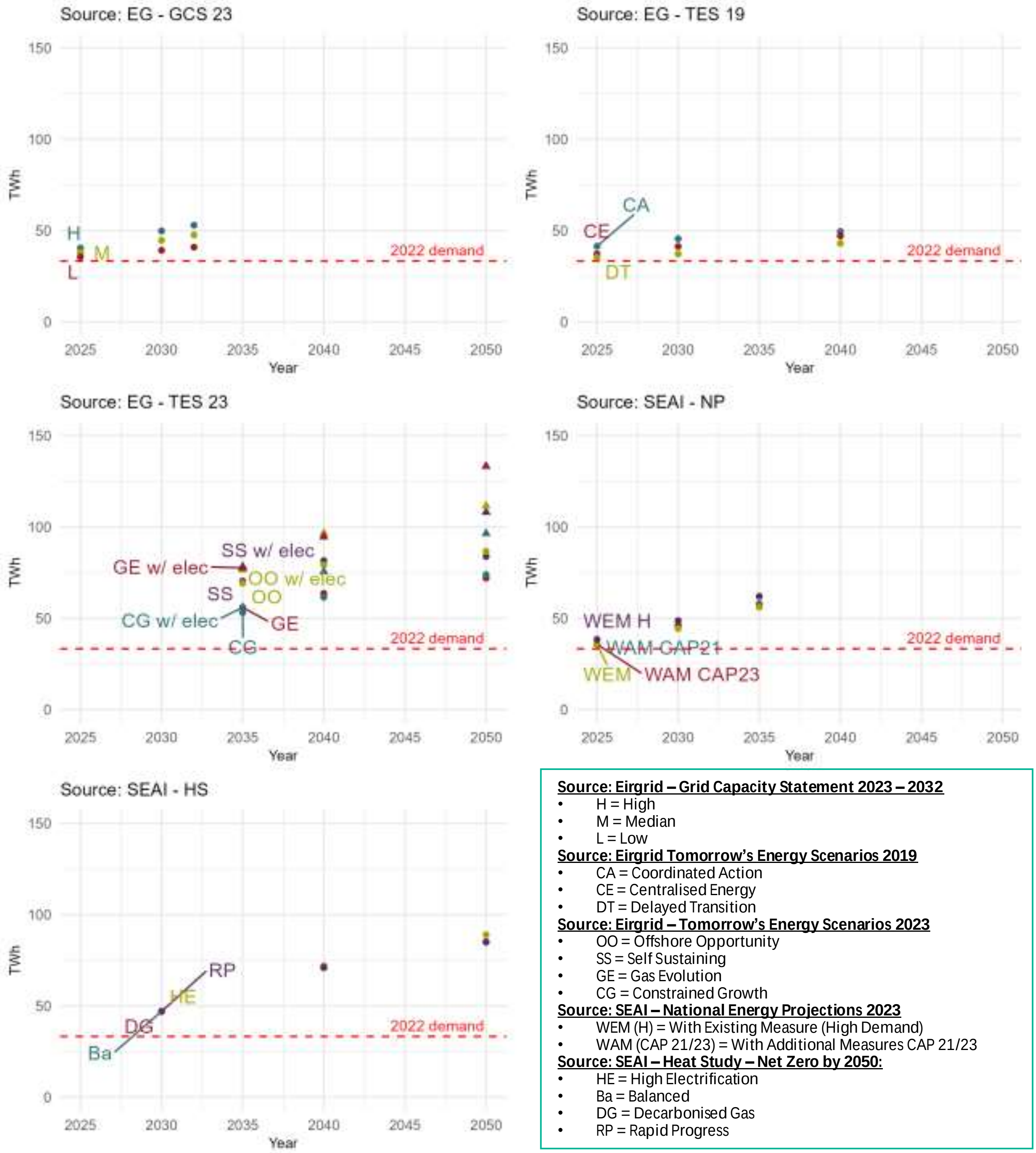
[64] SEAI. CCUS 'Suitability, Costs and Deployment Options in Ireland', available here

[65] Smith et al, The cost of CO2 transport and storage in global integrated assessment modelling, International Journal of Greenhouse Gas, vol 109, July 2021

Annex A – Assumptions behind the demand forecasts

This annex shows the demand projections according to the different sources (Figure 5) and summarise the main assumptions behind the various demand projections.

Figure 20Electricity demand forecasts by source



Source: Eirgrid – Grid Capacity Statement 2023 – 2032
- H = High
- M = Median
- L = Low

Source: Eirgrid Tomorrow's Energy Scenarios 2019
- CA = Coordinated Action
- CE = Centralised Energy
- DT = Delayed Transition

Source: Eirgrid – Tomorrow's Energy Scenarios 2023
- OO = Offshore Opportunity
- SS = Self Sustaining
- GE = Gas Evolution
- CG = Constrained Growth

Source: SEAI – National Energy Projections 2023
- WEM (H) = With Existing Measure (High Demand)
- WAM (CAP 21/23) = With Additional Measures CAP 21/23

Source: SEAI – Heat Study – Net Zero by 2050:
- HE = High Electrification
- Ba = Balanced
- DG = Decarbonised Gas
- RP = Rapid Progress

Source: *Eirgrid Grid Capacity Statement 2023 -2032 (EG - GCS 2023), Eirgrid Tomorrow's Energy Scenarios 2019 (EG - TES 2019), Eirgrid Tomorrow's Energy Scenarios 2023 (EG - TES 2023), SEAI National Energy Projections (SEAI – NP), SEAI Heat Study (SEAI – HS).*

Eirgrid, Grid Capacity Statement 2023 – 2032

The Grid Capacity Statement is published annually by Eirgrid. Following the methodology set out by the CRU and UR, the GCS examines the balance between electricity demand and supply in Ireland over the next 10 years to conduct an adequacy analysis. The growth in electricity demand forecast come from different drivers.

- Economic growth: The predicted Real Modified Gross National Income (Real GNI) is used to forecasts commercial and industrial electricity demand, while the personal consumption growth estimates are used for residential demand projections. In the median scenario, these numbers are respectively 3 and 2.5%.
- Data centres: Eirgrid forecasts strong growth in data centre demand out to 2026, with continued growth towards the end of the decade (total demand increase in the median scenario is 810 MVA, 304 MVA in the low and 1276 MVA in the high). Eirgrid assumes that this growth is all from previously contracted projects.
- Heat and Transport: The median scenario assumes that by 2030, 100% of the CAP23 targets will be met. By 2030, the low scenario assumes 75% and the high scenario assumes 110%. A gradually increasing uptake is assumed for the interim years

Eirgrid, Tomorrow's Energy Scenarios 2023

In the TES 2023 scenarios, Eirgrid updated its long-term projections. We note that the scenarios published may not be the final ones, as there still in the consultation phase. The increased demand in TES 2023 is driven by various factors. Figure 22 below shows demand disaggregated by sector.

- Population Growth: The projections are based on the CSO high fertility scenario, foreseeing a population of 5.2 million in 2030 and 6.2 million by 2050.
- Data Centres and New Tech Loads (NTLs): Aligned with the GCS, strong growth is assumed until 2030. The expected demand from data centres is projected to range between 21 to 27 TWh in 2030, increasing to 27-36 TWh by 2050.
- Heat and Transport: It is assumed that the targets will be met by scenarios Self-Sustaining and Offshore Opportunity, while Constrained Growth and Gas Evolution scenarios fall short.

Figure 22 -TES 2023 demand forecasts disaggregated by sector

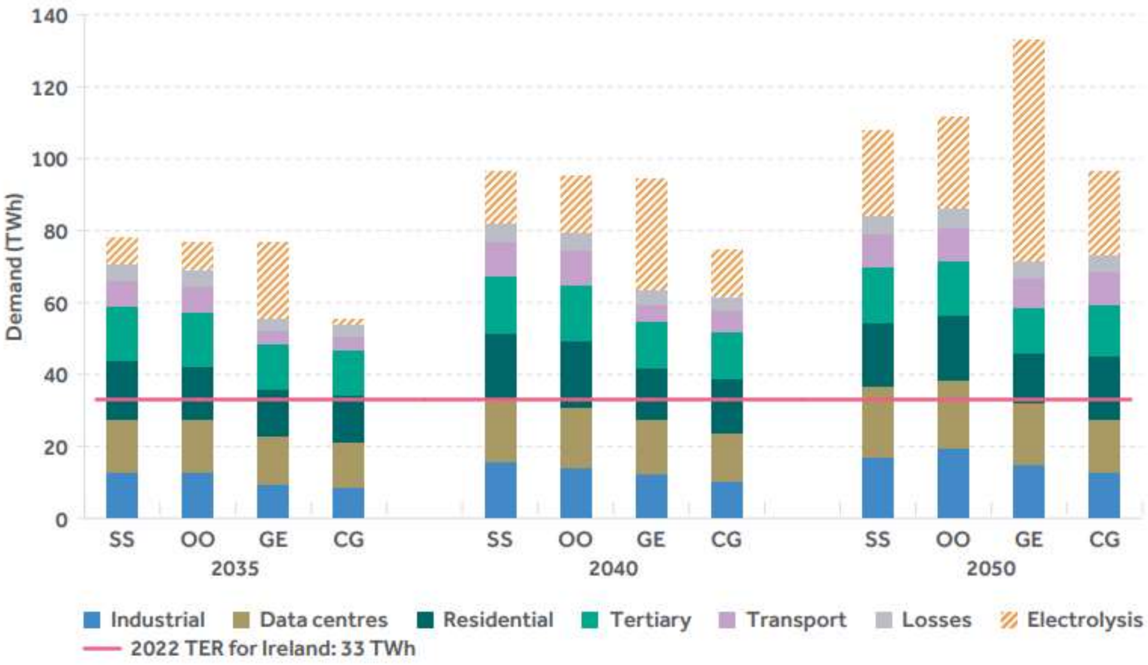


Figure 5.1: Annual Total Electricity Requirement (IE)

Source: EirGrid Tomorrow's Energy Scenarios 2023. Available here

SEAI – National Projection to 2023

The National Energy Projections 2023 Report assesses the potential impact of current government policies on energy use and greenhouse gas emissions in Ireland from 2022 to 2030.

In SEAI national projections, demand growth is driven by the electrification of heating and transport, as well as data centre demand. To provide perspective, by 2030, in the WAM-CAP23 scenario, total final electricity consumption is projected to increase by 16 TWh. This includes 4.7 TWh from heat and transport electrification, 6.1 TWh from data centres, and 5.5 TWh from other sources.

- In heating and transport, WAM CAP 21 and WAM CAP 23 assumed that the respective targets will be met, while WEM (normal and high demand) sees lower heat pump and electric vehicle uptake.
- Datacentre: Data centre electricity demand projections follow EirGrid's "Median" growth scenario, except for WEM high demand, which aligns with the "High" scenario.
- Other: Other sectors, such as industry, services, and residential, also contribute to an increase in demand.

SEAI - Heat Study

The National Heat Study aims to provide an analysis of the options to reduce CO2 emissions associated with heating in Ireland. As part of this study, the SEAI forecasted demand to 2050. The increased demand in this study is driven by data centres, EVs and heat. Figure 23 below shows demand growth disaggregated by these sector.

- Data Centre: Data centres are the primary driver of growth to 2030 (+9.2 TWh with respect to 2022), and keep being an important driver of growth to 2050 (+13 TWh).
- Transport: Electric vehicle demand manifests a bit later, contributing 13.6 to 14.1 TWh of demand by 2050.
- Heat: Similarly, the electrification of heat mostly occurs between 2030 and 2050. By 2050, heat electrification emerges as the dominant growth area in all scenarios except the Baseline, accounting for a range of 11.7 to 17.4 TWh.

Figure 23 - SEAI Heat Study demand forecast growth

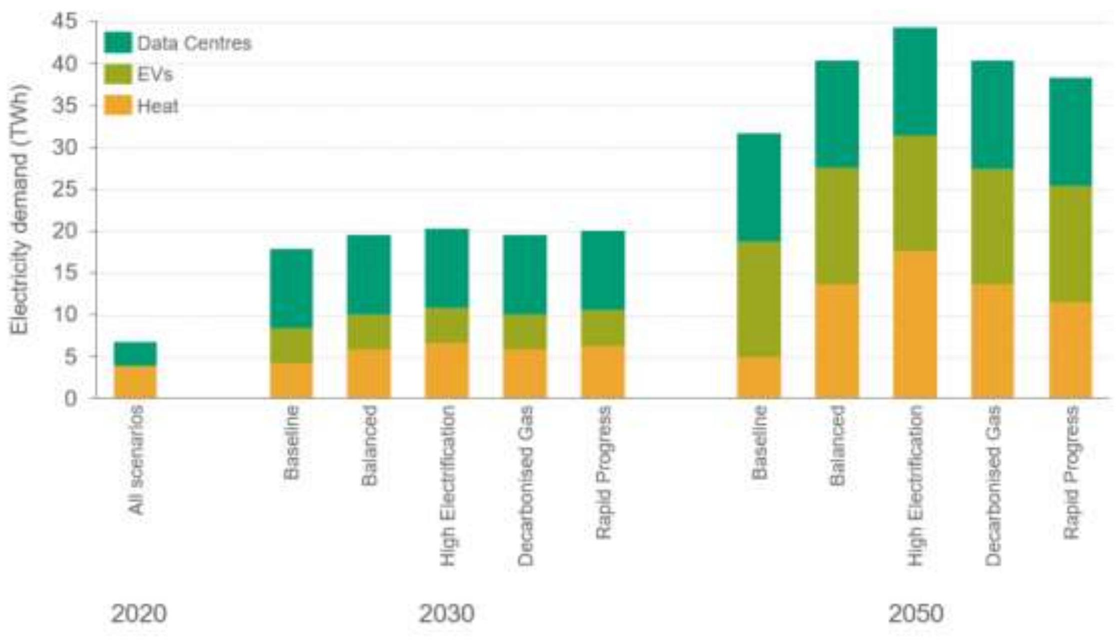


Figure 58: Electricity demand from primary growth sectors for electricity demand in 2020, 2030, and 2050, by scenario

Source: SEAI (2022) National Heat Study – Net Zero by 2050. Available here

Annex B - Grid Electrolysis

It is possible to supply power to electrolysers via the electricity grid. However, this raises further questions as to the true carbon impact of producing hydrogen, especially in the context of the conversion losses and energy requirements discussed within this report. Although this issue should become less relevant as the share of renewables in electricity generation increases to meet the 2030 targets, the EU has established rules determining whether hydrogen from grid electrolysis is considered renewable.[66] These rules state that it must be produced in an electricity system with greater than 90% renewables over a calendar year or is produced during periods of curtailment or dispatch down. Much regulatory work is yet to be done at the European level to provide guarantees of origin for green hydrogen however.

The Irish National Hydrogen Strategy models the costs and benefits of different scenarios under which operating grid electrolysis is permitted. Benefits are expected to be positive if electrolysers are run during times of high wind to reduce curtailment, or where electrolysers operate at 50% of full load to deliver balancing and operating reserve system services. Counteracting these benefits are the opportunity costs that arise whereby electrolysers compete against other storage assets for excess RES.

At the core of each of the scenarios outlined in the NHS is the need to reduce the levelised cost of hydrogen (LCOH) by using the electrolysers as much as possible, balanced against concerns of efficiency losses and additional strain placed on the grid by electrolysers. It is reasonable to assume that a certain level of grid electrolysis is necessary as it is unlikely that electrolyser demand will be fully satisfied by off-grid capacity alone. Given the high degree of uncertainty around the future of electrolysis, EirGrid do not include it in its modelling of Total Electricity Requirement. It is unclear what share of the extra load that electrolysers may provide will be supplied by non-grid connected generators.

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[66] European Commission (2022) Production of renewable transport fuels – share of renewable electricity (requirements) – Commission adoption Article 4.1. Available here

Sustainable Energy Authority of Ireland
Three Park Place
Hatch Street
Upper Dublin 2
Ireland
D02 FX65

w: www.seai.ie
e: info@seai.ie
t: 01 8082100

Document 4.1 Draft SEAI DESS Report v1.0

SEAI presented provisional results of this expert elicitation to the CBWG in April and June 2024. A final Decarbonised Electricity System Study report documenting the methodology and results of the surveys will be published by SEAI in late 2024.

Note on Aviation & Maritime for Carbon Budgets Working Group

Contents

1. Introduction

This paper provides an overview of aviation and maritime emissions for Ireland, presents drivers of demand and overall international trends for discussion with the Carbon Budgets Working Group. It then provides an overview of relevant International, EU and National legislation covering both sectors and current policies and measures to address these emissions.

The material outlined in this paper may be used as part of the evidence base to inform the Technical Report for the 2nd programme of Carbon Budgets being prepared by the CCAC Secretariat. The paper will be presented at the Carbon Budgets Working Group meeting on the 28th of June 2024 and feedback from the Working Group on additional areas to consider is welcome.

2. Current Policy Context

Energy use for international aviation and marine bunkers is included in the SEAI National Energy Balance, based on the tax and excise rates applied to the sale of these fuels with emissions then calculated from these. Emissions from international aviation and maritime navigation are reported as "memo items" in the national emission inventory for Ireland under the IPCC reporting format[1]. While emissions are not currently counted within Ireland's national emissions reporting[2] or within the carbon budgets it will be critical to reduce emissions in these areas consistent with the Paris Agreement.

By 2030, the European Commission's scenarios that underpin the overall 55% reduction objective under the Green Deal require emissions from international aviation and maritime transport to peak in 2025 and return to 2005 levels[3]. In its June 2023 advice to the European Commission, the European Scientific Advisory Board (ESAB) recommended keeping the EU's greenhouse gas emissions budget within a limit of 11 to 14 Gt CO_2 eq between 2030 and 2050. Staying within this budget requires emission reductions of 90–95% by 2040, relative to 1990. The target and budget figures in the headline refer to net domestic greenhouse gas emissions, including emissions from intra-EU aviation and maritime transport.

The Climate Action and Low Carbon Development Act 2021 (as amended) included a 51% target as the primary constraint on carbon budgets over the course of the first two budget periods ending on 31 December 2030, relative to 2018 as set out in the national greenhouse gas emissions inventory. International Aviation and Maritime were excluded from the carbon budget calculations for CB1 and CB2. Section 6A of the Act notes that '*The Government shall make regulations for determining the greenhouse gas emissions to be taken into account, and the manner of calculating and accounting for such emissions…*'

S.I. No. 531/2021[4] requires the Climate Change Advisory Council to take account of the most recent national greenhouse gas emissions inventory for the preparation of future carbon budgets, which excludes International Aviation and Maritime. However, this may be re-considered in the context of the future programme of carbon budgets and international developments in the interim and there are some examples of other national carbon budgets which reflect these sectors. The UK's sixth carbon budget, running from 2033 to 2037, included aviation and maritime emissions for the first time, while the French Climate Council has recommended the inclusion of international aviation and maritime emissions in French national targets. In New Zealand, the Climate Change Commission is required to provide advice by the end of 2024 on whether the 2050 target should be amended to include emissions from international maritime and aviation (and, if so, how the target should be amended)[5].

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[1] This means they are not counted as part of Ireland's national total emissions but are reported by Ireland to the UNFCCC and EU for information purposes.

[2] The UN bodies responsible for the aviation and maritime sectors are the International Civil Aviation Organisation (ICAO) and the International Maritime Organization (IMO).

[3] https://climate-advisory-board.europa.eu/reports-and-publications/towards-eu-climate-neutrality-progress-policy-gaps-and-opportunities

[4] https://www.irishstatutebook.ie/eli/2021/si/531/made/en/print

[5] https://www.climatecouncil.ie/councilpublications/councilworkingpaperseries/FINAL%20WP%2025%20Carbon%20Budgeting%20in%20Selected%20Countries.pdf

The Joint Committee on Environment and Climate Action, in its February 2022 report on the proposed carbon budgets[6], suggested '*measures be taken to plan for the appropriate assessment or inclusion of shipping and aviation emissions in future proposed Carbon Budgets.*' While it is not the role of the Carbon Budgets Working Group or the Climate Change Advisory Council to develop policies in this area, this paper aims to provide some background information relevant to this assessment.

3. Aviation

3.1 Aviation emission trends and projections

In 2022, aviation accounted for approximately 2% of global energy-related CO_2 emissions and has been one of the fastest growing transport sectors globally[7].

Aviation emissions are calculated based on the sales of jet kerosene apportioned into international and domestic take-off and landing cycles and distance covered. The allocation of jet kerosene use to international aviation is done by subtracting jet kerosene used in civil aviation from total jet kerosene fuel sales compiled by SEAI. Domestic aviation is reported as part of national transport sector emissions (amounting to 21.5 kt CO_2 eq in 2022) but their overall effect on transport emission trends is negligible. Domestic aviation emissions peaked in 2006 and have declined due to a reduction in the number of domestic flights[8].

In 2018, international aviation was the second highest transport energy consuming activity making up 21% of transport energy use. Based on the final EPA inventories, in 2022, international aviation contributed 3.05 Mt CO_2 from over 126,500 return flights from Irish airports[9][10]. The trend in international aviation emissions from 1990-2022 is shown in Figure 1. It should be noted that there are also a number of non-CO_2 effects from aviation with significant global warming potential[11].

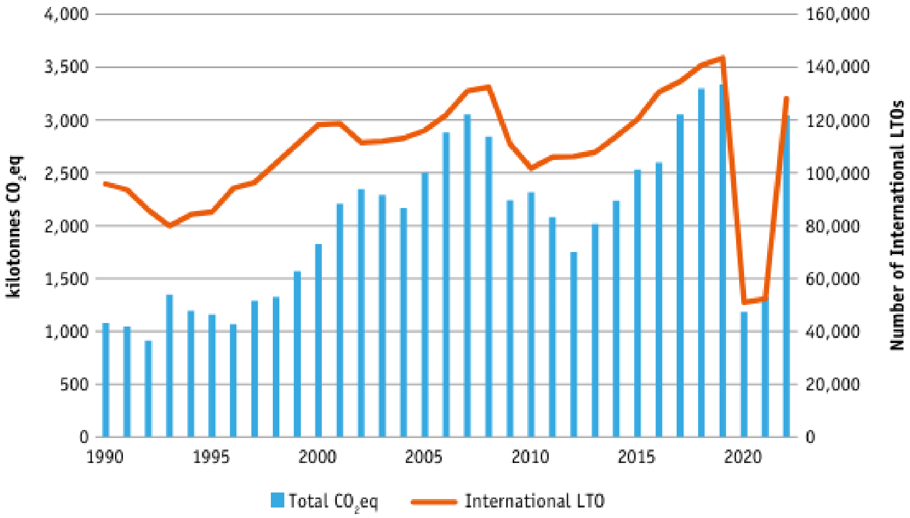

Figure 1, Trend in International Aviation Emissions 1990-2022. LTOs refer to 'landing and take off' activities Source: EPA Inventory

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[6] https://data.oireachtas.ie/ie/oireachtas/committee/dail/33/joint_committee_on_environment_and_climate_action/reports/2022/2022-02-07_report-on-the-proposed-carbon-budgets_en.pdf

[7] https://www.iea.org/energy-system/transport/aviation

[8] https://www.epa.ie/publications/monitoring--assessment/climate-change/air-emissions/Ireland's-NIR-2024_cov.pdf

[9] Environmental Protection Agency, 'Ireland's Final Greenhouse Gas Emissions 1990-2022', May 2024. Accessed: May 21, 2024. [Online]. Available: https://www.epa.ie/publications/monitoring--assessment/climate-change/air-emissions/EPA-1990-2022-GHG-Report-Final.pdf

[10] The main reasons for overseas travel from a 2019 CSO survey are for recreation, followed by visits to friends and family and business. See: https://data.cso.ie/table/HTA01

[11] https://www.gov.ie/en/publication/1c01c-aviation-taxation-in-ireland-report-and-key-findings/

In 2023, Ireland used 1.36 billion litres of jet kerosene, the highest recorded annual energy demand for air travel to date[12]. If aviation energy use continues to grow, it will make it challenging for the Transport sector to deliver its share of reduction in final energy use in 2030 required by the Energy Efficiency Directive[13].

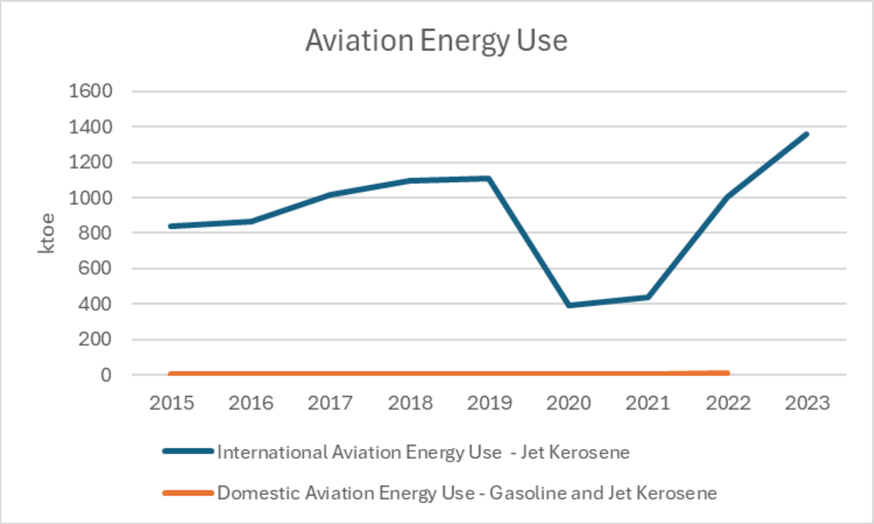
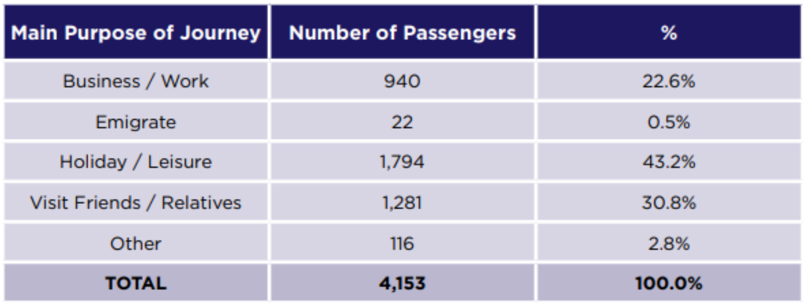


Figure 2, Aviation Energy Use. Source: SEAI National Energy Balance

3.2 Drivers of Demand and Statistics for Ireland

The NTA has carried out passenger surveys at Dublin, Cork and Shannon airports in 2022, 2016 and 2011, showing for example the main journey purpose (for Dublin airport) in Table 1. In all airports surveyed, the main trip purpose was holiday/leisure followed by visiting friends/relatives and business/work.



Main Purpose of Journey	Number of Passengers	%
Business / Work	940	22.6%
Emigrate	22	0.5%
Holiday / Leisure	1,794	43.2%
Visit Friends / Relatives	1,281	30.8%
Other	116	2.8%
TOTAL	**4,153**	**100.0%**

Table 1, Main Purpose of Journey from Dublin Airport. Source: NTA Passenger Survey

Comparing Table 1 to data for 2023 from the CSO Household Travel Survey, 58% of journeys were for holidays, 28% to visit friends/relatives, 8% for business and 7% for other reasons[14].

In 2023, just under 39.2 million people used Irish airports, the highest number of passengers recorded to date and an increase of 20% from 2022. The most popular destinations for passengers travelling through Dublin airport, which handled 84% of all flights, were London-Heathrow, London-Gatwick, and Amsterdam-Schiphol. The most popular destinations in 2023 were Great Britain, Spain, United States, France, Germany,

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[12] Sustainable Energy Authority of Ireland, 'National Energy Balance | Key Publications | SEAI'. Accessed: May 21, 2024. [Online]. Available: https://www.seai.ie/data-and-insights/seai-statistics/key-publications/national-energy-balance/

[13] Sustainable Energy Authority of Ireland, 'National Energy Projections 2023 Report', Nov. 2023, Accessed: May 21, 2024. [Online]. Available: https://www.seai.ie/publications/National-Energy-Projections-2023.pdf

[14] https://www.cso.ie/en/methods/surveybackgroundnotes/householdtravelsurvey/

Italy, Portugal, Netherlands, Poland and the UAE respectively. These top destinations accounted for 86% of all trips abroad in 2023[15].

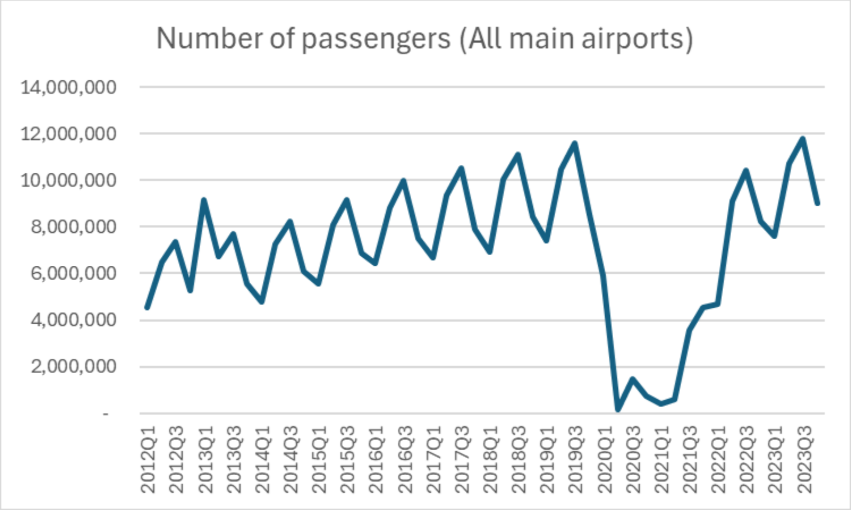

Figure 3, Number of passengers across all main airports in Ireland. Source: CSO[16]

There is limited information available on the frequency of travel broken down by individual households but some general information is published by the CSO on the frequency of trips abroad to various different destinations. On average Irish residents travel abroad 4 times per annum, split into about 2 trips to continental Europe, 1.4 trips per person to Great Britain, 0.4 trips per person to US/Canada and 0.15 trips per annum to other destinations. Irish residents take a journey by sea about 0.2 times per annum on average. Of over 20m journeys undertaken in the last 12 months only 6% were by sea. As Ireland is an island with limited substitutes for air travel, demand has been estimated as more inelastic to price particularly for mode substitution[17].

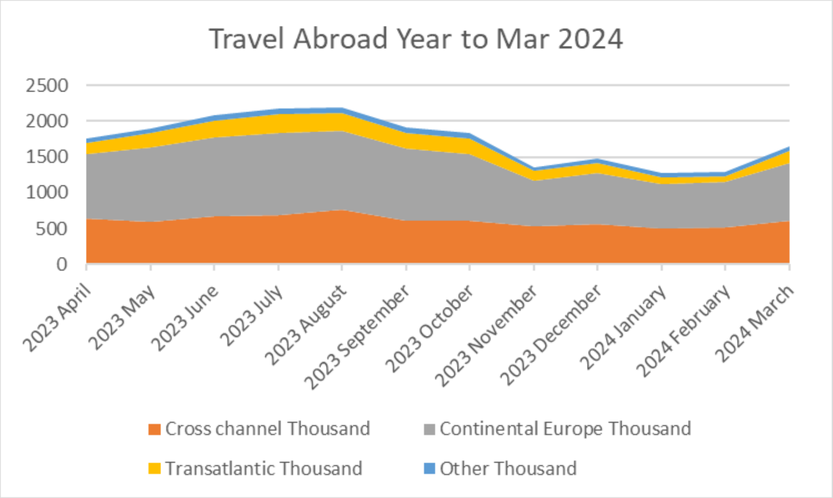

Figure 4, number of trips abroad per April 2023-March 2024. Source: CSO Table HTA01

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[15] https://www.cso.ie/en/releasesandpublications/ep/p-as/aviationstatisticsquarter4andyear2023/

[16] This includes Cork, Dublin, Kerry, Knock and Shannon

[17] https://www.climatecouncil.ie/councilpublications/councilworkingpaperseries/Working%20Paper%20No.%2015.pdf

The CSO also collects data on airfreight and mail (in tonnes) classified by arrivals and departures, national and international traffic, which has remained relatively constant for the last three years totalling 169.6 thousand tonnes in 2023.

Based on findings from IATA[18], the air transport sector supports 143,000 jobs and contributes $20bn in GVA to Ireland's GDP. The IATA briefing estimates that the air transport market in Ireland is forecast to grow by 55% in the next 20 years resulting in an additional 9.6 million passenger journeys by 2037.

3.3 Relevant EU Legislation

The European Green Deal aims to achieve net-zero emissions by 2050.

EU ETS

CO_2 emissions from aviation have been included in the EU emissions trading system (EU ETS) since 2012 however with substantial free allocations. Under the EU ETS, all airlines operating in Europe are required to monitor, report and verify their emissions, and to surrender allowances against those emissions. Theytreceive a certain number of free tradeable allowances and must purchase additional allowances to cover the balance of emissions from all of their flights in a year.

A substantial proportion of Ireland's international aviation emissions are included in the EU ETS, including intra EU flights and flights within the European Economic Area (EEA)[19] . The EU ETS will apply to both intra and extra-EU flights from 1 January 2027[20] however expansion to extra-EU flights is dependent on further legislation and the development of the international carbon offsetting and reduction scheme for international aviation (CORSIA). The revised EU ETS will also phase out free allocations for aviation, apart from the use of Sustainable Aviation Fuels.

The ESAB has recommended that the EU should ensure that the same carbon price applies to extra-EU flights either through the EU ETS, the carbon offsetting and reduction scheme for international aviation (CORSIA) or a combination of the two[21].

Energy Taxation Directive

The Energy Taxation Directive (2003 Council Directive 2003/96/EC) currently includes tax exemptions for aviation fuels and states that states that EU Member States must exempt aviation fuel from taxation for intra-EU and extra-EU flights. The current proposed revision to the ETD would limit tax-based exemptions for aviation fuels with the introduction of a minimum rate of Excise Duty on aviation fuel for intra-EU flights, however this has not yet been adopted[22] and it remains to be seen how this will progress through the new European Parliament and Commission.

It should be noted that the current ETD allows for bilateral jet fuel tax agreements between member states to domestically tax jet fuel[23]. No member states have agreed to increase taxation on kerosene since the 2003 Directive came into effect, however, a number of EU countries have implemented taxes on flights as

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[18] https://www.iata.org/en/iata-repository/publications/economic-reports/ireland--value-of-aviation/

[19] Environmental Protection Agency, 'Ireland's Final Greenhouse Gas Emissions 1990-2022', May 2024. Accessed: May 21, 2024. [Online]. Available: https://www.epa.ie/publications/monitoring--assessment/climate-change/air-emissions/EPA-1990-2022-GHG-Report-Final.pdf

[20] https://climate-advisory-board.europa.eu/reports-and-publications/towards-eu-climate-neutrality-progress-policy-gaps-and-opportunities

[21] European Scientific Advisory Board on Climate Change, 'Towards EU climate neutrality: progress, policy gaps and opportunities'. Accessed: May 21, 2024. [Online]. Available: https://climate-advisory-board.europa.eu/reports-and-publications/towards-eu-climate-neutrality-progress-policy-gaps-and-opportunities

[22] European Scientific Advisory Board on Climate Change, 'Towards EU climate neutrality: progress, policy gaps and opportunities'. Accessed: May 21, 2024. [Online]. Available: https://climate-advisory-board.europa.eu/reports-and-publications/towards-eu-climate-neutrality-progress-policy-gaps-and-opportunities

[23] Transport & Environment, 'Roadmap to climate neutral aviation in Europe', Mar. 2022, Accessed: May 21, 2024. [Online]. Available: https://www.transportenvironment.org/assets/files/TE-aviation-decarbonisation-roadmap-FINAL.pdf

a way to address the lack of effective carbon pricing or taxation mechanisms in the sector[24]. A number of other countries such as the US, Canada, Australia, Thailand, Vietnam and Japan levy excise duties directly on jet fuel. Subsidies and taxation are discussed further in Section 2.4.

ReFuelEU Aviation regulation

The ReFuelEU Aviation regulation will mandate the increasing deployment of Sustainable Alternative Fuel (SAF) at Union airports and include a ten-year transition period where fuel suppliers can supply the required level of SAF as a weighted average across the EU. This sets a mandatory requirement for aircraft operators to use a minimum share of 2% sustainable aviation fuels by 2025, increasing to 6% by 2030 and 70% by 2050 (with specific sub-targets for synthetic aviation fuels)[25].

ReFuelEU Aviation is more stringent than RED III on some types of biofuels (e.g., by excluding fuels made from intermediate crops), but it does not apply a cap on waste oils and animal fats (which are restricted under RED III)[26].

Alternative Fuels Infrastructure Regulation

The Alternative Fuels Infrastructure Regulation aims to enhance the production and uptake of SAF in aviation. The regulation acknowledges that aviation will depend on liquid and gaseous fuels, due to slow electrification in the sector, until at least 2030.

The Regulation notes that transitioning to renewable alternatives such as advanced biofuels in the medium term is essential to meet climate neutrality targets alongside clear decarbonisation pathways out to 2050. The regulation notes that existing refuelling infrastructure can largely support SAFs with minor adjustments, but investments are required now for electricity supply to stationary aircrafts. National policy frameworks need to be in place which set out planned initiatives to promote alternative fuels in these difficult to decarbonise sectors. An interim review of the regulation will occur by December 2026 and every 5 years thereafter to ensure the market is assessed in relation to hydrogen and electric propulsion progress in aviation.

3.4 Relevant International Legislation and Policy

Due to the inherent cross-border and international nature of aviation emissions, efforts to reduce aviation emissions to date have been undertaken within an international framework. The UN body responsible for the aviation sector is the International Civil Aviation Organisation (ICAO). The ICAO formulates policies and Standard and Recommended Practices (SARPs) on aircraft emissions. The ICAO 'basket of measures' framework includes aircraft technology improvements, operational improvements in air navigation and airport operations, the development of sustainable aviation fuels, and a market-based international carbon off setting scheme known as CORSIA. Article 24 (a) of the Chicago Convention on International Civil Aviation (and several associated resolutions of the Council of ICAO) led to a general exemption from taxation for aviation fuel[27].

The ICAO Assembly adopted a global long-term aspirational goal (LTAG) for international aviation of net-zero carbon emissions by 2050, to be met by aircraft technology improvements, operational improvements, sustainable aviation fuels and market-based measures (i.e. CORSIA). The Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA) aims to stabilise CO_2 emissions at 2020 levels by requiring airlines to buy credits to offset the growth of their emissions after 2020. While the cost of compliance with CORSIA is low at present, measures to increase this could entail cost increases for the sector and lead to further emissions reductions over the long term. Between 2020 and 2027 the system is voluntary and thereafter becomes mandatory; all EU countries have joined the scheme to date.

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[24] Transport & Environment, 'Roadmap to climate neutral aviation in Europe', Mar. 2022, Accessed: May 21, 2024. [Online]. Available: https://www.transportenvironment.org/assets/files/TE-aviation-decarbonisation-roadmap-FINAL.pdf

[25] https://climate-advisory-board.europa.eu/reports-and-publications/towards-eu-climate-neutrality-progress-policy-gaps-and-opportunities

[26] https://climate-advisory-board.europa.eu/reports-and-publications/towards-eu-climate-neutrality-progress-policy-gaps-and-opportunities

[27] https://www.gov.ie/pdf/?file=https://assets.gov.ie/207238/5b243876-e193-4746-b0a3-8cd4e79aa035.pdf#page=null

3.5 Subsidies and taxation

International aviation currently benefits from significant fossil fuel subsidies including exemptions to Excise Duty, Carbon Tax, VAT and the National Oil Reserves Agency (NORA levy). Total revenue forgone on jet kerosene amounted to €634 million in 2019 in Ireland, which is exempt from excise and carbon taxes in commercial use and continues to be exempt from taxation in the EU.

Many EU member states tax air travel by applying taxes to air passengers at the national level. The rates generally depend on the distance travelled and vary considerably across the EU. Ireland currently does not impose a passenger tax. The Irish Air Travel Tax (ATT) was applied between March 2009 and April 2014. This introduced a tax of €2 per passenger on flights leaving from Dublin Airport to airports within 300km and €10 for airports over 300km away. The differential rate was considered by the EU to be an interference with the internal market and from 1 March 2011 a flat rate of €3 was introduced before it was abolished in 2014[28].

A study carried out by the ESRI in 2021 found that the most effective method of taxation on aviation is by targeting CO_2 directly[29]. This leads to the greatest emission reductions at the lowest cost to the economy or the aviation sector. This is in line with previous research which shows that taxing CO_2 directly by targeting the carbon content of fuel is more efficient than taxing flights or passengers. It also found that the removal of free EU ETS allowances that airlines receive and taxing kerosene fuel would lead to the greatest emission reductions at the lowest cost to the Irish aviation industry and the economy. As noted in Section 2.2 many of these measures would require changes to EU legislation and international coordination.

3.6 Decarbonisation policies and outlook

More efficient aircraft and engines along with improvements in traffic efficiency have reduced energy intensity in recent years but demand growth has outstripped energy efficiency improvements. Decarbonisation measures include the production of low-emission fuels, improvements in aircraft and engine efficiency, optimisation of logistics and operations, development of alternatively fuelled aircraft and demand management measures. The development of SAFs is considered in Section 2.7 below.

All scenarios considered by the ICAO on reaching the LTAG of net zero by 2050 do not reach zero CO_2 emissions through technology, operations and SAF policy measures, with overall growth in air traffic having an important residual impact on emissions. The ICAO has noted some potential for improvements to the overall energy efficiency of the international aviation system through aircraft design and technology improvements and improvements to flight performance. It carried out modelling of technology, operations and fuel-based policy measures to reduce CO_2 emissions from aviation under three scenarios shown in figure 5. In all scenarios, drop in SAF have the largest impact on emissions. Costs and investments associated with the three scenarios by governments, aircraft manufacturers, operators, airports and fuel suppliers have also been estimated in the ICAO report.

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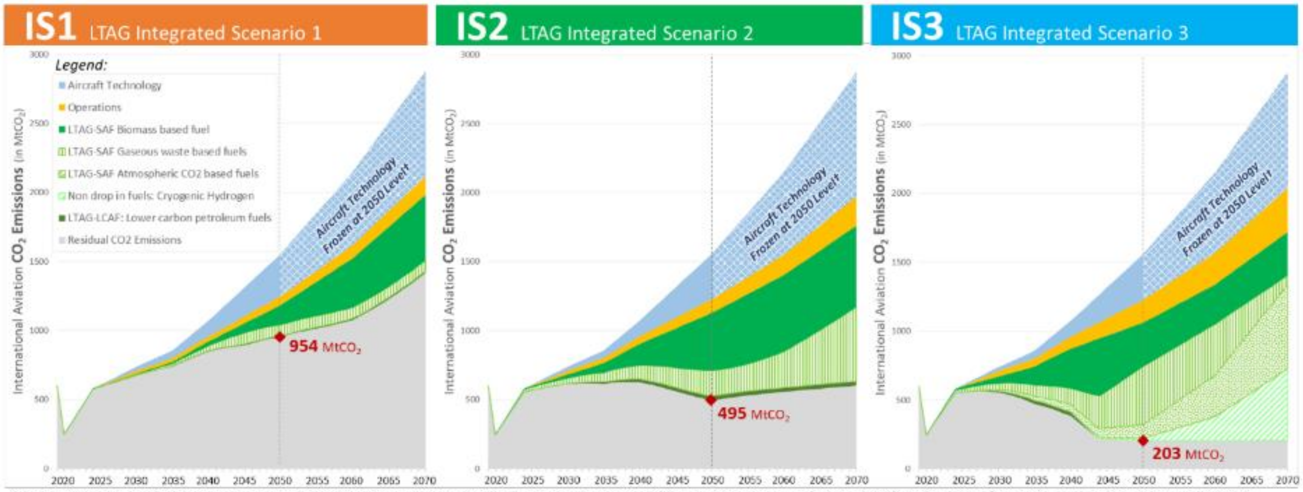
[28] https://www.gov.ie/pdf/?file=https://assets.gov.ie/207238/5b243876-e193-4746-b0a3-8cd4e79aa035.pdf#page=null

[29] https://www.gov.ie/en/publication/1c01c-aviation-taxation-in-ireland-report-and-key-findings/



† Caution required with the interpretation of absolute CO_2 emissions levels after 2050 due to modelling assumptions e.g., frozen aircraft technology after 2050. Under these assumptions, CO_2 emissions are higher than in an alternative scenario (and modelling approach) where aircraft technology would continue to improve after 2050.

Figure 5, CO_2 emissions from international aviation associated with long-term global aspirational goal (LTAG) Integrated Scenarios

Research commissioned by the UK CCC has noted that governments and industry will be required to lead with a coordinated response to make alternatives to flying practical and preferable rather than relying on individual behaviour change decisions, and to provide information on more sustainable choices[30]. In France, domestic flights on short routes that can be covered by train have been banned and the French government has introduced higher climate charges for private jets from 2024.

3.7 Sustainable Aviation Fuels

Demand for aviation fuel is currently dominated by jet kerosene, with SAF accounting for less than 0.1% of all fuels in 2022[31]. Sustainable Aviation Fuels (SAF) are renewable or waste-derived aviation fuels that meet certain sustainability criteria set out by the ICAO[32]. A report prepared by the ICAO on the pathway to achieving net-zero emissions by 2050 concluded SAF had the greatest potential to reduce CO_2 emissions from international aviation between now and 2050, particularly from 'drop in' fuels which do not require modification to aircrafts currently in operation and refuelling infrastructure.

Industry groups have also put forward decarbonisation strategies which assume a large uptake of SAFs in the form of either hydrogen or bioenergy. The International Air Transport Association (IATA), which represents 290 airlines or 83% of total air traffic, has proposed a net zero strategy that relies on sustainable aviation fuel for 65% of the reductions and offsets, plus carbon capture for another 19%[33]. Synthetic jet fuels for aviation are beginning to emerge as viable options with some pilot projects in operation, however SAFs are expensive to produce and their global supply is limited[34][35]. A small quantity of bio jet kerosene (aviation biofuel) was used in Ireland for the first time in 2022[36]. The planned production capacity of SAFs

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[30] K. Mitev, L. Player, C. Verfuerth, S. Westlake, and L. Whitmarsh, 'The implications of behavioural science for effective climate policy, Centre for Climate Change and Social Transformations (CAST)'. Accessed: May 21, 2024. [Online]. Available: https://www.theccc.org.uk/publication/the-implications-of-behavioural-science-for-effective-climate-policy-cast/

[31] https://www.iea.org/energy-system/transport/aviation

[32] https://www.icao.int/environmental-protection/Pages/SAF.aspx

[33] C. Mc Gookin, A. Menon, S. Mc Donagh, B. Ó Gallachóir, and P. Deane, 'Ireland's Climate Change Assessment Volume 2: Achieving Climate Neutrality by 2050', 2023. Accessed: May 21, 2024. [Online]. Available: https://www.epa.ie/publications/monitoring--assessment/climate-change/irelands-climate-change-assessment-volume-2.php

[34] European Scientific Advisory Board on Climate Change, 'Towards EU climate neutrality: progress, policy gaps and opportunities'. Accessed: May 21, 2024. [Online]. Available: https://climate-advisory-board.europa.eu/reports-and-publications/towards-eu-climate-neutrality-progress-policy-gaps-and-opportunities

[35] The International Transport Forum, 'Sustainable Aviation Fuels, Policy Status Report, Case-Specific Policy Analysis', Accessed: May 21, 2024. [Online]. Available: https://www.itf-oecd.org/sites/default/files/docs/sustainable-aviation-fuels-policy-status-report.pdf

[36] Sustainable Energy Authority of Ireland, 'ENERGY IN IRELAND 2023 Report', Dec. 2023, Accessed: May 21, 2024. [Online]. Available: https://www.seai.ie/publications/Energy-in-Ireland-2023.pdf

will provide only a small fraction of jet fuel demand before 2030 (the IEA estimates that SAFs will provide just 1-2% of jet fuel demand by 2027).

The use of hydrogen in medium and long-haul aircraft would require significant redesign of engine and airframes in addition to the fuel supply chain such as ground storage and refuelling, leaving it a prospect for the long term. The ICAO has noted that hydrogen is not expected to have a significant contribution to emissions reduction by 2050 but may develop further with improved technical feasibility[37].

The development of a SAF Policy Roadmap to accelerate SAF deployment is set out as an action in Climate Action Plan 2024. A SAF policy taskforce has been established to assist with the development of a national SAF Policy Roadmap by the end of 2024[38]. A recent industry report by Avolon[39] suggested that to meet mandated SAF volumes under ReFuel EU (requiring a 6% SAF blend at EU airports rising to 70% by 2050), Ireland could require approximately 10 SAF plants. The report recommends inclusion of specific targets in national climate action plans along with investment incentives and funding for research and development. Some countries including countries such as France and Norway have SAF introduced SAF blending mandates.

The European Scientific Advisory Board has recommended that the overall transport sector should be electrified where possible, with the use of limited stocks of sustainable biofuels and hydrogen-based fuels only to be used for modes for which direct electrification is not suitable such as aviation. The development and deployment of sustainable aviation fuels will need to be supported by regulation and financing mechanisms.

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[37] https://www.icao.int/environmental protection/LTAG/Documents/REPORT%20ON%20THE%20FEASIBILITY%20OF%20A%20LONG-TERM%20ASPIRATIONAL%20GOAL_en.pdf

[38] https://www.gov.ie/en/publication/23102-sustainable-aviation-fuel-task-force/#:~:text=SAFs%20are%20considered%20sustainable%20because,emissions%20from%20the%20aviation%20sector

[39] https://www.avolon.aero/news/potential-for-2-5-billion-sustainable-aviation-fuel-industry-in-ireland-by-2050

4.Maritime

4.1 Maritime emission trends and projections

International marine navigation is another important source of emissions that is also excluded from Ireland's national total emissions, carbon budgets and any EU or UN reduction commitments. In 2022, emissions from this source amounted to 0.41 Mt CO_2eq for Ireland, which is a reduction of 24.4% on 2021[40].

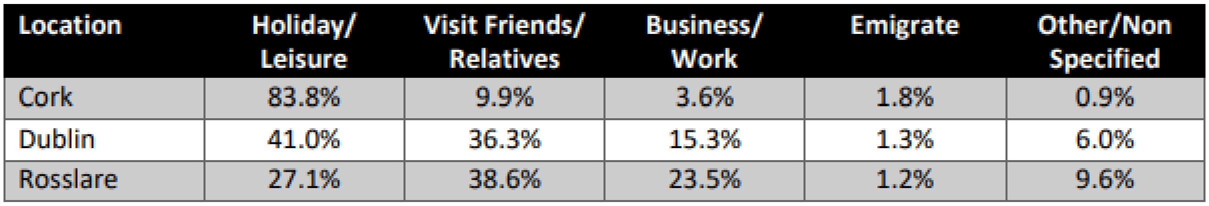
A study by the International Maritime Organisation estimated that emissions from shipping in 2018 accounted for approximately 2.89% of global anthropogenic GHG emissions[41]. The International Energy Agency estimates international shipping accounted for circa 2% of global energy-related CO_2 emissions in 2022, representing a 5% increase on 2021.

4.2 Drivers of Demand and statistics for Ireland

The total tonnage of goods handled by the main Irish ports in 2023 was 46.4 million tonnes, down by 13% compared with 2022[42]. Goods forwarded from Irish ports amounted to 15.2 million tonnes in 2023, while a total of 31.2 million tonnes of goods were received.

The UK accounted for 37% of the total tonnage of goods handled in the main ports by region of trade in 2023, while EU countries accounted for 43% of the total tonnage of goods handled. In 2023 12,105 vessels arrived in Irish ports, with Dublin port accounting for 59% of all vessel arrivals.

A total of 272 cruise ships arrived in Irish ports in 2023. Most of the cruise ships arrived in Cork (94) followed by Dun Laoghaire (75). In April and May 2023, the NTA, in conjunction with the port authorities, undertook a survey of Ferry Port passengers in Dublin, Cork, and Rosslare ports[43]. Table 2 provides an overview of the primary purpose of travel for residents departing from each port. Dublin and Rosslare ports display similar trip making characteristics by purpose with a wide variety of purposes observed, whereas Cork primarily serves holiday/leisure trips. The survey also showed a majority used cars to access the ports with only 5% using buses and 1.7% by rail (with the only direct rail link to Rosslare Port)[44]. Dún Laoghaire port was used in the past for regular ferry services and was well connected by rail.



Location	Holiday/ Leisure	Visit Friends/ Relatives	Business/ Work	Emigrate	Other/Non Specified
Cork	83.8%	9.9%	3.6%	1.8%	0.9%
Dublin	41.0%	36.3%	15.3%	1.3%	6.0%
Rosslare	27.1%	38.6%	23.5%	1.2%	9.6%

Table 2, Passenger main trip purpose by port. Source: NTA Survey of Ferry Port passengers

4.3 Relevant EU Legislation

EU ETS

For maritime transport, the EU ETS now covers CO_2 emissions from all cargo and passenger ships of and above 5,000 gross tonnage (GT), that call at EEA (European Economic Area) ports. This also includes 100% of emissions from ships calling at an EEA port for voyages within the EEA, 50% of the emissions from voyages starting or ending outside of the EEA and 100% of emissions produced when ships are within EEA ports. Each company with ships trading in the European Economic Area (EEA) will be required to surrender emission allowances corresponding to a certain amount of its GHG emissions over a calendar year, starting with 40% of emissions in 2024, 70% in 2025 and 100% in 2026[45].

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[40] https://www.epa.ie/publications/monitoring--assessment/climate-change/air-emissions/EPA-1990-2022-GHG-Report-Final.pdf

[41] https://wwwcdn.imo.org/localresources/en/OurWork/Environment/Documents/annex/MEPC%2080/Annex%2015.pdf

[42] https://www.cso.ie/en/releasesandpublications/ep/p-spt/statisticsofporttrafficq4andyear2023/

[43] https://www.nationaltransport.ie/planning-and-investment/transport-modelling/data/nta-ferry-port-survey-2023/

[44] National Transport Authority, 'Ferry Ports Passenger Survey 2023 Report, Transport Modelling Section', 2023, Accessed: May 21, 2024. [Online]. Available: https://www.nationaltransport.ie/wp-content/uploads/2023/11/Port-Survey-Report-2023.pdf

[45] https://www.iea.org/energy-system/transport/international-shipping

Emissions that are expected to be covered by the EU ETS ('at berth', intra-EU and 50 % of extra-EU maritime transport) correspond to 64 % of the international maritime emissions reported in the GHG inventory[46]. Half of extra-EU maritime transport remains exempt from the EU ETS.

Energy Taxation Directive

The ETD currently exempts maritime transport from energy taxation on maritime industry heavy oil. Proposed revisions to the ETD would remove exemptions for fuel uses from energy taxation (applying to bunker fuel sold within the EU and fuel used for intra-EU waterborne navigation) in the EU but as discussed above this has not progressed.

FuelEU Maritime Regulation

FuelEU Maritime requires the average GHG intensity of maritime fuels to decrease by 2% by 2025, 6% by 2030 and 80% by 2050 (compared with a reference value of 91.16 g CO2e/MJ)[47]. The baseline for the calculation of the annual GHG targets is set at 91.16gCO2e/MJ (the 2020 GHG intensity of EU fleet). FuelEU maritime applies to 100% of energy used on voyages between European Economic Area (EEA) ports and 50% of energy used on voyages between EEA and non-EEA ports. The IEA has noted some concern that these limits may make liquified natural gas the cheapest compliance solution, with risks for methane leakage and technology lock-in[48].

AFIR and the FuelEU Maritime regulations will require the development of on-shore electricity supply in TEN-T ports and the increased take-up of renewable maritime fuels in larger vessels.

The FuelEUMaritime regulation is more stringent than the RED III with regard to fuels made from food and feed crops (which cannot count towards the targets under the regulation) but does not put restrictions on biofuels from other feedstocks with high ILUC risks. Analysis of the regulation has noted that oil-based fuels and fossil gas are likely to still make up the majority of fuel demand under 2045[49].

Alternative Fuels Infrastructure Regulation

For the maritime sector, the Alternative Fuels Infrastructure Regulation aims to support and boost the transition to low and zero emission fuel alternatives such as biofuel blends, biomethane and electrification. Electrification is occurring in the industry, motivated particularly by the ETS for larger vessels, and requires adequate infrastructure investment and development.

The Regulation highlights the need for fossil sourced methane to be phased out and an adequate supply of shore-side electricity in ports will be required as a prerequisite to the mandatory use of on-shore power in trans-European transport network (TEN-T) ports[50]. The TEN-T network includes core and comprehensive ports that must comply with the AFIR regulation and have clear targets to shore-side electricity infrastructure deployment. Ireland has 3 core ports, Dublin, Cork and Shannon-Foynes and 3 comprehensive ports, Galway, Waterford and Rosslare[51]. The AFIR calls on Members States to decide on the best way to deploy infrastructure within their ports and terminals to ensure high occupancy rates and efforts to reduce emissions and air pollution.

Stranded assets must be avoided, and investments must be future-proofed and contribute to climate neutrality. The mandatory deployment targets should consider vessel types and traffic volumes to avoid underused capacity. It is noted that refuelling points for liquified methane in TEN-T core maritime ports should be available by 2025, driven by market demand.

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[46] https://climate-advisory-board.europa.eu/reports-and-publications/towards-eu-climate-neutrality-progress-policy-gaps-and-opportunities

[47] https://climate-advisory-board.europa.eu/reports-and-publications/towards-eu-climate-neutrality-progress-policy-gaps-and-opportunities

[48] https://www.iea.org/energy-system/transport/international-shipping

[49] The impact of FuelEU Maritime on European… | Transport & Environment (transportenvironment.org)

[50] The TEN-T network is a network of roads, rail line, ports and airports which connects all regions in Europe developed in the 1990s. A revision to the TEN-T regulation is currently close to adoption: Carriages preview | Legislative Train Schedule (europa.eu)

[51] TENtec Interactive Map Viewer (europa.eu)

4.4 Relevant International and National Legislation

The UN body responsible for the maritime sector is the International Maritime Organization (IMO). In 2023, the IMO adopted a revised strategy which sets a goal of net zero GHG emissions from ships by or around 2050. This is a significant increase in ambition compared to the initial 2018 strategy which targeted a 50% reduction compared to 2008 levels[52]. The International Energy Agency has noted that legally binding measures are needed to ensure this goal is achieved[53].

The strategy includes a basket of candidate mid-term GHG reduction measures including improvements to the design and energy efficiency of ships, uptake of new fuels and energy sources and an economic element on the basis of maritime GHG emissions pricing[54].

4.5 Maritime fuels

Oil products constitute over 99% of total energy demand for international shipping, with biofuels representing 0.5% in 2022.

Alternative fuels in maritime include biofuels, synthetic fuels (renewable fuels of non-biological origin) and electricity. Biofuels for maritime are produced using a multitude of various feedstocks listed in Parts A and B of Annex IX to FuelEU Maritime Directive (EU) 2018/2001. They include algae, animal manure, used cooking oil and forestry residues. These feedstocks must be sourced sustainably to ensure minimal environmental impact, including on land use and direct and indirect land use change. Synthetic maritime fuels, produced using renewable electricity, include synthetic diesel (e-diesel), liquefied petroleum gas (e-LPG), methanol (e-methanol), electrified liquefied natural gas (e-LNG), dimethyl ether (e-DME), hydrogen (e-H2) and methane (e-NH_3)[55]. The IMO is encouraging the use of alternative fuels such as biofuels, hydrogen, ammonia as well as other zero and low carbon energy sources.

The Renewable and Low-Carbon Fuels Value Chain Industrial Alliance is a component of the Fuel EU Maritime regulation, bringing together a diverse group of stakeholders to link the producers and consumers of alternative fuels. It aims to ensure cooperation by assessing challenges such as feedstock sourcing for fuels, meeting financial and technological needs and understanding the role of governments in ensuring the availability of low-carbon and environmentally responsible fuels[56].

4.6 Decarbonisation policies and outlook

The ITF estimates that technologies currently available or in development could make it possible to almost completely decarbonise maritime shipping by 2035[57]. One of the more immediate decarbonisation measures involves energy efficiency improvements. For vessels this includes the development of wind assistance technologies, hull design improvements and reduced friction through protection of hulls from fouling along with management of shipping capacity and logistics through speed limitation and route optimisation[58].

Low carbon fuels are another area of focus, with biofuels, hydrogen, ammonia, synthetic fuels and electrification of certain ships for short distance routes currently the most promising options. Low battery energy densities currently limit their deployment for long distance journeys however the use of onshore power with well-developed charging infrastructure could support further electrification of maritime transport. Shipping as a sector could provide a market for renewable hydrogen, with hydrogen fuels in shipping expected to be competitive with fossil fuels by 2030 and have lower overall costs by 2040. There would however be significant costs associated with the retrofitting of ships and the construction of

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[52] https://www.gov.ie/en/press-release/2fb1a-minister-eamon-ryan-welcomes-global-agreement-on-reducing-green-house-gas-ghg-emissions-from-shipping/

[53] https://www.iea.org/energy-system/transport/international-shipping

[54] https://www.imo.org/en/OurWork/Environment/Pages/2023-IMO-Strategy-on-Reduction-of-GHG-Emissions-from-Ships.aspx

[55] Regulation - 2023/1805 - EN - EUR-Lex (europa.eu)

[56] Renewable and Low-Carbon Fuels Value Chain Industrial Alliance - European Commission (europa.eu)

[57] https://www.itf-oecd.org/sites/default/files/docs/decarbonising-maritime-transport-2035.pdf

[58] https://www.itf-oecd.org/sites/default/files/docs/navigating-cleaner-maritime-shipping.pdf

additional infrastructure[59]. Compressed hydrogen also requires large storage volumes which may make it less suitable for long distances. Biofuel and synthetic fuel use in the maritime sector will also compete with other transport sectors with a need to ensure sustainable criteria for biofuel production are in place.

Effective carbon pricing and taxation for shipping and maritime fuels would also be expected to reduce emissions in the sector and encourage further investment in alternative fuel supply chains and vessels.

The adoption of alternative fuels will require close cooperation throughout supply chains between shipowners, operators, ports, fuel producers and distributors and ensure alignment with legislative requirements. This will need to address fuel production, transport, the design of storage tanks and fuel delivery systems, engines and retrofitting of current vessels.

5. Summary

- S.I. No. 531/2021 establishes which sectors and gases are to be included in carbon budgets and sectoral emissions ceilings.
- Emissions from aviation and maritime have continued to increase at a global level. International cooperation on aviation and maritime emissions is evident and will need to be maintained and augmented.
- The ETD and EU ETS may influence change in this area in the near future and Ireland should remain attentive to opportunities to support international action in regard to both aviation and maritime emissions.

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[59] C. Mc Gookin, A. Menon, S. Mc Donagh, B. Ó Gallachóir, and P. Deane, ‘Ireland’s Climate Change Assessment Volume 2: Achieving Climate Neutrality by 2050’, 2023. Accessed: May 21, 2024. [Online]. Available: https://www.epa.ie/publications/monitoring--assessment/climate-change/irelands-climate-change-assessment-volume-2.php

GOBLIN scenario narratives

1. Forestry scenarios

Forestry scenarios 1-3 were selected based on a selection from eight scenarios run in the FERS CBM-CFS3 model by FERS (Table 1).

The three selected scenarios all represent “more sustainable silviculture”, i.e. a reduced rate of harvest closer to the economic optimum, compared with the trend towards shorter harvest intervals (current silviculture). This applies to existing and to new forest (afforestation).

Scenario 1 represents the current policy target for afforestation of 8,000 ha per year being achieved from 2027 through to 2100, comprising a 50:50 split between slower-growing (but more biodiverse) broadleaf species and faster-growing conifer species. The soil type is split 15:85 organic/mineral soils, with significant CO_2 emissions incurred from planting on organic soils – accounted for within the forest net GHG flux results from CBM.

Scenario 2 represents an ambitious afforestation rate of 25,000 ha per year from 2031 to 2080 (spanning more than one average rotation interval) to avoid problems with future forestry carbon dynamics as previously highlighted in scenarios that where elevated planting rates ceased in 2050 (Duffy et al., 2022)[1]. A reduced rate of afforestation from 2081-2100 is based on achieving a 30% forest cover by 2125 (if extrapolated out). The species mix and soil mix is as per Scenario 1. The 25,000 ha per year afforestation rate is highly ambitious but approximates to the maximum rate achieved in the early 1990s in Ireland, demonstrating technically feasibility.

Scenario 3 represents a scenario of maximum forest carbon sink. Afforestation rates are the same as for Scenario 2, but the species mix is weighted 70:30 in favour of fast-growing conifers, and planting on organic soils is avoided.

All forestry scenarios include standard NIR accounting of carbon storage for harvested wood products (HWP), based on harvested volumes (which reflect management of existing and new forests, afforestation areas and species mixes).

However, an additional carbon storage credit was added based on escalating shares of low-value forest (bioenergy) side streams and end-of-life product (waste wood) outflows going to bioenergy with carbon capture and storage (BECCS) from 2030 onwards. Rates of BECCS deployment across bioenergy facilities are assumed to ramp up from 2030 in the following pattern:

- 2030-2039: 20%
- 2040-2049: 40%
- 2050-2059: 60%
- 2060-2100: 80%

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[1] https://www.nature.com/articles/s41893-022-00946-0

Such BECCS deployment is likely to be expensive, but economically attractive at future carbon prices. BECCS has been shown to increase both the magnitude and duration of climate mitigation from commercial forestry (Forster et al., 2021)[2].

Table 1. Eight scenario combinations run in FERS CBM-CFS3 model, with the three scenarios selected for CB analyses shaded

Scenario	**Afforestation rate (ha/yr**				**Total forest area 2100**	**Species mix**	**Soil type**	**Management**
	2024-2026	**2027-2030**	**2031-2080**	**2081-2100**	**ha**	**Broadleaf / Conifer %**	**organic / mineral %**	
	4000	8000	8000	8000	1377254	50:50	15:85	Current silviculture
1	4000	8000	8000	8000	1377255	50:50	15:85	More sustainable silviculture
	4000	8000	8000	8000	1377256	30:70	15:85	Current silviculture (high)
	4000	8000	8000	8000	1377257	30:70	15:85	More sustainable silviculture
	4000	16000	25000	10144	2300000	50:50	15:85	Current silviculture
2	4000	16000	25000	10144	2300000	50:50	15:85	More sustainable silviculture
	4000	16000	25000	10144	2300000	30:70	0:100	Current silviculture
3	4000	16000	25000	10144	2300000	30:70	0:100	More sustainable silviculture

2. Other land use

Across all scenarios, other land use was treated simply with an ambitious level of organic soil rewetting assumed. New organic soil emission factors have not yet been incorporated into the python version of GOBLIN, so as placeholder CO_2 emissions from grassland soils and wetlands were linearly reduced by 90% out to 2050 to reflect progressive rewetting of most drained organic soils. Methane emissions were held constant at 2020 (baseline) levels based on the revised NIR timeseries values. Whilst this may overestimate future net climate mitigation

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[2] https://www.nature.com/articles/s41467-021-24084-x

potential from organic soils, it was also assumed that mineral soil carbon sequestration declines to zero by 2050 as grassland improvement effects drop out of the inventory (which may be pessimistic in light of revised transition times for mineral soils that also need to be reflected in GOBLIN).

3. Agriculture scenarios (a-e)

Agriculture scenarios were based on recent analysis undertaken as part of Daniel Henn's PhD thesis, in which different levels of ambition were applied to key aspects of management and technology driving abatement potential within the main-emitting bovine sectors of agriculture out to 2050 (Table 2). GOBLIN was run for 2050 results, but emissions trajectories were forced through the 25% sectoral emission ceiling target for 2030.

All scenarios apart from Sc-e were based on maintaining constant level of bovine protein production in Ireland to minimise the risk of carbon leakage, and were selected (or interpolated/extrapolated) to approximate with the 2050 agriculture sector GHG reductions stipulated by the CCAC (Table 3).

Animal numbers and productivity

Sc-a assumes that the current cattle herd and sheep flock structure is maintained, whilst Sc-b assumes a shift out of suckler beef and towards milk plus more dairy-beef (Ambition 1 in Table 2). This reflects economic factors (dairy is far more profitable than beef farming) and future risks (and possible costs) associated with exporting a very GHG- and land- intensive product (suckler beef) from a country unlikely to achieve climate neutrality. Notably, Ireland could produce a substantial quantity of dairy beef in all scenarios in excess of national beef demand and in excess of the ratio of beef to milk needed for a sustainable and healthy diet (Willett et al., 2019[3]; Porto-Costa et al., 2023[4]).

Sc-c and Sc-d reduce dairy cow numbers needed to maintain bovine protein output owing to an average increase in milk productivity of approx. 4.2 litres per cow per day relative to 2020, approximating to a 1% annual increase out to 2050 (Ambition 2 in table 2).

Sc-e scales down animal numbers to achieve a specified 60% reduction in agriculture sector emissions by 2050.

The sheep flock is reduced by 20% to spare land, reflecting low profitability.

Average dairy and beef cow productivity scales up from current performance (Sc-a) through intermediate performance (Sc-b) to higher levels of performance (Sc-c-e) (Table 2).

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[3] https://doi.org/10.1016/S0140-6736(18)31788-4

[4] https://doi.org/10.1016/j.jclepro.2023.138826

Management and technologies

All scenarios involved high rates of deployment of efficient management practises and abatement technologies, proxying maximum deployment of existing proven practises and technologies by 2050. This represents a considerably higher level of emission abatement compared with the Teagasc MACC (for 2030), but is a relatively conservative approach for the 2050 timescale.

Management practises and technologies all come from the "Ambition 2" column in Table 2, and include, *inter alia*:

- a widespread adoption of grass-clover swards to reduce synthetic nitrogen application by 75% vs 2020 (and to increase grass yields on low-input areas, sparing land).
- all residual fertiliser nitrogen being applied as protected urea.
- increased efficiency of grass(clover) utilisation by animals, from an average of 72% and 55% for dairy and beef systems in 2020, to 75% and 65% for these systems, respectively, in 2050. This reflects improved grazing management, and spares land, but doesn't directly reduce emissions.
- Use of additives to inhibit methane from enteric fermentation by 30% and from manure management by 75%

Table 2. Cattle herd numbers and abatement measures applied to critical aspects of agricultural management

Aspect	2020 Baseline (Ambition 0)	Ambition 1	Ambition 2
Livestock protein output	2020 cattle herd 2020 sheep flock 2020 dairy cow productivity (14.85 L/day)	2020 protein outputs (1.725m dairy cows and 150k beef cows) 2020 sheep flock decreases by 20% Increased dairy cow productivity (15.3 L/day)	2020 protein outputs (1.418m dairy cows and 150k beef cows) 2020 sheep flock decreases by 20% Increasing dairy cow productivity strongly (19.2 L/day)
Livestock management	2020 mean slaughter ages 2020 mean slaughter weights	Mean slaughter ages decrease by 50 days 2020 mean slaughter weights	Mean slaughter ages decrease by 100 days 2020 mean slaughter weights
Grassland sward composition and management	0% white clover swards (WCS) 100% perennial ryegrass swards (PRS) with 2020 inorganic N fertilisation rates	50% WCS without inorganic N fertilisation 50% PRS with 2020 inorganic N fertilisation rates	75% WCS without inorganic N fertilisation 25% PRS with 2020 inorganic N fertilisation rates
Fertiliser type	0% inorganic N fertiliser spread as protected urea	50% inorganic N fertiliser spread as protected urea	100% inorganic N fertiliser spread as protected urea
Grassland use efficiency	2020 dairy farm GUE (72%) 2020 beef farm GUE (55%)	Dairy farm GUE increase (75%) Beef farm GUE increase (60%)	Dairy farm GUE increase (75%) Beef farm GUE increase (65%)
Methane inhibition	0%	15% enteric fermentation 38.5% manure management	30% enteric fermentation 75% manure management

Table 3. Summary of cattle numbers and agriculture sector GHG emissions for scenarios a-e

Scenario	GHG reductions vs 2020	kt CO_2e	Dairy Cows	Suckler Cows	% change adult herd	Sheep	Bovine protein (kt yr^{-1})
Baseline	**NA**	**21,270**	**1,555,000**	**915,000**		**2,556,000**	**440**
A	**-30%**	14,889	1,555,000	915,000	0	2,556,000	440
B	**-40%**	12,762	1,643,651	516,068	-13%	2,289,420	440
C	**-45%**	11,518	1,725,000	150,000	-24%	2,044,800	440
D	**-50%**	10,635	1,418,000	150,000	-37%	2,044,800	440
E	**-60%**	8,508	1,151,647	121,824	-48%	1,660,710	361

4. Anaerobic digestion (AD)

The modified LCAD EcoSCreen model was run to calculate the life cycle and inventory emissions consequences of digesting sufficient feedstock to generate the 5.7 TWh biomethane target set out in the Biomethane Strategy. Feedstock input prioritised readily-available waste streams, in line with maximising the climate mitigation efficacy of AD (Styles et al., 2016[5]; 2022[6]; O'Donell et al., 2021[7]). This included 75% of current food waste volumes and 75% of pig and poultry slurry volumes, along with the estimated stored slurry volume generated by dairy animals. This left a requirement for grass-clover production equivalent to 9 t dry matter per hectare across 134 kha to generate the 5.7 TWh (gross) biomethane.

The AD model was parameterised to consider an optimised AD plant configuration, with closed digestate storage and comparatively low fugitive emissions of methane and ammonia, as per the most optimistic assumptions in Styles et al. (2022). Energy substitution credits were calculated based on substitution of diesel out until 2040, and natural gas (with progressive application of CCS) thereafter. However, these avoided emissions were not included in the results submitted to the CCAC as the would represent double counting. Only fugitive emissions from the AD plant and digestate handling were included in core results, along with an estimate of negative emissions associated with progressive deployment of BECCS to biomethane combusted in stationary energy generation post 2040 (at the same deployment rates assumed for wood energy - aforementioned). Highly optimistically for AD, it was assumed that the CO_2 component of biogas was also captured during biomethane purification at the prevailing CCS deployment rates through time – providing an upper-bound estimate of negative emissions potential associated with AD.

5. Negative emissions

All scenarios involved considerable negative emissions, generated in the land sector via afforestation, in the built environment via HWP carbon storage, and in the energy sector via BECCS. In 2050, net negative emissions from terrestrial carbon stores in forestry and HWP ranged from -1.2 Mt CO_2e for Sc-1 to -6.7 Mt CO_2e for Sc-8. BECCS contributed a further -1.1 Mt CO2e (Sc-1) to -2.0 Mt CO2e (Sc-3). These latter values are speculative and based on 60% of available wood low-value side streams and waste streams going to BECCS.

Finally, CCS application to CO_2 from biogas and BECCS application to biomethane combustion resulted in a negative emission of -0.38 Mt CO_2e across

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[5] https://doi.org/10.1016/j.scitotenv.2016.03.236
[6] https://doi.org/10.1016/j.jclepro.2022.130441
[7] https://www.sciencedirect.com/science/article/pii/S0048969721023226

all scenarios. Again, this value is speculative and assumed CCS applied across 60% of all potential biogenic CO_2 streams. Capturing all CO_2 from biogas purification to biomethane across hundreds of AD facilities may not be feasible (compared with more centralised combustion of biomethane distributed via the gas grid and wood combusted in larger power stations).

PATHWAYS FOR IRELAND'S ENERGY SYSTEM TO 2050

Modelling analysis to support the Climate Change Advisory Council on the Second Carbon Budget Programme

Prof. Hannah Daly[1], Dr Vahid Aryanpur, Bakytzhan Suleimenov & Dr. Paul Deane

Energy Policy and Modelling Group, University College Cork

June 2024

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[1] Comments and feedback can be sent to [redacted]

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EXECUTIVE SUMMARY

Globally, fossil fuel demand has not yet peaked, and the world is on track to significantly breaching the temperature goals set out in the Paris Agreement. Temperatures will continue to rise until greenhouse gas emissions from burning fossil fuels reach net-zero. Ireland, which contributes disproportionately to global heating, has set out an ambitious legal framework and detailed implementation plan to cut greenhouse gas emissions in the period to 2030. While the energy transition is gathering pace, mitigation measures are not yet on track to bringing emissions on track to legally-binding carbon budgets: this projected overshoot presents both a major risk, and lost opportunity. Moreover, mitigation plans currently end at 2030: the urgency of limiting cumulative emissions (and hence warming), and the need to align immediate climate action measures with a long-term strategy calls for the development of scenarios for the energy system that go beyond 2030.

This report sets out eight scenarios for possible pathways for Ireland's energy system in the period to 2050 under varying levels of climate ambition. The main focus is on the decade following 2030, in order to inform the Climate Change Advisory Council's consideration of third and fourth carbon budgets. The scenarios outline the necessary investments, mitigation measures and choices to be made across energy supply, electricity, transport, heating and industry, under carbon budgets of different stringency. This is not a final report: Following stakeholder feedback and review of this study, we will present a final set of scenarios for the Council's consideration in Q3, 2024.

Key findings are as follows:

- Net-zero is a critical milestone, but cumulative CO_2 emissions determine total global warming. For this reason, Ireland's climate ambition is framed as cumulative carbon budgets, and planning the sustainable energy transition to deliver net-zero by 2050 is not sufficient: understanding this difference is critical for appreciating the scale of Ireland's mitigation challenge. The implications are that it is likely that emissions from Ireland's energy system must fall to net-zero, or close to zero, well before 2050. For example, this report shows that carbon budgets aligned with a global effort to limit global warming to 1.5°C would require existing carbon budgets in the period to 2030 to be reduced, and for Ireland's energy system to achieve net-zero by around 2035, as well as delivering significant cuts in non-CO_2 emissions. Moreover, if emissions overshoot committed carbon budgets in the period to 2030, this overshoot must be compensated for by reducing carbon budgets in subsequent periods. The scale of projected carbon budget overshoot would leave little-to-no carbon budget left following 2030, even under moderate ambition.
- All scenarios detail significantly greater greenhouse gas emissions cuts in the period to 2030 and 2040 than planned under current policies. An immediate acceleration in implementing mitigation measures is necessary to close this gap. Making up for this overshoot in the long-term may not be feasible, or is likely to be significantly more costly than cutting emissions now.
- Electrification of transport and heat, complemented by decarbonising electricity supply, are the main mitigation levers. While this energy transition requires significant upfront investment, and brings new risks and challenges, the falling cost of renewables and batteries, and the social, health, energy security and economic benefits, makes it cost effective. Greater climate ambition lowers the damage caused by greenhouse gas emissions. While this report quantifies the cost of greater climate ambition, the benefits of earlier fossil fuel phase-out for energy security, economic sectors, air pollution and household energy bills are not quantified, but are likely to be substantial.
- The feasibility of delivering the scenarios described in this report relies on political, societal and institutional capacity. With some exceptions, the technologies and measures necessary to cut emissions are available, mature, cost-effective and well tested. Time, not technology, is the main challenge. The following are some of the main technical challenges associated with delivering these pathways:
    - Operation of the power system with very little natural gas (and other fossil fuels) by the early 2030s. Moreover, total electricity demand grows at an unprecedented rate in all scenarios to meet the need to electrify transport, heating and industry.
    - This will require significant innovations and investment in the power system, including in developing short- and long-duration energy storage, strategic annual storage, flexibility and interconnection, and

  investment in electricity transmission and distribution. Technologies that are currently nascent and an evolution of electricity markets are necessary to realise this level and pace of decarbonisation.
  - Lowering final energy demands makes the most ambitious climate scenarios more feasible than a strategy that relies on technology transitions alone, and can bring additional co-benefits. This can be achieved by reducing dependence on private cars, promoting greater housing density, wasting less energy in buildings and industries, and lowering reliance on carbon-intensive materials such as cement. While these changes will require individuals to change some of their daily practices, this "behaviour change" requires significant state investment and regulation, and the provision of information, to change the choice architecture – such improving public transport provision - to facilitate lifestyles that require lower final energy.
  - All scenarios rely to some extent on emissions removals, either through Biomass with Carbon Capture and Storage (BECCS), which is modelled explicitly, or another form of carbon dioxide removal (CDR), which is not modelled. More emissions removals are required in scenarios with greater mitigation ambition, with higher early overshoot of carbon budgets to 2030, and with higher final energy demands. Reliance on removals brings significant risks and trade-offs, which can be limited through strong early mitigation and lowering demands. Careful assessment of the sustainability and opportunity cost of BECCS feedstock is necessary. Meanwhile, this report indicates that emissions removal options must be explored to limit global temperature rise to the Paris Agreement commitments.
  - These scenarios indicate that buildings and transport should be close to fully decarbonised by the early-to-mid 2030s. This can be achieved through accelerating the pace and scale of decarbonisation measures outlined in the Climate Action Plan: efficiency, retrofitting, district heating and electrification. More ambitious climate scenarios require a more rapid phase-out of natural gas heating systems and of freight vehicles and vans using oil products. All scenarios require a very rapid transition away from oil-based central heating systems and heating with coal and peat.
  - Moreover, all scenarios see the end of sales of new internal combustion engine private cars sales by 2025, which is significantly misaligned with current trends. This highlights how new investments in technologies dependent on fossil fuels from now have a significant bearing on delivering on carbon budgets, even beyond 2035: New investments either lock in greenhouse gas emissions, or else will become stranded assets as they are retired early. Either the State or private individuals will have to bare this cost.
- The European Commission has recommended that the European Union set a target to cut greenhouse gases by 90% in 2040 relative to 1990. While we do not know yet how this target would be translated to Ireland, or be distributed across sectors, we benchmark the scenarios presented in this report against a range of possible 2040 targets.

ACKNOWLEDGEMENTS

We acknowledge and are grateful for the contributions of past and current members of UCC's Energy Policy and Modelling Group, particularly those who contributed to the development of TIM and its predecessor, the TIMES-Ireland Model. We are also thankful to the CCAC and members of the CBWG, particularly SEAI's energy modelling team and Prof. John FitzGerald, for constructive feedback on previous iterations of this research. This research was part-funded by the Department of Environment, Climate and Communications through the CAPACITY project.

1 INTRODUCTION

1.1 TERMS OF REFERENCE

UCC's Energy Policy and Modelling Group (EPMG) is supporting the Climate Change Advisory Council (CCAC) as part of the Carbon Budgets Working Group (CBWG) in the Council's statutory role of proposing the finalisation of carbon budgets 3 from 2031-35 and for Carbon Budget 4 from 2034-40, by the end of 2024. The CBWG is tasked with developing an evidence base for the Council's carbon budget proposals, including the provision of modelling and analytical support.

As part of this process, the EPMG is modelling future potential pathways for Ireland's energy system consistent with different levels of decarbonisation ambition, covering energy supply, electricity, transport, buildings and industry. The purpose of these scenarios is to indicate the pace and depth of change across the energy system necessary to meet different levels of mitigation ambition, including the timing of introducing new technologies, indicating the reliance on speculative technologies, and the role of energy demand reduction. While TIM does not explicitly model important implications of climate action, including the just transition, biodiversity impacts, climate justice, and consequences for investment, the macroeconomy, energy bills and energy security, these modelled scenarios can provide a quantitative basis for developing analyses on these aspects of climate action.

This report describes the approach we have taken so far, and the results of a second round of three modelling iterations. The report also contains an accompanying descriptive narrative for each of the modelled scenarios, outlines the rates of deployment and costs by technology, describes the role of negative emissions, and includes a commentary on potential pitfalls and practical implications. The report also discusses the implications of overshooting existing carbon budgets in the period to 2030.

This set of scenarios have been developed following feedback and review from the Council and other members of the CBWG. While our approach has been endorsed by the Council, it should not be seen in any way as an indication of the Council's position on the second carbon budget programme.

This report contains three appendices. Appendix 1 contains an in-review academic paper, which examines the implications of early carbon budget overshoot. This study is based on the first iteration of modelled scenarios for the CBWG but insights remain applicable to this report. Appendix 2 describes our approach to developing carbon budgets (2021-2050) for Ireland. And Appendix 3 contains more details model assumptions and data sources.

2 METHODOLOGY AND KEY ASSUMPTIONS

Model description: The TIMES-Ireland Model (TIM) produces detailed technology-explicit pathways on the future evolution of Ireland's energy system – which encompasses the import and extraction, processing, transformation and consumption of all energy carriers (electricity, heat, and liquid, gaseous and solid fuels, whether fossil or non-fossil) in each sector (transportation, buildings and industry), as well as the investment and operation of all technologies that generate, transform or consume energy, and resultant greenhouse gas emissions arising from the combustion of fossil fuels and industrial processes. Rather than predicting or forecasting the future, this model works backwards from a given carbon budget, set of future energy demands and assumptions around available technologies, to develop "least cost" pathways. User-defined constraints are typically imposed to reflect the speed at which new technologies can be deployed. In this way, models like TIM can inform the necessary milestones for the energy transition, which can be used to develop policy, prepare infrastructure and examine trade-offs between certain objectives.

Carbon budgets: As shown in Figure 1, five different Carbon Budgets (CB) for the period 2021-2050 are modelled based on the IPCC assessment of the global Remaining Carbon Budget (RCB). Appendix 2 provides detailed information on how the global CBs were downscaled to estimate Ireland's CB[1]. These budgets cover GHGs arising from fossil fuel combustion across Ireland's energy system plus industrial process emissions. The analysis focuses on the RCBs aligned with 1.5°C to 2°C of global warming with different levels of confidence. These CBs modelled for Ireland are as follows:

- 450Mt aligned with 67% likelihood of limiting global warming to 2.0°C (IPCC AR6 1150Gt CO_2 RCB)
- 400Mt aligned with 1.7°C (33%) (IPCC AR6 1050Gt CO_2 RCB)
- 350Mt aligned with 1.5°C (17%) and 2.0°C (83%) (IPCC AR6 900Gt CO_2 RCB)
- 300Mt aligned with 1.7°C (50%) (IPCC AR6 850Gt CO_2 RCB)
- 250Mt aligned with 1.5°C (33%) and 1.7°C (67%) (IPCC AR6 650-700Gt CO_2 RCB)

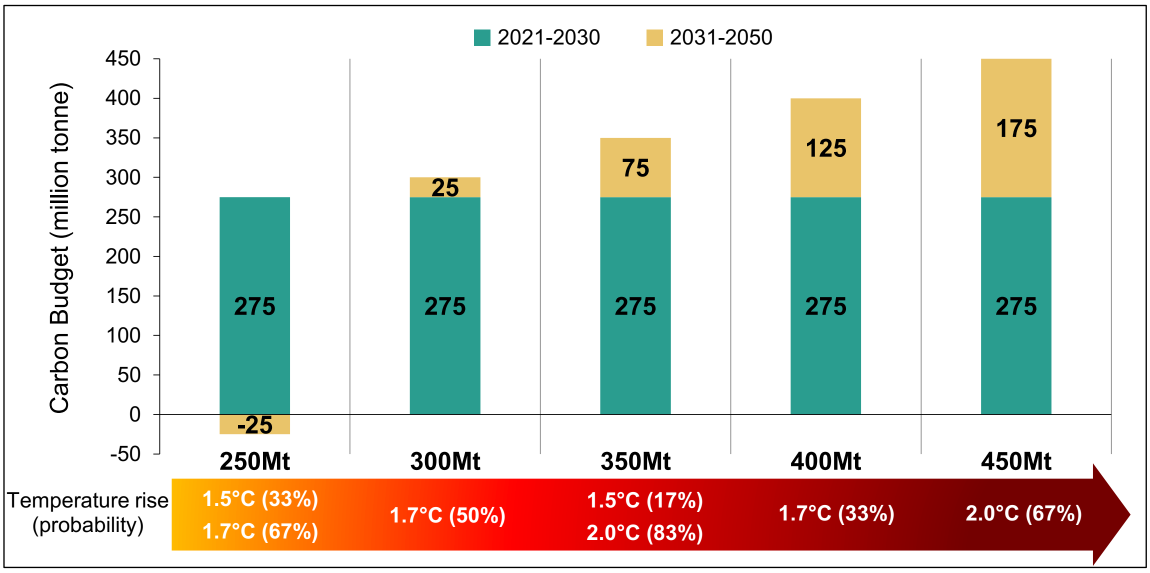

FIGURE 1: MODELLED CARBON BUDGET SCENARIOS FOR THE ENERGY SYSTEM, COMPARED TO CARBON BUDGETS COMMITTED DURING CARBON BUDGETS 1 & 2, AND THE REMAINING CARBON BUDGET FROM 2031-50. THESE ARE RELATED TO PROBABILITIES OF EQUIVALENT GLOBAL TEMPERATURE RISE; THE METHODOLOGY FOR THIS APPROACH IS DESCRIBED IN APPENDIX 2.

All scenarios are assumed to meet the steep GHG reductions in the period to 2030 as mandated under the Sectoral Emissions Ceilings. The implications of overshooting early carbon budgets are explored in a paper, contained in Appendix 1.

Two distinct demand projection scenarios, Business as Usual (BAU) and Low Energy Demand (LED), are considered (see in detail in Appendix 3). Additional details of the distinction between the two scenarios can be found in the peer-reviewed journal article (see Appendix 1)[2]. We model all five CBs with the BAU demand projection. The lower three CBs (250, 300, and 350Mt) are also modelled with the low energy demand projection. Combining the CB and demand projection pathways, we analyse mitigation pathways across eight scenarios (Figure 2).

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[1] Note that this analysis is one interpretation of Ireland's responsibility under the Paris Agreement. Different interpretations according to historical responsibility and capability can be taken: this requires both normative judgements and also consideration of GHG emissions pathways in other sectors. The CBWG is undertaking a detailed analysis on these aspects. More details on the approach taken for this report is contained in Appendix 2.

[2] Gaur, A., Balyk, O., Glynn, J., Curtis, J. & Daly, H. Low energy demand scenario for feasible deep decarbonisation: Whole energy systems modelling for Ireland. *Renewable and Sustainable Energy Transition* **2**, 100024 (2022).

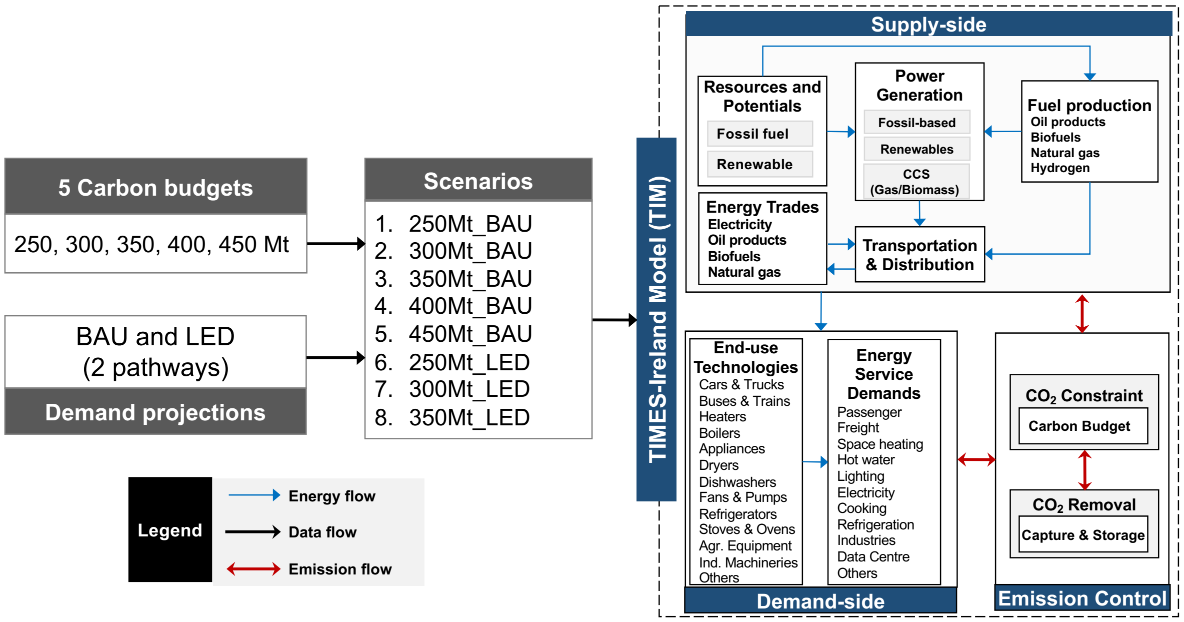

FIGURE 2: SCENARIO DEFINITIONS AND MODEL SCHEMATIC

Key assumptions and detailed methodology: Details on TIM's core methodology can be found in the model documentation paper[1]. The model itself is open-source and its files can be downloaded from EPMG's GitHub repository[2]. The software tools necessary to solve and interact with the model are available, but require advanced training[3].

Generally speaking, these scenarios do not model the impact of existing policies or targets, such as the number of electric vehicles or production of biomethane in 2030. Rather, these are key outputs of the model, which choses the "optimal" level of technology deployment in a given year to meet carbon budgets and energy demands in each scenario. However, in some cases, technology deployment rates are influenced by user constraints, which are often used to limit the speed at which new energy sources and technologies can be deployed. Otherwise, the model could choose pathways that could be considered "infeasible" – such as installing 5 GW of offshore wind capacity in 2025. Choosing user constraints to reflect "feasible" rates of technology deployment requires some level of subjective judgement. Key assumptions are detailed in Appendix 3.

Detailed results: Detailed results for all scenarios can be explored and downloaded on a web portal: https://epmg.netlify.app/TIM-Carbon-Budget-2024/

3 CARBON BUDGET PATHWAYS

Figure 3 describes the annual GHG pathways, and Figure 4 shows the 5-year distribution of carbon budgets for each scenario. Higher carbon budgets allow for greater emissions in later periods, and allow for longer-term flexibility.

To achieve the most ambitious mitigation scenario, the sectoral emissions ceilings assigned to the energy system in carbon budgets 1 and 2 would have to be reduced (*250Mt-LED*) or greater reliance in GHG removal would be required post-2050 (*250Mt-BAU*).

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[1] Balyk, O. et. al. (2022): TIM: Modelling pathways to meet Ireland's long-term energy system challenges with the TIMES-Ireland Model (v1.0), *Geoscientific Model Development*, https://doi.org/10.5194/gmd-2021-359

[2] https://github.com/MaREI-EPMG/times-ireland-model

[3] IEA-ETSAP, Antti-L, & G. Giannakidis. (2021). ETSAP-TIMES/TIMES_model: TIMES Version 4.5.3 (v4.5.3). Zenodo. https://doi.org/10.5281/zenodo.4660551

LED scenarios can achieve lower carbon budgets with lower overshoot[1], indicating the importance of low energy demand strategies to meet ambitious climate targets. For instance, there is an overshoot of 86 Mt in the *250Mt-BAU* scenario, which reduces to 14 Mt in *250Mt-LED.*

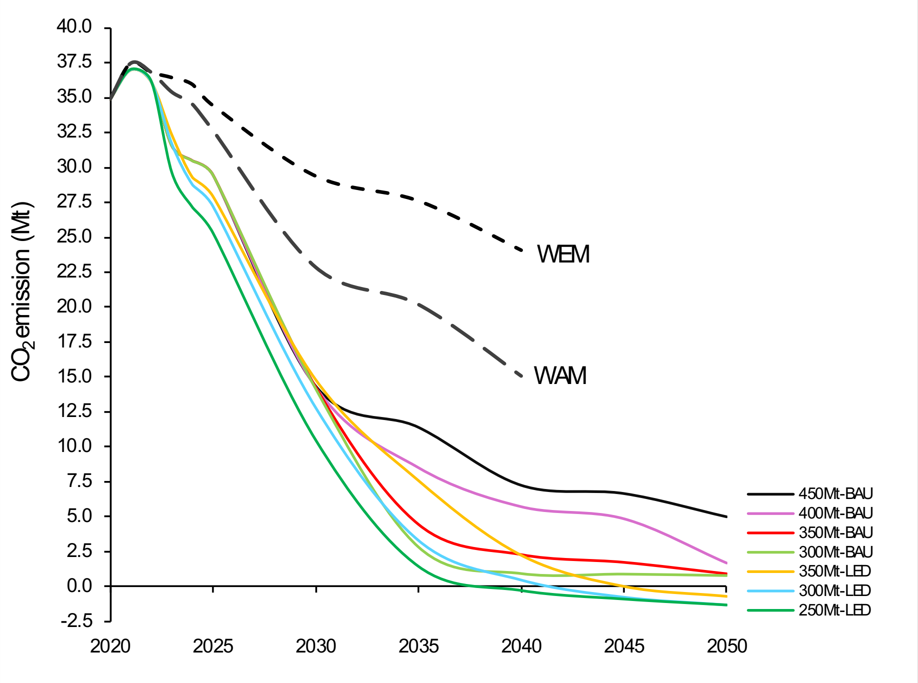
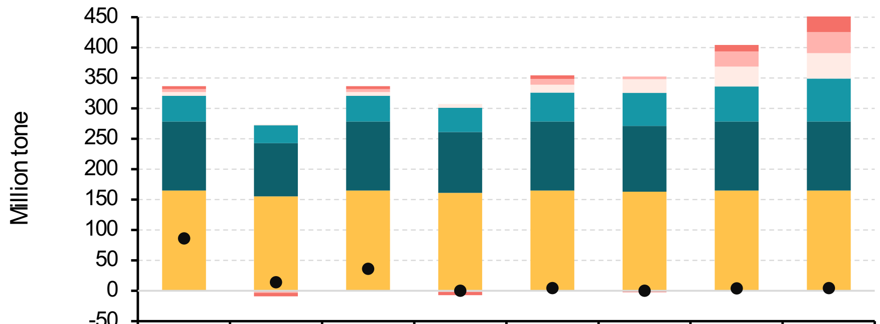


FIGURE 3: EMISSIONS PATHWAYS IN EACH MODELLED SCENARIO, COMPARED TO THE EPA "WITH EXISTING MEASURES" (WEM) AND "WITH ADDITIONAL MEASURES" (WAM) SCENARIS. *300MT-BAU* AND *250MT-BAU* HAVE THE SAME PATHWAY.



	250Mt BAU	250Mt LED	300Mt BAU	300Mt LED	350Mt BAU	350Mt LED	400Mt BAU	450Mt BAU
■ 2046-50	4	-6	4	-5	6	-2	11	29
■ 2041-45	5	-3	5	-2	9	5	25	35
■ 2036-40	7	1	7	6	13	22	33	42
■ 2031-35	42	30	42	40	48	55	58	71
■ 2026-30	113	87	113	100	113	108	113	114
■ 2021-25	165	155	165	161	165	163	165	165
● Overshoot	86	14	36	0	4	0	4	4

FIGURE 4: DETAILED 5-YEAR CARBON BUDGET FOR EACH SCENARIO, INCLUDING "OVERSHOOT" (UNMITIGATED EMISSIONS)

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[1] "Overshoot" in this context refers to greenhouse gas emissions from the energy system which the model could not find a viable solution to mitigate (at a cost of <€2000/t), within the given scenario framework - the modelled set of carbon budgets, demands and technology assumptions.

Table 1 details total CO_2 reductions relative to 2018 in each scenario. Total emissions in 2030 fall by 62-73%, which is significantly higher than currently policy is planning to deliver. By 2040, emissions in six out of the eight scenarios fall by more than 90%, and in three already reach net-negative.

	2025	2030	2040	2050
250Mt BAU	31%	71%	105%	105%
250Mt LED	35%	73%	103%	105%
300Mt BAU	25%	64%	102%	102%
300Mt LED	29%	67%	99%	103%
350Mt BAU	25%	64%	94%	98%
350Mt LED	28%	62%	94%	102%
400Mt BAU	25%	64%	85%	96%
450Mt BAU	25%	64%	81%	87%

TABLE 1: TOTAL CO2 EMISSIONS REDUCTION RELATIVE TO 2018, %

Table 2 details key indicators in 2040, including annualised and cumulative cost, gross and net CO_2 emissions and reductions in primary energy demand relative to 2020.

	250Mt-LED	350Mt-LED	300Mt-LED	450 Mt-BAU	400Mt-BAU	350Mt-BAU	250Mt-BAU
2040 Annualised System Costs (MEUR)	€ 19,900	€ 17,100	€ 17,800	€ 24,900	€ 25,200	€ 25,900	€ 32,400
Cost as % of 2020 GDP	6.07%	5.21%	5.43%	7.59%	7.68%	7.90%	9.88%
2031-2040 Cumulative System Cost (MEUR)	€ 173,000	€ 156,000	€ 164,000	€ 222,000	€ 224,000	€ 230,000	€ 236,000
Gross Domestic CO_2 Energy Emissions (Mt)	1.51	3.9	2.8	7.2	5.7	4.1	2.8
Negative Emissions from Energy Sector (Mt)	-1.8	-1.7	-1.8	0	0	-1.8	-1.8
Net Domestic CO_2 Energy Emissions (Mt)	-0.29	2.2	0.96	7.2	5.7	2.2	0.96
Energy CO_2 Reduction Relative to 1990	100%	93%	97%	78%	83%	93%	97%
Reduction In Primary Energy rel to 2020	29%	29%	29%	4%	5%	2%	3%

TABLE 2: KEY INDICATORS ACROSS SCENARIOS IN 2040

4 MITIGATION MEASURES

Table 3 describes emissions reductions in each sector relative to 2018. The power sector decarbonises most rapidly - by 97% in 2030 across all scenarios, then turning net-negative by 2040 in the majority of cases. Transport and buildings decarbonise by 91-100% by 2040. The industrial sector is less well developed in the model and is undergoing re-development, and mitigation options are more limited than in other sectors. The following sub-sections describe in more detail the mitigation pathways across each sector.

		2025	2030	2040	2050
Industry	250Mt BAU	-4%	41%	59%	60%
Industry	250Mt LED	13%	57%	78%	93%
Industry	300Mt BAU	-4%	41%	59%	60%
Industry	300Mt LED	8%	50%	76%	93%
Industry	350Mt BAU	-4%	41%	53%	59%
Industry	350Mt LED	8%	45%	63%	93%
Industry	400Mt BAU	-4%	41%	40%	54%
Industry	450Mt BAU	-4%	41%	31%	43%
Power generation	250Mt BAU	41%	97%	117%	117%
Power generation	250Mt LED	50%	97%	117%	117%
Power generation	300Mt BAU	41%	97%	117%	117%
Power generation	300Mt LED	47%	97%	117%	117%
Power generation	350Mt BAU	42%	97%	117%	117%
Power generation	350Mt LED	47%	97%	116%	117%
Power generation	400Mt BAU	42%	97%	97%	117%
Power generation	450Mt BAU	42%	97%	95%	97%
Residential buildings	250Mt BAU	48%	77%	100%	100%
Residential buildings	250Mt LED	48%	80%	100%	100%
Residential buildings	300Mt BAU	48%	77%	100%	100%
Residential buildings	300Mt LED	41%	73%	100%	100%
Residential buildings	350Mt BAU	47%	76%	99%	100%
Residential buildings	350Mt LED	32%	58%	98%	100%
Residential buildings	400Mt BAU	47%	75%	97%	100%
Residential buildings	450Mt BAU	47%	74%	95%	98%
Services sector	250Mt BAU	38%	96%	100%	100%
Services sector	250Mt LED	39%	100%	100%	100%
Services sector	300Mt BAU	38%	96%	100%	100%
Services sector	300Mt LED	26%	83%	99%	100%

Services sector	350Mt BAU	38%	100%	91%	100%
Services sector	350Mt LED	24%	80%	93%	100%
Services sector	400Mt BAU	37%	99%	86%	100%
Services sector	450Mt BAU	37%	98%	85%	84%
Transport sector	250Mt BAU	10%	38%	99%	100%
Transport sector	250Mt LED	27%	56%	100%	100%
Transport sector	300Mt BAU	10%	38%	99%	100%
Transport sector	300Mt LED	22%	48%	95%	100%
Transport sector	350Mt BAU	10%	38%	98%	100%
Transport sector	350Mt LED	21%	43%	94%	100%
Transport sector	400Mt BAU	10%	38%	96%	100%
Transport sector	450Mt BAU	10%	37%	91%	99%

TABLE 3: SECTORAL CO2 EMISSIONS REDUCTION RELATIVE TO 2018, %

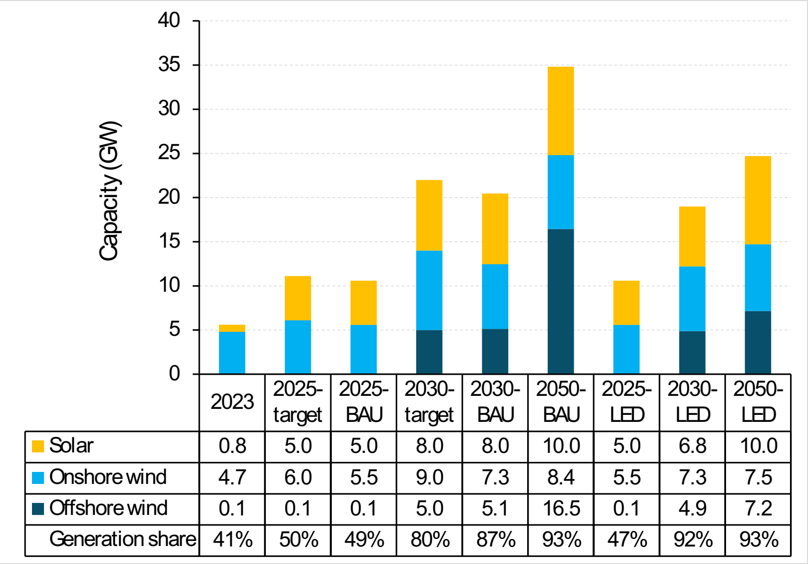
4.1 POWER SECTOR

Electrification, along with decarbonisation of power generation, is the main decarbonisation lever in all scenarios. Electricity demand as a share of total final energy consumption (excluding jet kerosene) grows from 22% in 2020, to 47% in 2030, and 58% in 2040. Because electricity end uses are far more efficient than applications based on combustion, such as biofuels, electricity demand represents an even greater share of useful energy demand for transport, buildings and industry. By 2040, electricity represents more than 80% of energy demand in both residential buildings and in domestic transport. This is driven by a transformation in power generation capacity, towards renewables and limited biomass, and in vehicle and home heating technologies.

4.1.1 POWER GENERATION CAPACITY

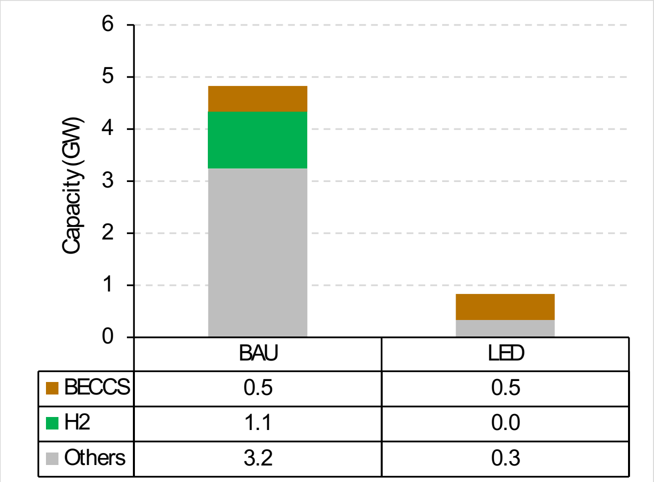
Figure 5 shows power generation from variable renewable energy sources across different scenarios. Both BAU and LED scenarios show a growing share of renewables in the power mix, with the BAU and LED scenarios reaching up to 93% by 2050, though the composition and scale of developments significantly vary (35 GW total installations in the BAU scenario versus 25 GW in LED by 2050). The *BAU* scenario shows an even higher share of renewables in 2030 (87%) compared to the target (80%), which could indicate that *350Mt* budget requires greater renewable integration in the BAU scenario for that period. Figure 6 also compares the installed capacity of other technologies in two scenarios in 2050.

BAU requires 1.1 GW of hydrogen-based capacity and about 3 GW of other technologies (mostly gas-fired power generation), significantly more than the *LED* scenario. However, additional analysis is necessary to fully explore the role of these (and other) technologies in the power system, as TIM is not designed to model in detail its operation, including investment in grids, storage and flexibility. Moreover, only energy demand for domestic demand is factored in: no exported energy is assumed, beyond that exported in currently planned interconnectors.



	2023	2025-target	2025-BAU	2030-target	2030-BAU	2050-BAU	2025-LED	2030-LED	2050-LED
🟨 Solar	0.8	5.0	5.0	8.0	8.0	10.0	5.0	6.8	10.0
🟦 Onshore wind	4.7	6.0	5.5	9.0	7.3	8.4	5.5	7.3	7.5
■ Offshore wind	0.1	0.1	0.1	5.0	5.1	16.5	0.1	4.9	7.2
Generation share	41%	50%	49%	80%	87%	93%	47%	92%	93%

FIGURE 5: POWER CAPACITY OF VARIABLE RENEWABLE ENERGY SOURCES IN 350MT-BAU SCENARIO



	BAU	LED
🟫 BECCS	0.5	0.5
🟩 H2	1.1	0.0
⬜ Others	3.2	0.3

FIGURE 6: POWER CAPACITY OF OTHER TECHNOLOGIES UNDER 350MT CARBON BUDGET IN 2050 (OTHERS: GAS, MSW AND HYDRO)

4.1.2 ELECTRICITY DEMAND

Figure 7 and Figure 8 display the average annual electricity demand growth and total electricity generation by source, respectively. Both *BAU* and *LED* scenarios require very significant demand growth

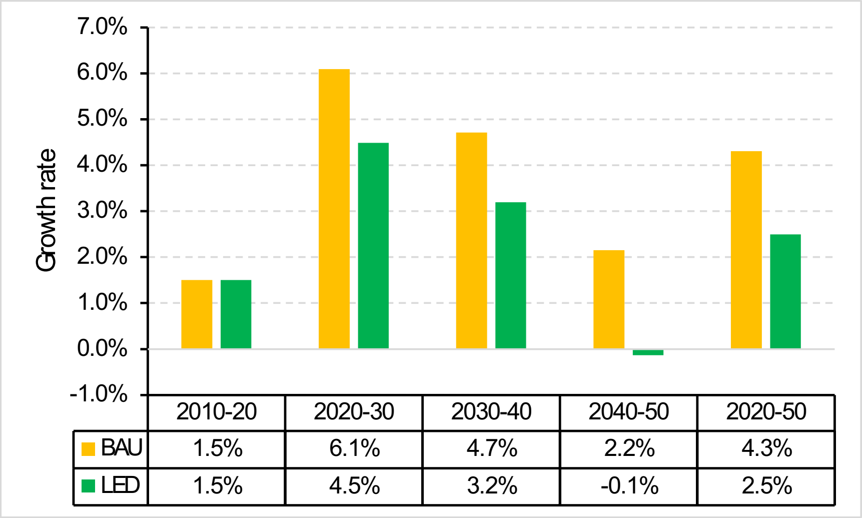


FIGURE 7: GROWTH RATE IN ELECTRICITY DEMAND

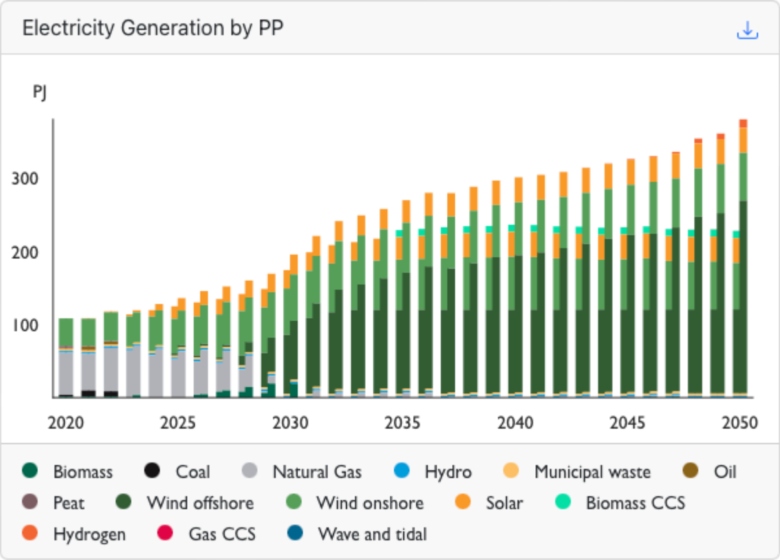


FIGURE 8: TOTAL ELECTRICITY GENERATION BY SOURCE, *250MT-LED* AND *450MT-BAU* SCENARIOS (LINK)

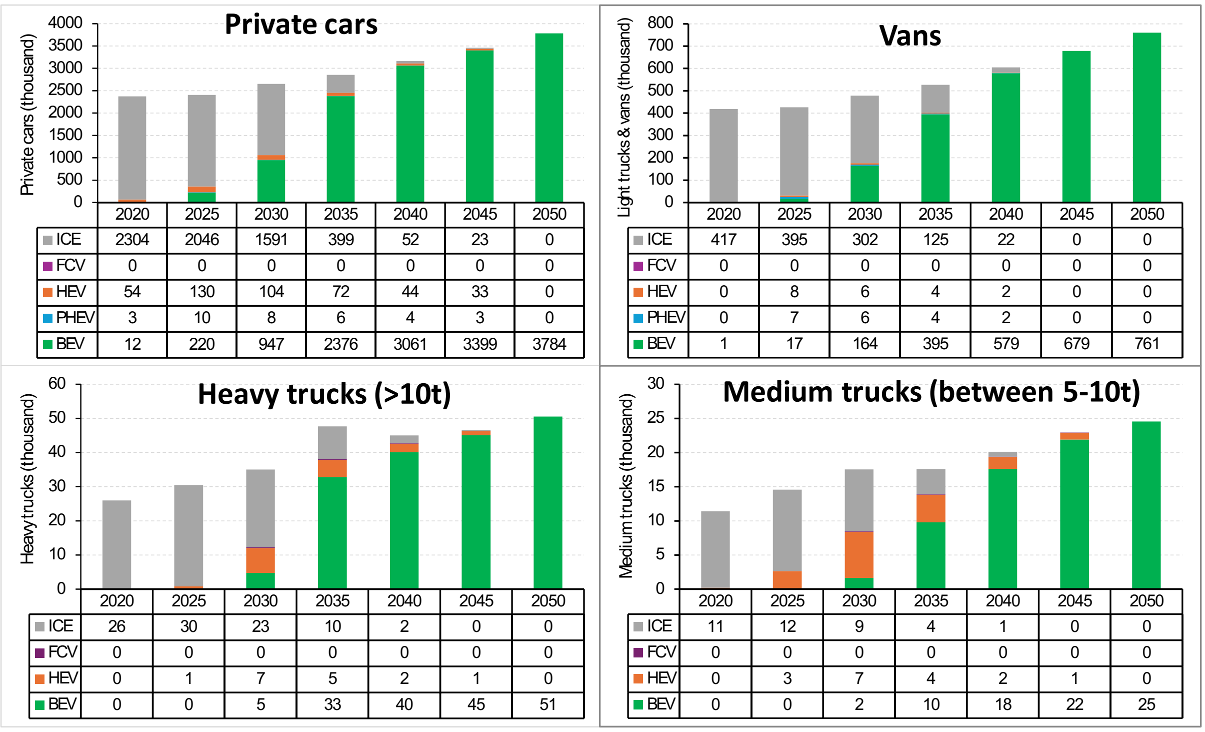
4.2 BIOENERGY

Bioenergy primary energy demand grows to around 32 TWh in 2030 in the *350Mt-BAU* scenario, more than tripling the level from 2020. Of this demand, 4.7 TWh is from biogas, which is all used in the industry sector, 4.6 TWh is from biodiesel, which is used in the transport sector in the period to 2030, and increasingly in industry in the period to 2050, and the remainder is used for power generation. LED scenarios and less stringent carbon budget scenarios rely on less bioenergy across the energy system.

Bioenergy and biomass supply limits and costs are derived from the SEAI Heat Study Bioenergy for Heat report. Detailed assumptions underpinning this sector are described in Appendix 3.

4.3 TRANSPORT

Figure 9 details the stock of vehicles in the *350Mt-BAU* scenario. Near full electrification of all vehicles is achieved by 2040. The sale of new internal combustion engine private vehicles, light vans and HGVs is ended by 2025, 2026, and 2031 respectively. More ambitious climate scenarios brings forward this date for freight vehicles. *LED* scenarios, which lower the dependence on private cars and reduces freight vehicle movements, allow a later phase out of new fossil-fuelled vehicle sales. These scenarios can be explored at this link.



Private cars

	2020	2025	2030	2035	2040	2045	2050
ICE	2304	2046	1591	399	52	23	0
FCV	0	0	0	0	0	0	0
HEV	54	130	104	72	44	33	0
PHEV	3	10	8	6	4	3	0
BEV	12	220	947	2376	3061	3399	3784

Vans

	2020	2025	2030	2035	2040	2045	2050
ICE	417	395	302	125	22	0	0
FCV	0	0	0	0	0	0	0
HEV	0	8	6	4	2	0	0
PHEV	0	7	6	4	2	0	0
BEV	1	17	164	395	579	679	761

Heavy trucks (>10t)

	2020	2025	2030	2035	2040	2045	2050
ICE	26	30	23	10	2	0	0
FCV	0	0	0	0	0	0	0
HEV	0	1	7	5	2	1	0
BEV	0	0	5	33	40	45	51

Medium trucks (between 5-10t)

	2020	2025	2030	2035	2040	2045	2050
ICE	11	12	9	4	1	0	0
FCV	0	0	0	0	0	0	0
HEV	0	3	7	4	2	1	0
BEV	0	0	2	10	18	22	25

FIGURE 9: VEHICLE STOCK IN 350MT-BAU SCENARIO (LINK)

4.4 BUILDINGS

Figure 10 details the transition in residential final energy consumption in the *350Mt-BAU* scenario. Coal and peat use for heating is phased out immediately, as the fuels with the greatest carbon intensity. Following this, the use of oil falls by nearly 80% in between 2020 and 2030, and is nearly fully phased out by 2035. The use of natural gas for heating falls in half in the decade to 2030, and is nearly fully phased out by 2040.

Electrification through heat pumps (facilitated by reducing the heat loss of building fabric) is the main mitigation pathway across the model. New research using TIM indicates that lowering the threshold for heat loss before supporting heat pumps can facilitate more rapid energy transition at lower cost[1]

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[1] https://www.sciencedirect.com/science/article/pii/S0378778824004997?ssrnid=4644106&dgcid=SSRN_redirect_SD

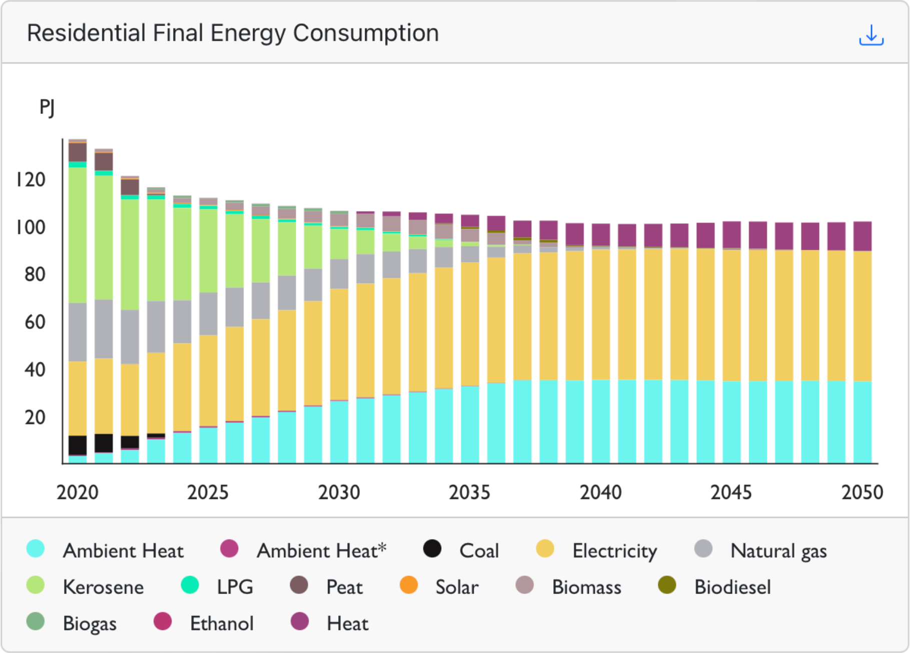

FIGURE 10: RESIDENTIAL FINAL ENERGY CONSUMPTION, 350MT-BAU (LINK)

4.5 INDUSTRY

The industrial sector is less well developed in TIM than other end-use sectors, and we are undertaking a re-development of the sector, informed by SEAI's Heat Study. Currently, mitigation options in the industrial sector are relatively limited, and include a CCS option for cement, which is assumed to be in operation from 2030, and fuel switching, for example from natural gas to biogas. The potential to electrify heat is not currently adequately captured in our model: the SEAI Heat Study has estimated that half of industrial heat can be directly electrified, with 9% and 77% of heating suitable for industrial heat pumps and hydrogen respectively[1]. New technological innovations in thermal energy storage could allow a large proportion of industrial heat to use lower-cost electricity when renewable generation is high. We are redeveloping the industrial sector of the model to take these factors into account, and anticipate that future iterations of carbon budget scenarios will feature faster and deeper reductions of fossil fuels in this sector, and may require lower reliance on biogas to replace natural gas.

In the most stringent climate scenario, the main mitigation levers in this sector are fuel switching from natural gas to biogas and from coke to solid biomass, and CCS installation on cement manufacturing, which captures and sequesters carbon dioxide from cement production (Figure 11).

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[1] https://www.seai.ie/publications/Low-Carbon-Heating-and-Cooling-Technologies.pdf

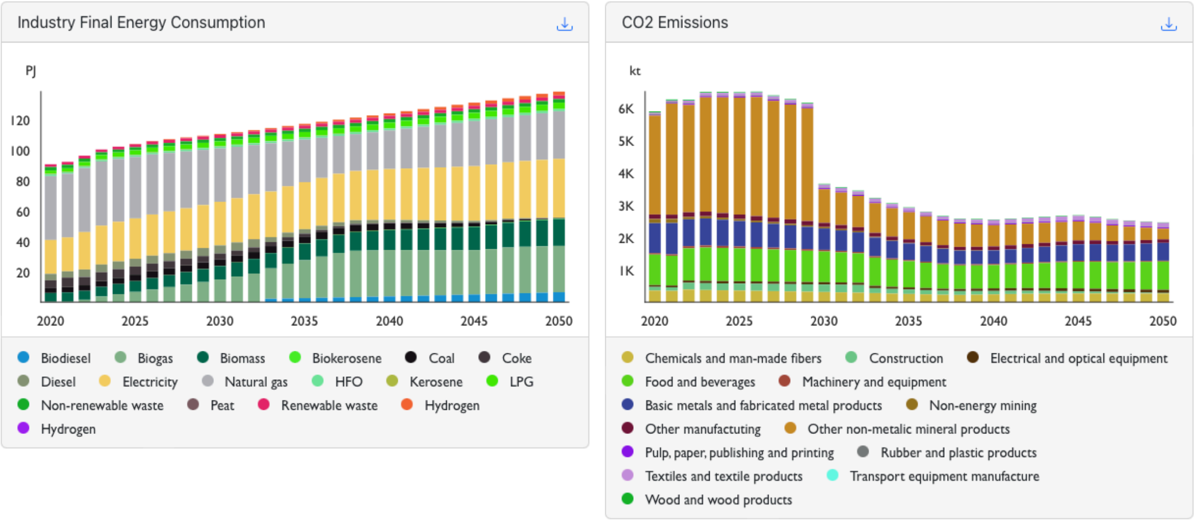
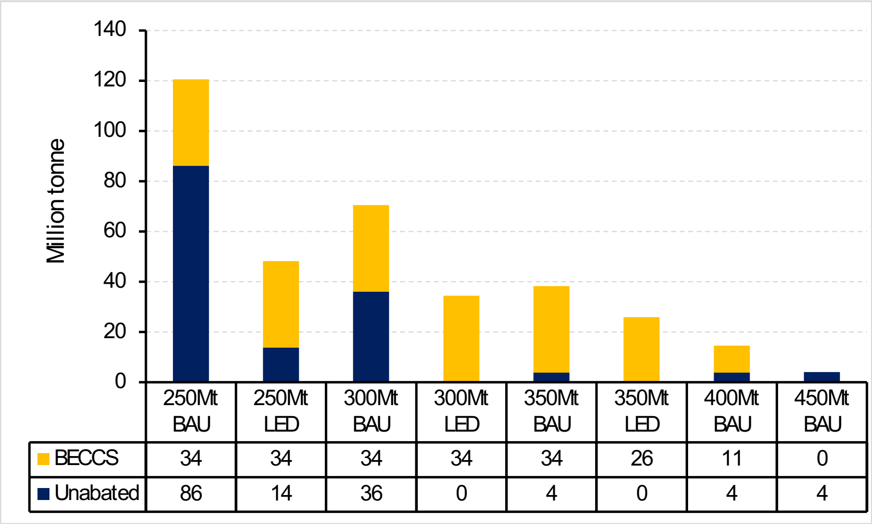


FIGURE 11: INDUSTRY FINAL ENERGY CONSUMPTION AND CO2 EMISSIONS IN 250MT-BAU SCENARIO (LINK)

4.6 ROLE OF CARBON DIOXIDE REMOVAL TECHNOLOGIES

Figure 12 shows the role of removal technologies, particularly BECCS, in meeting various carbon budget scenarios. “Unabated” refers to GHG emissions for which TIM could not find a mitigation solution costing less than €2000/tonne, and therefore relies on a backstop technology to meet. To meet the overall carbon budget, emissions removals would need to be found, for example through Direct Air Capture (DAC) or greater levels of peatland rehabilitation or afforestation, which are not modelled in this study.

All scenarios, regardless of their stringency or energy demand assumptions, rely on some form of carbon removal technology. Even with additional energy demand reduction strategies in LED scenarios, removal technologies are required for achieving and maintaining long-term climate goals. For stringent carbon budgets and scenarios with BAU energy demand BAU, significantly greater levels of carbon removal technologies are required.. Generally speaking, scenarios with lower carbon budgets (higher mitigation ambition) and with LED measures rely on lower levels of carbon removals. This is because the more ambitious the carbon budget, the greater the need to compensate for emissions that are not eliminated through mitigation measures alone. Moreover, separate analysis has shown that early overshoot of carbon budgets in the period to 2030 increases reliance on carbon dioxide removal technologies (see Appendix 1).



	250Mt BAU	250Mt LED	300Mt BAU	300Mt LED	350Mt BAU	350Mt LED	400Mt BAU	450Mt BAU
🟨 BECCS	34	34	34	34	34	26	11	0
■ Unabated	86	14	36	0	4	0	4	4

FIGURE 12: CARBON DIOXIDE REMOVAL BY SCENARIO.

5 BENCHMARKING AGAINST EU 2040 TARGET

The EU has set a target to reduce net GHG emissions by at least 55% relative to 1990 levels for 2030. Recently, the European Commission recommended a 2040 climate target, proposing a 90% reduction in net GHG emissions by 2040 relative to 1990 levels. The EU has not formally adopted this target, nor has it indicated how Member States will be allocated different targets, or whether sectors will be treated differently. In this section, we benchmark carbon budget scenarios for this report against illustrative targets which may be applied to Ireland's energy system in 2040.

Emissions from the Irish energy system were 33 $MtCO_2$ in 1990. If a 90% reduction target was applied to energy system CO_2 only, this would require emissions to fall to 3.3 $MtCO_2$ in 2040. Figure 13 illustrates emissions reduction pathways from the energy sector across the carbon budget scenarios modelled for this analysis compared to illustrative targets from 85% to 90% based on the energy system's CO2 emissions in 1990. The most ambitious carbon budget scenario – *250Mt-LED* – meets the 95% reduction target in 2035, while the least ambitious carbon budget scenario – *450Mt-BAU* – meets the 80% reduction target in 2041.

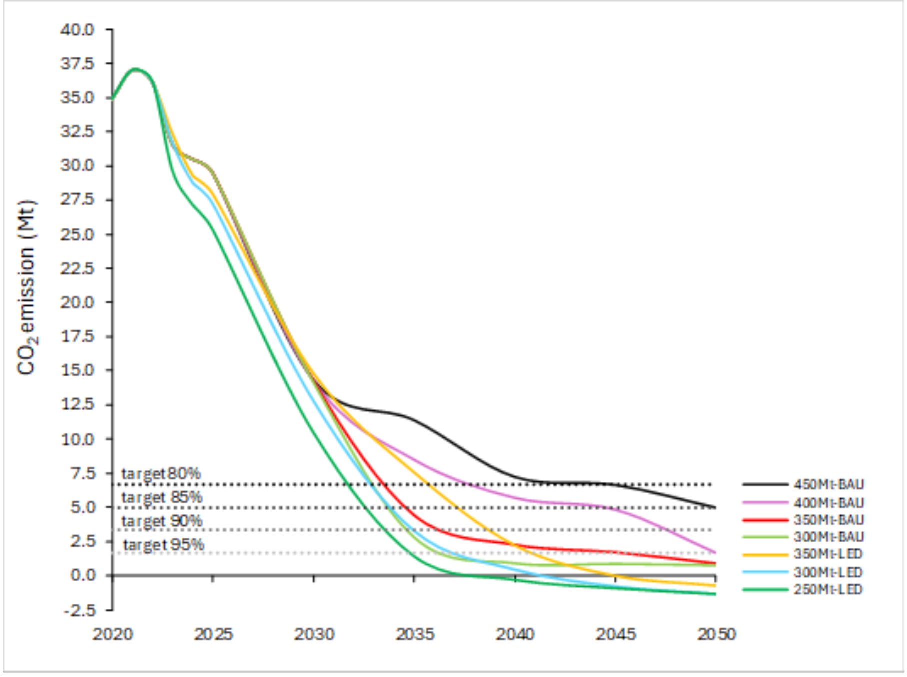


FIGURE 13: CARBON BUDGET SCENARIOS BENCHMARKED AGAINST ILLUSTRATIVE GHG REDUCTION TARGETS

6 PRACTICAL IMPLICATIONS, POTENTIAL PITFALLS AND CHALLENGES

6.1 KEY FINDINGS

Key findings are as follows:

- Net-zero is a critical milestone, but cumulative CO_2 emissions determine total global warming. For this reason, Ireland's climate ambition is framed as cumulative carbon budgets, and planning the sustainable energy transition to deliver net-zero by 2050 is not sufficient: understanding this difference is critical for appreciating the scale of Ireland's mitigation challenge. Consequently, it is likely that emissions from Ireland's energy system must fall to net-zero, or close to zero, well before 2050. For example, this report shows that carbon budgets aligned with a global effort to limit global warming to 1.5°C would require existing carbon budgets in the period to 2030 to be reduced, and for Ireland's energy system to achieve net-zero by around 2035, as well as delivering significant cuts in non-CO_2 emissions. Moreover, if emissions overshoot committed carbon budgets in the period to 2030, this overshoot must be compensated for by reducing carbon budgets in subsequent periods. The scale of projected carbon budget overshoot would leave little-to-no carbon budget left following 2030, even under moderate ambition.

- All scenarios detail significantly greater greenhouse gas emissions cuts in the period to 2030 and 2040 than planned under current policies. An immediate acceleration in implementing mitigation measures is necessary to close this gap. Making up for this overshoot in the long-term may not be feasible, or is likely to be significantly more costly than cutting emissions now.
- A near-complete phase-out of all fossil fuels required is required in the period to 2030 to 2040 for power, buildings and transport in the majority of scenarios. The phase-out of coal and oil is urgent. From now, there is nearly no remaining carbon budget for additional investments in fossil fuel, such as internal combustion engine vehicles. This also has implications for natural gas infrastructure, for which a decommissioning plan is required.
- Electrification of transport and heat, complemented by decarbonising electricity supply, are the main mitigation levers. While this energy transition requires significant upfront investment, and brings new risks and challenges, the falling cost of renewables and batteries, and the social, health, energy security and economic benefits, makes it cost effective. Greater climate ambition lowers the damage caused by greenhouse gas emissions. While this report quantifies the cost of greater climate ambition, the benefits of earlier fossil fuel phase-out for energy security, economic sectors, air pollution and household energy bills are not quantified, but are likely to be substantial.
- The feasibility of delivering the scenarios described in this report relies on political, societal and institutional capacity. With some exceptions, the technologies and measures necessary to cut emissions are available, mature, cost-effective and well tested. Time, not technology, is the main challenge. The following are some of the main technical challenges associated with delivering these pathways:
    - Operation of the power system with very little natural gas (and other fossil fuels) by the early 2030s. Moreover, total electricity demand grows at an unprecedented rate in all scenarios to meet the need to electrify transport, heating and industry.
    - This will require significant innovations and investment in the power system, including in developing short- and long-duration energy storage, strategic annual storage, flexibility and interconnection, and investment in electricity transmission and distribution. Technologies that are currently nascent and an evolution of electricity markets are necessary to realise this level and pace of decarbonisation.
    - Lowering final energy demands makes the most ambitious climate scenarios more feasible than a strategy that relies on technology transitions alone, and can bring additional co-benefits. This can be achieved by reducing dependence on private cars, promoting greater housing density, wasting less energy in buildings and industries, and lowering reliance on carbon-intensive materials such as cement. While these changes will require individuals to change some of their daily practices, this "behaviour change" requires significant state investment and regulation, and the provision of information, to change the choice architecture – such improving public transport provision - to facilitate lifestyles that require lower final energy.
    - All scenarios rely to some extent on emissions removals, either through Biomass with Carbon Capture and Storage (BECCS), which is modelled explicitly, or another form of carbon dioxide removal (CDR), which is not modelled. More emissions removals are required in scenarios with greater mitigation ambition, with higher early overshoot of carbon budgets to 2030, and with higher final energy demands. Reliance on removals brings significant risks and trade-offs: technologies are not proven at scale, and if implemented at scale are likely to come with either significant land-use change implications (in the case of BECCS) or energy demands (in the case

of Direct Air Capture), as well as uncertain costs. These risks can be limited through strong early mitigation and lowering demands. Careful assessment of the sustainability and opportunity cost of BECCS feedstock is necessary. Meanwhile, this report indicates that emissions removal options must be explored to limit global temperature rise to the Paris Agreement commitments.

  - These scenarios indicate that buildings and transport should be close to fully decarbonised by the early-to-mid 2030s. This can be achieved through accelerating the pace and scale of decarbonisation measures outlined in the Climate Action Plan: efficiency, retrofitting, district heating and electrification. More ambitious climate scenarios require a more rapid phase-out of natural gas heating systems and of freight vehicles and vans using oil. All scenarios require a very rapid transition away from oil-based central heating systems and heating with coal and peat.
  - Moreover, all scenarios see the end of sales of new internal combustion engine private cars sales by 2025, which is significantly misaligned with current trends. This highlights how new investments in technologies dependent on fossil fuels from now have a significant bearing on delivering on carbon budgets, even beyond 2035: New investments either lock in greenhouse gas emissions, or else will become stranded assets as they are retired early. Either the State or private individuals will have to bare this cost.

6.2 FEASIBILITY & PRACTICAL IMPLICATIONS

The energy transition depicted in these scenarios requires more rapid deployment of measures and new technologies than Ireland has achieved in history. However, this does not imply these scenarios are infeasible. Feasibility is a function of the technical readiness of technologies – whether they are available on the market, including supply chain constraints – as well as societal readiness, political commitment, institutional capacity and the readiness of infrastructure. Broadly speaking, the majority of the mitigation measures and technologies depicted in these scenarios are already available, and are currently undergoing exponential growth globally. There are many examples of rapid energy transitions throughout history. Overcoming the barriers to a rapid energy transition is necessary to enable the scenarios depicted in this report. This transformation can be catalysed by political leadership, social movements and disruptive events (such as the war in Ukraine). At the same time, societal forces can also work against the delivery of these climate mitigation pathways.

The following summarises the main practical implications of delivering rapid energy transitions:

- Physical infrastructure: Expanding and upgrading the power grid and investing in flexibility, storage across timescales and interconnection; building district heating networks, public transport networks
- Planning: The speed at which the planning system can approve
- Human resources and skills: Upskilling workers to deliver the energy transition while providing retraining and support for workers transitioning from roles; human resource throughout public system, including planning, civil service, local authorities and education.
- Market design: Redesigning the power market to reward flexibility and storage
- Equity and building public support: Explaining the "how and why" of the energy transition to the public; avoiding backlash by designing the energy transition to deliver multiple benefits and communicating this clearly to the public. Designing energy transition measures in an equitable way, as an end in itself and to increase public acceptance of the necessary changes.
- Finance: The overall cost of the energy transition is manageable, and in many cases will come with net savings, but significant upfront cost is necessary across all sectors to transform the energy system, which must be financed, while capital is redirected from harmful activities.
- Environmental management: Mitigating potential environmental impacts of renewable energy.

- Innovation in industry: Developing cleaner production methods and processes in energy-intensive industries like cement.

7 NEXT STEPS

This interim report is being published to facilitate peer review of the scenarios and allow feedback from the CCAC and other experts before finalisation of the study. We will revise these scenarios in response to review and feedback and submit a final report to the Carbon Budgets Working Group in Q3, 2024.

Additional modelling, analysis and testing of these results is being undertaken by members of the CBWG, including an assessment of policy uptake, macroeconomic implications, climate impacts and biodiversity.

In parallel, we are undertaking improvements in the representation of the energy transition in the industry sector, particularly the scope for electrification, including with heat pumps and hydrogen. We anticipate that this will indicate a more rapid and deeper decarbonisation trajectory for the sector. We particularly welcome inputs and data on the industry sector, including a subdivision of energy flows for heating processes and the potential for waste heat from the sector to be recycled or used in district heating networks.

In the longer term, we are developing new features in TIM, including international aviation and shipping, Direct Air Capture (DAC), sustainable aviation fuel (SAF), and land use impacts assessment. We are also studying the energy security implications of reliance on weather-dependent power generation and increased electric-based heating and transportation

APPENDIX 2: CARBON BUDGET CALCULATIONS

In this report, we do not attempt to take a view on what contribution Ireland should make to the global goals set out in the Paris Agreement, or the Climate Act: we not attempt to interpret national or European law or international agreements to determine an appropriate carbon budget for Ireland. Instead, five different carbon budgets form the basis of the scenarios we model. It is essential to model cumulative carbon budgets, rather than targets for specific points in time: while the Climate Act sets forth a target of "climate neutrality" by 2050, it is cumulative emissions of long-live GHGs (CO_2 and N_20), as well as the rate of CH_4 emission, which determine overall contribution to global warming, rather than emissions at a given point in time. There are many different approaches to determining equitable efforts under the Paris Agreement [10], which require normative judgements as well as an understanding of the physical science of climate change.

Notwithstanding this caveat, we have developed these five carbon budget scenarios by downscaling the global Remaining Carbon Budget (RCB) as determined by the IPCC AR6 WG1 to Ireland on a per-capita basis. We do not claim that this is an equitable or fair approach to take: we leave this for others to analyse. Recent estimates indicate that GCB is continuing to rapidly reduce – from the beginning of 2023, the RCB for a 50% probability of limiting warming to 1.5°C is estimated to be 250 $MtCO_2$[11]. Inadequate non-CO_2 mitigation exhausts this budget already[12]. The following describes our approach to downscaling the RCB from IPCC for this study.

Table A1 shows the RCB from the beginning of 2020. The values in this table reflect RCBs aligned with 1.5°C to 2°C of global warming, with different likelihoods from 2020. Ireland's RCB is estimated by downscaling global RCBs on a per-capita basis to estimate Ireland's equitable share. This allocation considers population as a key factor. Therefore, Ireland's population share (0.0625% of the global population) is used to generate Ireland's RCBs in Table A2. Since we used carbon budget constraints from 2021, the total actual CO2eq emissions in 2020 (66 million tonnes) are deducted, and Table A3 shows Ireland's RCBs from the beginning of 2021.

Another factor allocates 70% of the carbon budget to Ireland's energy system, to account for CO_2 emissions not captured in our model from land use, land use change and forestry, and international aviation and shipping. The final values in Table A4 show Ireland's energy system RCBs for different temperature rises and with different probabilities. For this study, a range

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[10] Smith (2021) Rapid literature review of the setting of national carbon budgets, framed within the Irish context, with recommendations for Ireland's first and second carbon budgets. https://www.climatecouncil.ie/media/climatechangeadvisorycouncil/Andrew%20Smith%20Carbon%20Budgets%20Literature%20Review.pdf

[11] https://www.nature.com/articles/s41558-023-01848-5

[12] https://www.nature.com/articles/s43247-023-01168-8

of RCBs rounded to 250Mt to 450Mt is used, as highlighted in blue. For instance, the lowest RCB is approximately 250Mt, which aligns with at least a 33% likelihood of limiting global warming to 1.5°C or about a 67% likelihood of limiting global warming to 1.7°C (IPCC AR6 650-700Gt CO2 RCB).

Table (A1) Global carbon budget from the beginning of 2020 (billion tonne) (Source: IPCC AR6 Table SPM.2)

	Probability of meeting temperature target				
Temperature rise	17% Certainty	33% Certainty	50% Certainty	67% Certainty	83% Certainty
1.5 Degrees C	900	650	500	400	300
1.7 Degrees C	1450	1050	850	700	550
2 Degrees C	2300	1700	1350	1150	900

Table (A2) Ireland carbon budget from the beginning of 2020 (million tonne)

	Probability of meeting temperature target				
Temperature rise	17% Certainty	33% Certainty	50% Certainty	67% Certainty	83% Certainty
1.5 Degrees C	563	406	313	250	188
1.7 Degrees C	906	656	531	438	344
2 Degrees C	1438	1063	844	719	563

Table (A3) Ireland carbon budget from the beginning of 2021 (million tonne)

	Probability of meeting temperature target				
Temperature rise	17% Certainty	33% Certainty	50% Certainty	67% Certainty	83% Certainty
1.5 Degrees C	497	340	247	184	122
1.7 Degrees C	840	590	465	372	278
2 Degrees C	1372	997	778	653	497

Table (A4) Ireland's energy system carbon budget from the beginning of 2021 (million tonne)

	Probability of meeting temperature target				
Temperature rise	17% Certainty	33% Certainty	50% Certainty	67% Certainty	83% Certainty
1.5 Degrees C	**348**	**238**	173	129	85
1.7 Degrees C	588	**413**	**326**	**260**	194
2 Degrees C	960	698	544	**457**	**348**

APPENDIX 3: DETAILED MODEL ASSUMPTIONS

KEY PARAMETERS AND MODEL-WIDE ASSUMPTIONS

- Detailed model description described in model documentation paper and model files[13]
- Energy flows are calibrated to 2022 SEAI Energy Balances
- Social discount rate: 2%
- Planning horizon: 2023-50
- The power system modelling follows CAP 2023 targets and capacity outlook from EirGrid for renewable energy sources and for other fuel supply sectors, we use data from SEAI and IEA.
- "Unmitigated emissions": mitigation backstop technology €2000/tonne CO2
- Costs include fuel imports, energy technology investments; exclude infrastructure (including public transport and electricity network investment cost).
- Near-term power generation capacity development limited to those outlined in EirGrid's 2024 Generation Capacity Statement[14]
- Heat pump deployment for existing buildings is only possible after retrofitting the building to a B energy rating

ENERGY SERVICE DEMAND PROJECTIONS

Energy service demand projections	BAU	LED
Non-Energy Mining	-2.9%	-3.0%
Food and beverages	2.2%	-0.2%
Textiles and textile products	3.3%	1.7%
Wood and wood products	0.3%	-1.2%
Pulp, paper, publishing and printing	3.5%	0.5%
Chemicals and man-made fibres	1.2%	-0.8%
Rubber and plastic products	-1.7%	-2.3%
Other non-metallic mineral products	0.9%	-1.7%
Basic metals and fabricated metal products	0.2%	-1.3%
Machinery and equipment n.e.c.	0.5%	-1.2%
Electrical and optical equipment demand	7.9%	2.9%
Transport equipment manufacture	-2.4%	-2.8%
Other manufacturing	0.9%	-0.9%
Construction	6.3%	2.1%
Transport Demand: Short-range passenger travels	1.1%	0.9%
Transport Demand: Medium-range passenger travels	1.4%	-0.1%
Transport Demand: Long-range passenger travels	1.1%	-0.2%
Transport Demand: Goods vehicle for freight	4.2%	-0.4%
Transport Demand: Fuel tourism	-3.1%	-3.1%
Transport Demand: Navigation fuel	5.8%	0.0%
Transport Demand: Unspecified fuel	-3.1%	-3.1%
Transport Demand: Aviation domestic	0.0%	0.0%
Transport Demand: Aviation international	1.1%	0.0%

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[13] Balyk, O. et. al. (2022): TIM: Modelling pathways to meet Ireland's long-term energy system challenges with the TIMES-Ireland Model (v1.0), *Geoscientific Model Development*, https://doi.org/10.5194/gmd-2021-359 https://github.com/MaREI-EPMG/times-ireland-model

[14] Ten-Year Generation Capacity Statement 2023–2032, EIRGRID

Residential Apartment	6.2%	7.0%
Residential Attached	1.1%	1.3%
Residential Detached	0.7%	0.1%
Services - Commercial Services	2.0%	0.4%
Services - Public Services	2.0%	0.4%
Services-Commercial Services: Data centers	23.0%	19.2%
Services-Public Services: Public lighting	0.6%	0.4%
Residential Refrigeration	1.5%	1.2%
Residential Cooking	1.5%	1.3%
Residential Cloth Washing	1.5%	0.7%
Residential Cloth Drying	1.5%	2.6%
Residential Dish Washing	1.5%	2.6%
Residential ELC Appliances	1.5%	0.7%

TABLE 4 ENERGY SERVICE DEMAND PROJECTIONS 2018-2050 AVERAGE ANNUAL CHANGE RATE, %[15]

BIOENERGY DATA ASSUMPTIONS

Feedstock	**Price**	**2020**	**2025**	**2030**	**2035**	**2040**	**2045**	**2050**
	€/MWh	**GWh**	**GWh**	**GWh**	**GWh**	**GWh**	**GWh**	**GWh**
Forestry thinnings	29	59	62	43	22	11	11	11
Forestry thinnings	18	0	3	14	22	34	34	34
Forestry thinnings	17	1,088	1,340	1,549	1,512	1,415	1,163	723
Sawmill residues	16	1,544	1,989	2,451	3,001	3,648	3,648	3,648
Straw	25	7	0	10	10	10	10	10
Straw	15	26	0	37	37	37	37	37
Straw	10	14	0	20	20	20	20	20
Pig slurry	0	500	506	521	521	521	521	521
Residual waste	-47	1,846	1,262	1,018	680	712	732	737
Waste wood	4	75	85	96	107	115	120	122
Waste wood	0	0	0	54	120	130	136	137
Waste wood	-3	170	192	163	120	130	136	137
Industrial food waste	0	36	77	97	97	97	97	97
Food waste	-9	44	69	92	118	127	132	134
Food waste	-36	44	69	92	118	127	132	134
Food waste	-63	87	138	184	235	253	264	268
Used cooking oil	56	49	52	54	55	57	59	60
Used cooking oil	81	49	52	54	55	57	59	60
Tallow	40	323	328	328	328	328	328	328
Tallow	37	175	178	177	177	177	177	177

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[15] LED scenario described in Gaur, A., et. al., (2022) Low energy demand scenario for feasible deep decarbonisation: Whole energy systems modelling for Ireland. *Renewable and Sustainable Energy Transition* https://doi.org/10.1016/j.rset.2022.100024

Tallow	31	350	356	355	355	355	355	355

TABLE 5 SUSTAINABLE DOMESTIC BIOENERGY RESOURCES WITH ASSUMED COSTS[16]

	Cost (€/GJ)	2020	2025	2030	2040	2050
Import of Wood Pellets - Step 1	9.6	1.8	1.8	1.8	3.6	7.2
Import of Wood Pellets - Step 2	9.6	0	3.6	18	54	61.2
Import of Wood Pellets - Step 3	10.2	0	0	54	54	54
Import of Wood Pellets - Step 4	11.2	0	0	0	36	36

TABLE 6 WOOD PELLET IMPORT LIMITATIONS, PJ16[16]

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[16] Sustainable Bioenergy for Heat: Spatial Assessment of Resources and Evaluation of Costs and Greenhouse Gas Impacts, Report 7 of the National Heat Study, SEAI

CBWG Meeting 15 Submissions

Document Number	Document Name	Link
15.15	Jackson and Kelleher (2023) “Ireland’s Second-Generation Climate Act: Still Playing the Laggard During the Climate Crisis?” Irish Jurist 283: 283-321	Ireland's Second-Generation Climate Act: Still Playing the Laggard during the Climate Crisis? Special Edition: Law in a Time of Crises 70 Irish Jurist 2023