Quantifying the Net Carbon Dioxide Emissions Impact of Electricity Interconnectors flows for Ireland and the All-Island system for 2024

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Case Report

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Abstract

As Ireland works towards ambitious climate targets, the role of electricity imports via interconnectors has become an increasingly significant part of the electricity mix. While domestic power generation emissions are reported in national emissions inventories, the emissions embedded in imported electricity remains unreported under current accounting methods, potentially distorting perceptions of national progress. This study aims to quantify the carbon emissions impact of Ireland's interconnectors in 2024. To do this, the quantity of carbon embedded in imported electricity is found and compared with a counterfactual scenario, in which electricity imports are replaced by domestic generation, evaluating whether interconnection resulted in a net environmental benefit. The analysis includes imports through the Moyle Interconnector to Northern Ireland, the East–West Interconnector to the Republic of Ireland, and flows into the Republic via the North–South tie-line. Quarter-hourly data on carbon intensities and interconnector flows are used, allowing for emissions to be attributed on a time-sensitive basis rather than relying on annual grid averages. Findings indicate that interconnector imports abated over 634 thousand tonnes of CO_2 across the island of Ireland, and over 481 thousand tonnes of CO_2 for the Republic alone, when compared to domestic generation alternatives. Thus, electricity imports were found to be a net environmental benefit in 2024. However, these imports still carried a substantial carbon footprint, highlighting the need for clarity in emissions reporting frameworks.

1 Introduction

1.1 Background and Motivation

Ireland is undergoing a major energy transition, with national goals to significantly reduce carbon emissions and achieve net zero by 2050 [1]. The 2024 Climate Action Plan [1] has set highly ambitious targets for the power sector to limit greenhouse gas emissions to 40 million tonnes of CO_2eq across the time frame 2021 to 2025. While renewable capacity has increased in recent years, the system remains heavily reliant on gas-fired generation, with emissions reductions slower than expected. By the end of 2023, 69% of the electricity sector's 40 million tonne carbon budget for the 2021–2025 period had been used [2]. Notably, a significant fall in electricity sector emissions in 2023 was largely attributed to a rise in electricity imports, which are currently treated as zero-emissions under national reporting. According to the SEAI's 2024 Energy in Ireland report [3], 9.5% of Ireland's electricity supply came from net imports in 2023, with this figure expected to have risen to 14% in 2024. Despite this trend, the regional environmental impact of imported electricity has received limited attention in analysis. In this context, the role of interconnectors in supporting, or potentially undermining, emissions reduction efforts warrants closer investigation.

GHG emissions are generally estimated and evaluated at the point of production, using the so-called production-based accounting method. EU level and Irish level emissions targets are set using this approach and hence policy often focusses on this assessment of emissions. This means that electricity imported from Great Britain or Northern Ireland is recorded as zero-carbon, regardless of the source from which it was produced. This research was motivated by a need for greater understanding around the regional emissions impact of Ireland's electricity imports, particularly as they become an increasingly central part of the electricity mix. The goal of this research is therefore to quantify the emissions embedded in imported electricity and whether, from a climate perspective, interconnector usage is aiding Ireland's decarbonisation goals.

1.2 Research Objectives

The objective of this research is to determine whether electricity imports to Ireland via interconnectors in 2024 represent a net environmental benefit or simply shift emissions to the UK. To achieve this, the following objectives were established:

- Objective 1: Quantify the carbon emissions embedded in imported electricity to both the Republic of Ireland and the All-Island system using real-time carbon intensity data and interconnector flow records.
- Objective 2: Construct counterfactual scenarios for both the All-Island and Republic of Ireland electricity systems in which imported electricity is replaced by domestic generation, in order to estimate the emissions that would have occurred without interconnector imports.
- Objective 3: Assess the emissions abatement enabled by interconnection, specifying how much emissions were avoided via the Moyle and East–West Interconnectors for the All-Island system, and via the Tie-Line and East–West Interconnector for the Republic of Ireland.

1.3 Paper Structure

This paper is organized as follows:

- Section 2 presents a contextual background, including Ireland's climate commitments, legislative frameworks, and interconnection network.
- Section 3 reviews relevant literature on emissions quantification methodologies.
- Section 4 details the procedures employed for data acquisition, processing, and analysis, as well as the calculation methodologies used to quantify emissions.
- Section 5 presents the core results and analysis, divided into findings for the All-Island and the Republic of Ireland specifically.
- Section 6 discusses the implications of the findings, including emissions impacts, interconnector strategy, and policy recommendations.
- Section 7 concludes the report by summarising the key findings.

2 Contextual and System Background

2.1 Ireland’s Climate Commitments and Challenges

2.1.1 Climate Action Plan Overview

There is broad scientific consensus that ongoing greenhouse gas emissions from the burning of fossil fuels will drive further global warming, with projections indicating temperature increases of 1.5°C compared to pre-industrial levels in the near future [1]. Ireland’s Climate Action Plan (CAP24) details that 2023 was Ireland’s warmest year on record, with average air temperatures reaching 11.2°C, which is 1.6°C higher than the 1961-1990 long-term average. In essence, CAP24 represents the government’s policy framework for achieving the nation’s climate objectives. These objectives include significant greenhouse gas (GHG) reductions and the transition to a low-carbon, sustainable economy. The first CAP was introduced in 2019 and has since been revised annually. The report reflects a dynamic approach, aligning with national and international climate commitments, with the primary objective being to reduce GHG emissions in Ireland by 51% between 2018 and 2030, and reach net-zero emissions by 2050. All goals in the CAP are created in relation to the base year of 2018.

2.1.2 Electricity Sector Emission Ceilings

On the 28th of July 2022, the Irish Government approved Sectoral Emission Ceilings [4], which set maximum allowable GHG emissions for each sector of the economy through to 2030. These ceilings operate within the framework of Ireland's carbon budgets and are designed to achieve the 51% reduction in emissions by 2030 (relative to 2018 levels) and net-zero emissions by 2050, as outlined in CAP24. The ceilings apply to each sector and aid in the quantification of emissions abatement aforementioned. Each sector is assigned a specific emissions reduction target necessary to remain within its ceiling. For the electricity sector this means achieving a 75% reduction in emissions by 2030 compared to 2018 levels. The primary measure of each sectorial ceiling is in million tonnes of carbon dioxide equivalent ($MtCO_2$-eq). This common unit allows for the comparison of the potential warming impact of GHGs across different sectors.

The electricity sector ceilings outlined in CAP 24 [1] and further expanded upon in the analysis report for the preparation of the ceilings [4], mandate that GHG emissions be limited to 40 $MtCO_2$-eq between 2021 and 2025, and 20 $MtCO_2$-eq between 2026 and 2030. This corresponds to a 40%

decrease by 2025, and a 75% decrease by 2030, when compared to 2018 electricity sector emissions. This would involve yearly emissions falling to approximately 6 $MtCO_2$-eq per year by 2025 and approximately 3 $MtCO_2$-eq per year by 2030. The extent of this reduction can be seen in **Error! Reference source not found.**:

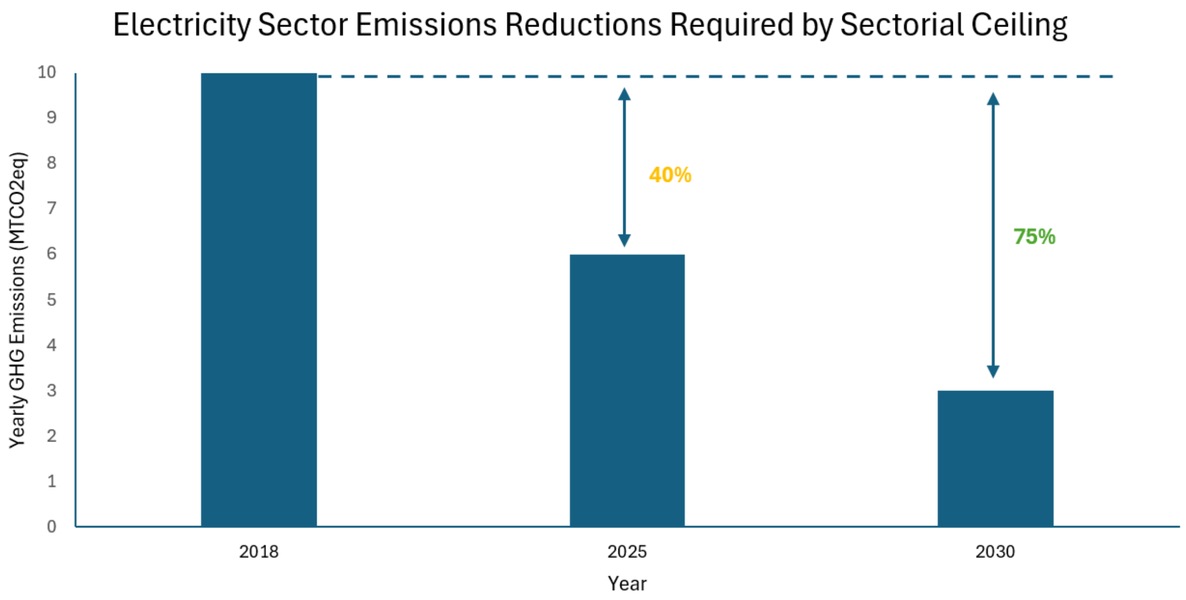

Figure 1: Yearly Emissions Reductions Needed for Irish Electricity Sector to Stay within its budget.

2.2 Geographic and Energy System Context

2.2.1 Current Interconnection Network

The Republic of Ireland currently has three operational electricity interconnectors, the East-West Interconnector (EWIC), Moyle interconnector, and the Greenlink Interconnector, all of which are connected to Great Britain. There is also a "tie-line" between the Republic of Ireland and Northern Ireland, which is not technically classed as an interconnector due to the single electricity market. The approximate locations of these lines can be seen in Figure 2. These interconnectors enable bidirectional electricity flows, allowing for both imports and exports between Ireland and the UK. In this paper, power flows associated with the Greenlink Interconnector are not considered, as it became operational in early 2025, which was subsequent to the data acquisition phase of this project.

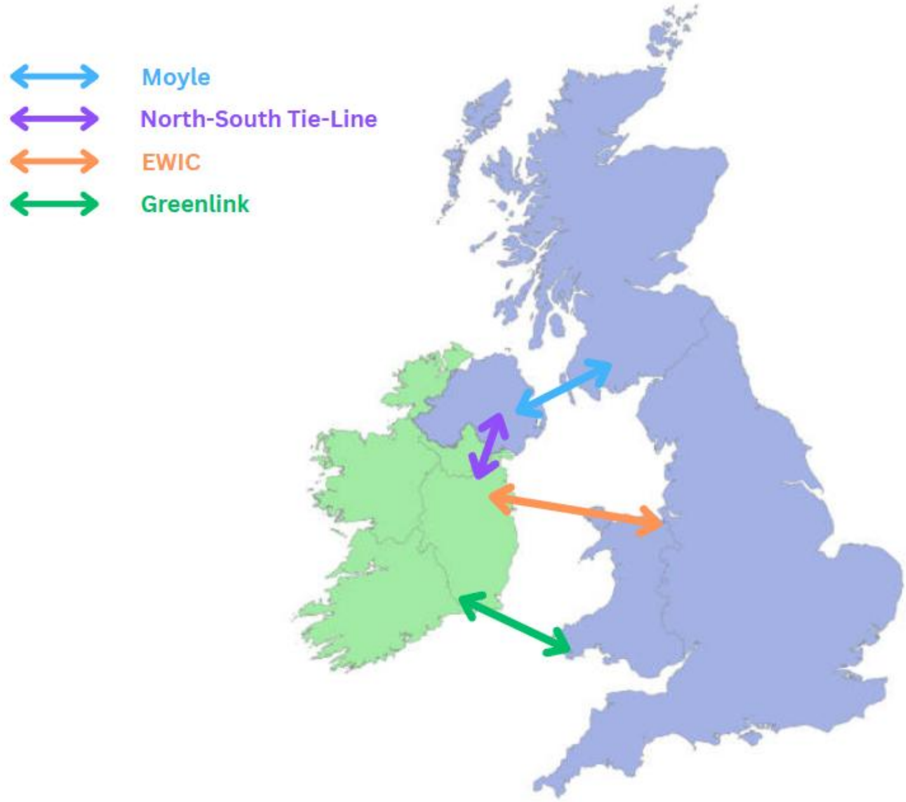

Figure 2: Approximate Locations of Irish Electrical Interconnectors

2.2.1.1 East-West Interconnector (EWIC)

The EWIC is a high-voltage direct current (HVDC) subsea cable connecting the electrical power grids of the Republic of Ireland and Great Britain. The EWIC has been fully operational since December 2012 and has a power rating of 500 MW. This made it one of the largest HVDC systems utilising voltage source converter technology at the time of construction [5]. The 260 kilometre (km) long cable is publicly owned by Eirgrid Interconnector Limited and runs from Portan in Ireland to Shotton in Wales. The EWIC has been the ROI's sole electricity interconnection with Great Britain (GB) since 2012, with the energisation of the Greenlink interconnector changing this in early 2025. Since its introduction, the EWIC has facilitated significant electricity flows between the ROI and GB.

2.2.1.2 Moyle Interconnector

Similarly to the EWIC, the Moyle Interconnector is a 500 MW HVDC submarine link [6]. The cable connects the electricity networks of Northern Ireland and Scotland. It runs between the Ballycronan More substation in Islandmagee, NI, and the Auchencrosh substation in Ayrshire, Scotland. The line is owned and operated by Mutual Energy. The Moyle combined with the EWIC therefore provide a total of 1 GW in import capacity for the Island of Ireland.

2.2.1.3 North-South Tie-Line

Publicly available data on the North–South tie-line is limited. Currently, it is the sole transmission line connecting NI and ROI, forming the backbone of the all-island Single Electricity Market (SEM). While the tie-line was primarily designed for grid balancing and frequency management, as will be discussed in the results, it has increasingly been used to facilitate electricity imports into the Republic in recent years. Although technical details remain difficult to obtain, EirGrid's 2024 System Data Report [7] indicates that the tie-line reached a maximum recorded flow of 508 MW in 2024. A detailed analysis of tie-line flows and their implications will be presented in the ROI results section of this paper.

2.2.1.4 Greenlink Interconnector

As of the start of 2025, the new Greenlink interconnector has been commercially operational. Similarly to the EWIC, Greenlink is a 500 MW HVDC cable, running from Great Island substation in Co. Wexford to Pembrooke substation in Wales [8]. The interconnector is 200 km long, 160 km of which are under the sea. Unlike the EWIC, the Greenlink interconnector is privately owned and operated by Greenlink Interconnector Limited. Electricity flows through Greenlink will not be considered under the scope of this paper.

2.3 Current Energy Landscapes

2.3.1 Domestic Electricity Generation Mix

In order to understand the potential carbon emissions avoided through interconnection, the electricity generation mix in Ireland must first be investigated. On average, the carbon intensity of domestically generated electricity has fallen steadily over the past two decades. According to SEAI data, the carbon intensity of domestic generation fell by 60% between 2005 and 2023 [3]. This has been illustrated in Figure 3 using the SEAI data [9].

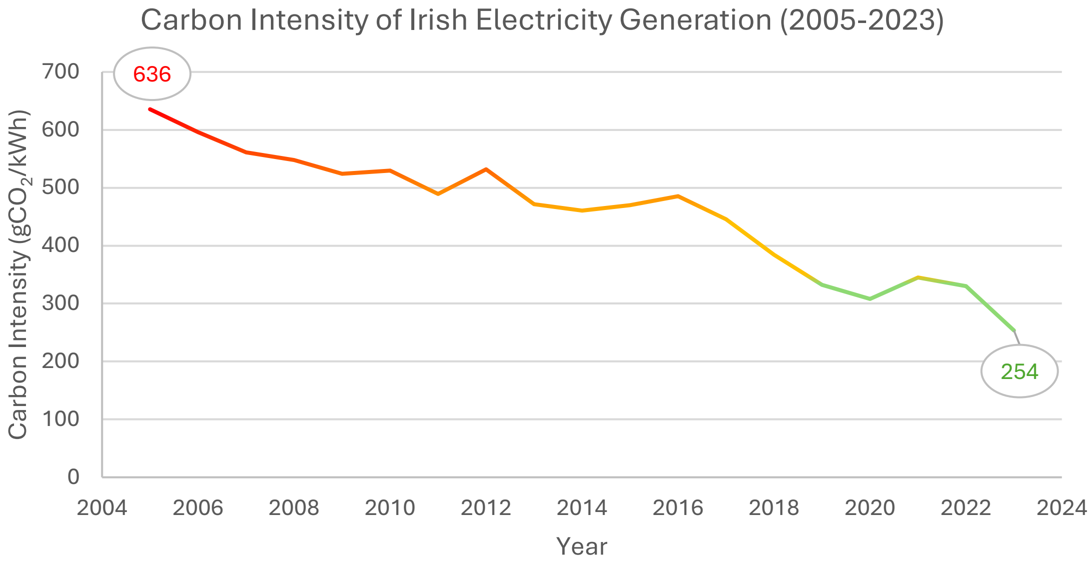

Figure 3: Reduction in the Carbon Intensity of Irish Electricity Generation Between 2005 and 2023

This substantial reduction in carbon intensity has been largely attributed to decreased use of fossil fuels such as coal and oil, increased renewable electricity via wind production, and in more recent years, a greater reliance on imports through interconnection. To understand this reduction, the trends in each category will be discussed.

Fossil Fuel Generation: Since the inception of the state in 1922, Ireland's electricity system has gone through several energy transitions. This transition is outlined in detail by Gaffney et al.'s "100 Year Review of Irish Electricity Policy" [10]. The paper details how Ireland transitioned from a system powered mainly through hydro-electric power and peat in the early years of the state to a system heavily reliant on oil in the 1970's. Concerns over security of supply relating to oil caused the state to switch to a system largely powered through natural gas and coal from the 1980's onwards. As can be seen in Figure**,** which has been created using data from the International Energy Agency's (IEA) website regarding Ireland [11], at the turn of the 21st century Ireland's electricity supply was still predominantly reliant on fossil fuels, with a combined 94% of generation coming from coal, oil, and natural gas. Due largely to the substantial investment in wind energy over the following two decades, the proportion of coal, oil and gas fell to 54% of national generation by 2023. As can be seen in Figure, this involved an 84% reduction in generation using coal and a 95% reduction in generation using oil. Notably, natural gas generation increased by approximately 67% over this period, rising quickly in the early 2000's but remaining relatively stable since then.

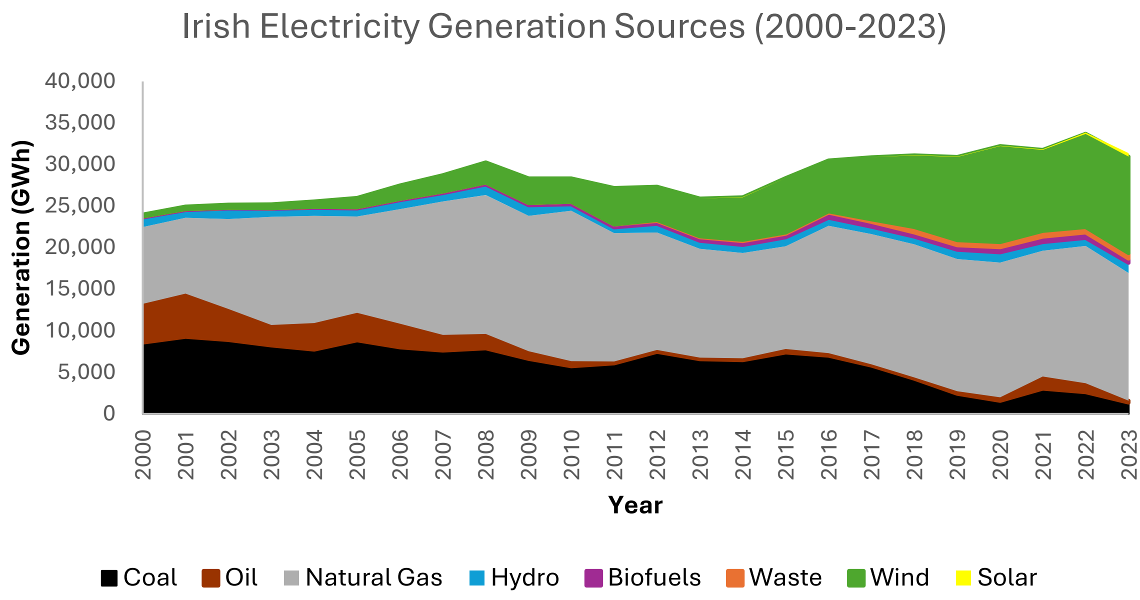

Figure 4: Irish Electricity Generation Sources Mix Between 2000 & 2023 [10]

Renewable Generation:

Ireland's electricity generation has undergone an unusual transition over the last century. Unlike most countries, Ireland's electricity system was initially dominated by renewables, with the hydroelectric power from Ardnacrusha providing enough power to meet 100% of national demand at the time of the ESB's foundation [10]. Over the following decades there was a shift towards a fossil fuel-based system, which remained until the 21st century, in which we have seen a transition back towards renewables once more, where the electricity system began.

Imports/Exports: The introduction of the EWIC in 2012 marked a significant shift in Ireland's electricity system, enabling substantial cross-border electricity trade. While imports and exports fluctuated over the years, with some prolonged periods of importation, for example 2013 to 2015 as can be seen in Figure 5 from the SEAI's 2024 Energy in Ireland Report [12], the last two years have seen a clear and sustained increase in electricity imports. According to the same report, net-imported electricity accounted for 9.5% of Ireland's total electricity supply in 2023, while the SEAI provisionally estimated that this will rise to approximately 14% in 2024, indicating an increasing dependency on electricity imports. This trend highlights the importance of understanding the carbon impact of electricity imports in making informed policy decisions.

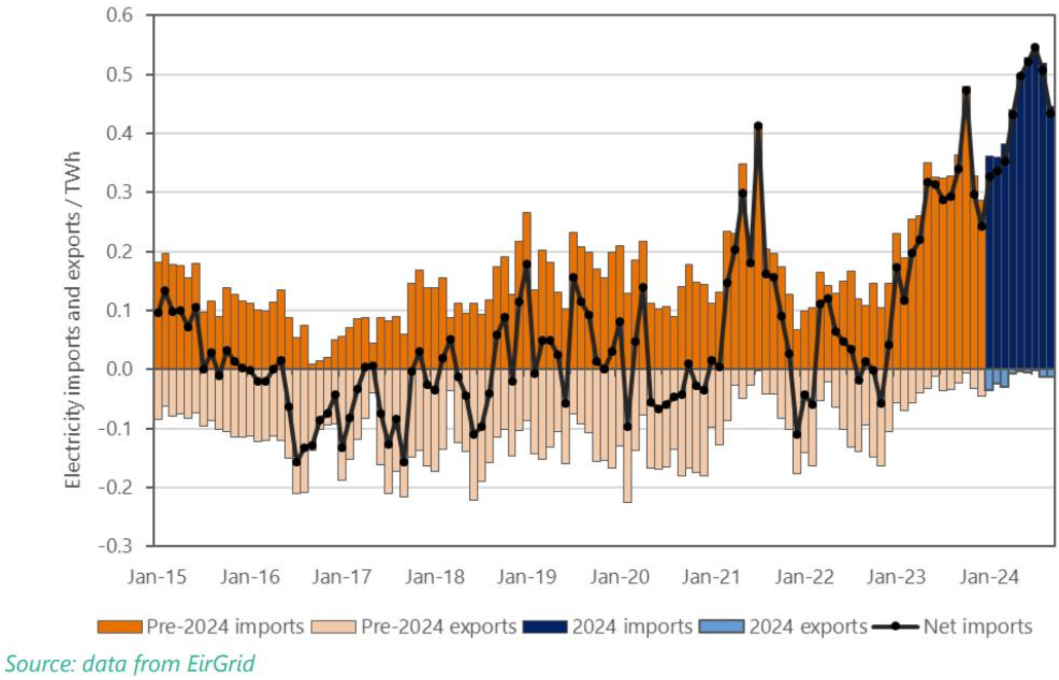

Figure 5: Monthly Net Imports/Exports of Electricity for Ireland from 2010 to 2024 (Source: SEAI 2024 energy in Ireland [12])

2.3.2 UK Electricity Generation Mix

A synopsis of the UK's historical electricity mix is outlined in McGarry's 2023 report for the Department from Energy Security & Net Zero [13]. Similarly to Ireland, the UK's electricity generation mix has evolved significantly over the past century. The UK's electricity mix was coal dominated for more than half a century. In fact, almost all electricity was supplied using coal until the 1950's. This can be seen in Figure , taken from McGarry's report. At the beginning of the 1990's, the Uk's electricity mix was significantly different to Ireland's, with a large reliance on domestic coal and nuclear. However, since then the UK has seen a similar transition to natural gas and renewables as Ireland, with coal generation falling below 1930 levels by 2020 [14].

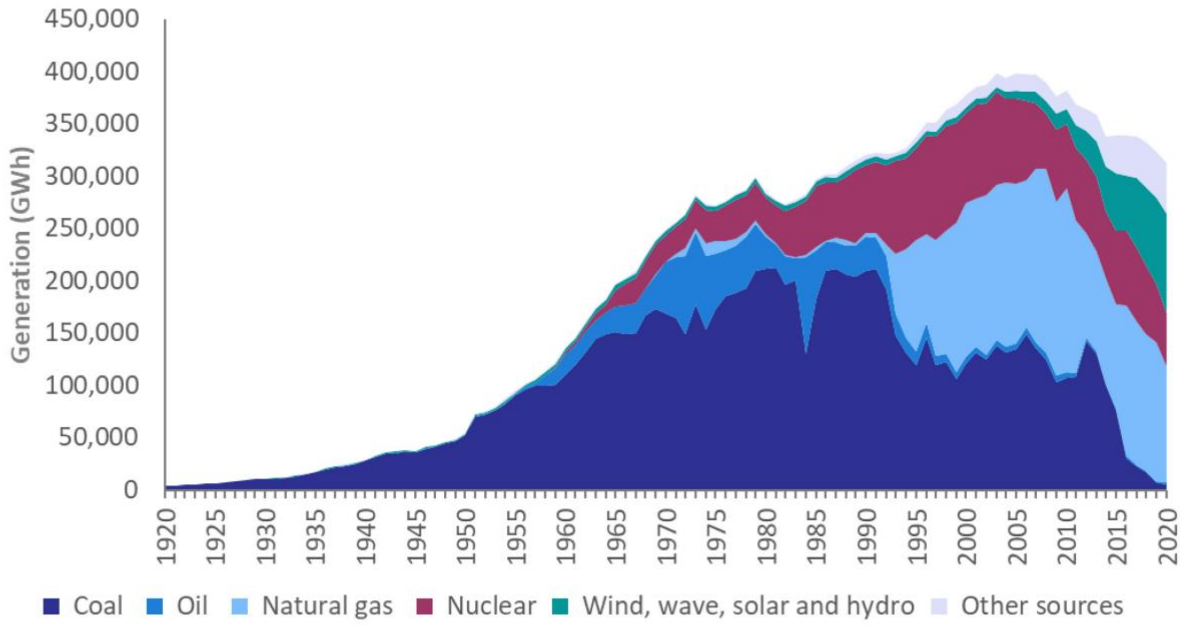

Figure 6: UK Electricity Generation Sources Mix Between 1920 & 2020 [13]

3 Literature Review

3.1 Quantification of Carbon Emissions from Electricity

Quantifying the specific carbon emissions associated with electricity generation is a difficult task, especially in relation to interconnection. Due to the dynamic and variable nature of power systems, carbon intensity often varies significantly over time. It is therefore important that a precise methodology is chosen for this report, ensuring accurate emissions accounting. Numerous studies have been published attempting to accurately account for these emissions.

Rüdisüli et al.'s 2022 paper [14] evaluated the embedded emissions in Swiss electricity imports. Rüdisüli employs a marginal emissions model using hourly data to assess the GHG emissions from Switzerland's electricity imports. This marginal model differs from conventional approaches that assume imported electricity has the same emissions intensity as the exporting country's average grid mix. The model estimates hourly marginal emissions by identifying the specific power plants that ramp up production to meet the demand of Swiss imports. As outlined by Rüdisüli, the GHG intensity of these imports varied significantly, with peak emissions intensity coming from sources such as blast furnaces in Germany. While the approach outlined in the paper accurately traces electricity import flows and their marginal emissions, the required dispatch information needed for this report was not available for this study. For this reason, marginal emissions tracing will not be implemented in this study of Ireland, but instead accurate granular grid emissions factors from the UK will be used. This time-accurate method aims to ensure a practical, yet reliable estimation of Ireland's electricity import emissions. While this method may slightly underestimate emissions by not isolating marginal generation, it aims to provide a consistent and replicable approach given current data constraints.

Another study highlighting the critical role of using accurate granular data in emissions calculations is the hourly accounting method proposed by Miller et al. [16]. The study demonstrates the potential for traditional annual average-based carbon accounting to miss variations in electricity generation emissions, leading to miscalculations in emissions attribution. Miller's report investigates the discrepancies between the use of annual averages and hourly data, through the study of thousands of residential, commercial, industrial, and agricultural facilities in the US. The report finds that using average carbon emissions factors can misestimate carbon emissions by up to 35% in some cases, and very little in other cases [16]. This variation can be seen in Figure , taken from Miller's report. As mentioned by Miller, this fluctuation is caused by several variables such as regional carbon intensity and changeable consumption patterns. Ultimately, Miller et al. argue that hourly data should be used to more accurately account for the carbon emissions from electricity consumption.

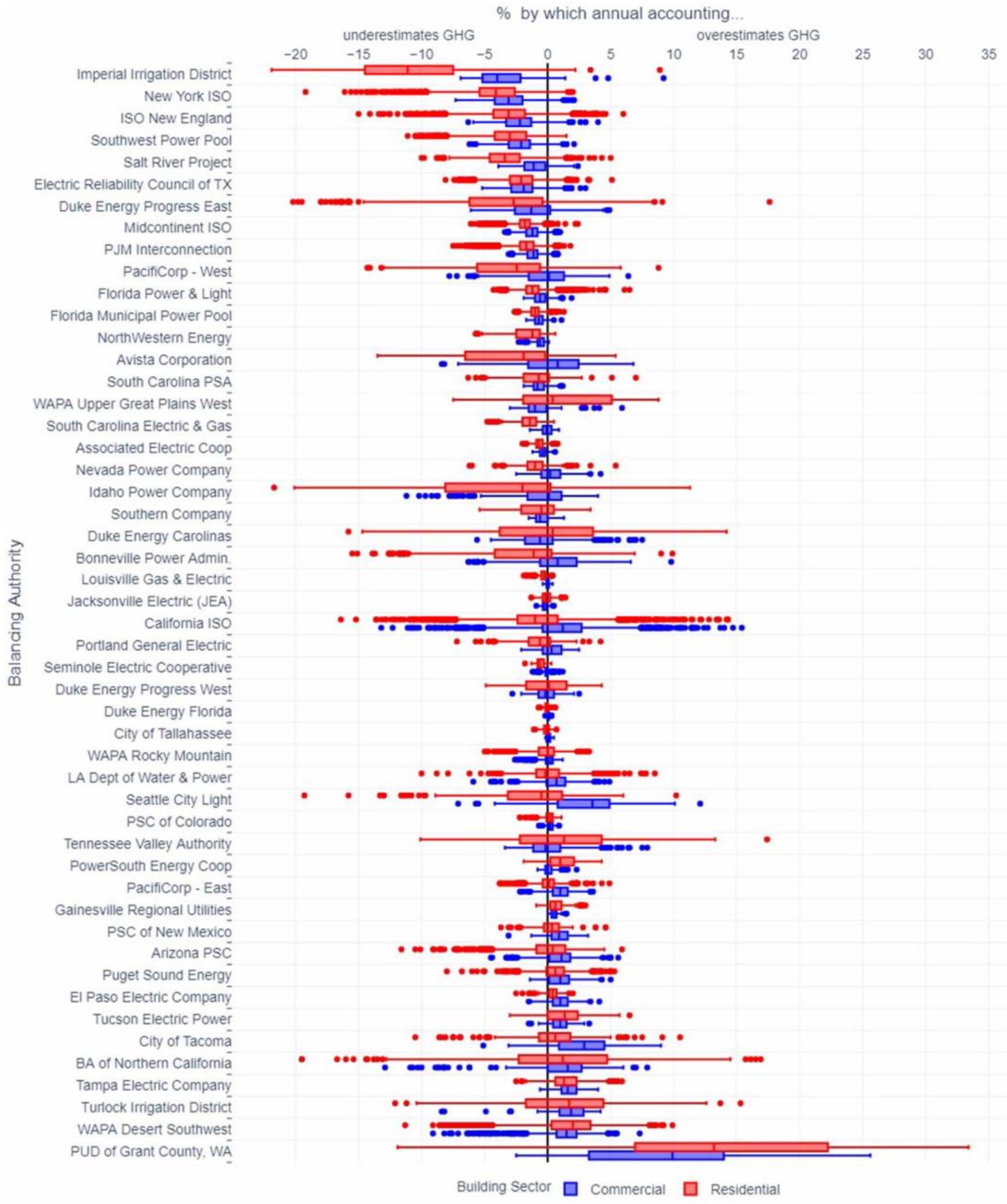

Figure 7: Box plots show the bias from annual vs. hourly carbon accounting across grid regions for residential and commercial buildings [16]

A comprehensive review of the various methods to quantify carbon emissions from the electricity sector is outlined in Khan's 2019 paper titled "*Greenhouse gas emission accounting approaches in electricity generation systems: A review*" [17]. The study highlights the limitations of common methods used currently such as life cycle assessment (LCA) and absolute emissions. Khan argues that none of the present methodologies are well suited for GHG accounting. Kahn cites evidence that GHG emissions can vary considerably according to the time of day or season [18], which thus makes current methodologies inadequate. Ultimately, although difficult to implement, Kahn recommends the further investigation and use of time-varying approaches to better capture temporal variations. Especially, as grids integrate more renewables, time-varying carbon intensity analysis is identified as a useful and accurate method.

Considering this analysis, we have chosen to use quarter-hourly carbon intensity data for the UK and Irish grids for this analysis to provide a more precise representation of emissions. As explained in Miller and Khans respective analysis, this approach better captures the temporal variation of emissions from electricity generation, ensuring that variations in fossil fuel and renewable contributions are accurately reflected. Using this accurate granular data helps to avoid the oversimplifications made by the average emissions estimates mentioned, offering a more reliable assessment of the true carbon footprint associated with Ireland's electricity imports.

4 Methodology

4.1 Data Acquisition & Sources

The analysis completed in this report focus primarily on 2024, with high-resolution, granular data available for all necessary criteria. Thus, several datasets were compiled to quantify the emissions impact of the interconnectors over this period:

Carbon intensity data for the ROI was obtained from EirGrid's real-time system information portal [19]. UK carbon intensity data was retrieved from the National Energy System Operator's (NESO) generation mix and carbon intensity report [20] . Interconnector flow data for 2024, including the EWIC and the Moyle, was obtained via EirGrid's 2024 Historical Quarter-Hourly System Data report [21] . This report also details flows across the North-South Tie Line, as well as generation and demand data for the ROI and NI.

To provide broader historical context, a supplementary historical dataset was compiled covering the period from January 2016 to October 2024. This was used to provide context on long-term trends in interconnector usage and carbon intensities. Carbon intensity data for Ireland was again found using EirGrid's System Dashboard [19], while NESO's archive was again used to determine GB carbon intensity data over the same period [20]. Due to limitations in EirGrid's interconnector dashboard (which only provides data from April 2024 onward), historical hourly flow data for the EWIC and Moyle was instead collected from ELEXON's Interconnector Flow Portal [22].

4.2 Data Handling & Processing

4.2.1 EirGrid Data Scraping

To obtain carbon intensity data for the ROI and NI, a custom Python script was developed to collect information from EirGrid's real-time system dashboard, as no historical archive is made available for download. The script used the requests library to send automated daily queries to EirGrid's underlying API and extracted the relevant data from the JSON responses. Timestamps and carbon intensity values were captured for each entry and compiled using the Pandas library into a structured dataset. This process was repeated iteratively, covering every day from January 1st, 2024, to December 31st , 2024. Once complete, the final dataset was exported to CSV format for further processing. This process was repeated to find granular carbon intensity data for the ROI, NI, and the Island as a whole. This same methodology was used to find Irish carbon intensity data from 2016 to 2024 subsequently.

4.2.2 UTC to GMT Conversions

As part of the data preparation process, it was necessary to align all data to a standard time. All EirGrid data was provided in local Irish time, which alternates between Greenwich Mean Time (GMT) and Irish Standard Time (IST) depending on the time of year, changing due to daylight savings. Conversely, both NESO's and ELEXON's datasets are timestamped in Coordinated Universal Time (UTC), meaning they do not reflect daylight savings. To ensure consistency across all data sources, all timestamps were converted to local Irish time. This involved accounting for daylight saving transitions in the NESO and ELEXON data. The exact daylight saving changeover dates and times were retrieved [80] and coded into a Python script, which correctly adjusted the UTC timestamps into either GMT or GMT+1, depending on the date and time. This ensured that all data could be directly compared and merged without misalignment due to time zone formats.

4.2.3 DateTime Alignment

After aligning time zones, all datasets were standardised to a common 15-minute interval. This resolution was chosen as most EirGrid data is provided at quarter-hourly frequency, including data on generation, demand, carbon intensity, and interconnector flows. For datasets with a lower resolution, such as NESO's half-hourly UK carbon intensity data and EirGrid's half-hourly dispatch down reports, forward-filling was applied to generate intermediate 15-minute values.

This approach preserved the integrity of the original data while aligning it with other data. In contrast, ELEXON's interconnector flow data, reported at five-minute intervals, was reduced to quarter-hourly resolution by retaining only the values at minutes 00, 15, 30, and 45, removing all other entries. This process ensured that all datasets were aligned to a consistent 15-minute interval, allowing for accurate comparison of all criteria.

4.2.4 Unit Conversions

Once all datasets were aligned to a common 15-minute resolution, power values were converted from MW to energy values in megawatt-hours (MWh) to allow for direct comparison with carbon intensity metrics. This was done by dividing each MW value by four to account for the quarter-hourly data frequency. Carbon intensities for all regions were also converted from grams of $C0_2$ per kilowatt-hour (gCO_2/kWh) to tonnes of CO_2 per megawatt-hour (tCO_2/MWh), enabling simplified emissions quantification.

4.2.5 Data Validation

To ensure the accuracy and integrity of the processed datasets, extensive validation was carried out at multiple stages. Wherever possible, values were cross-referenced against original dashboards and alternative data sources. For example, EirGrid's quarter-hourly system data was compared against its real-time dashboard, while interconnector flows were validated bidirectionally between EirGrid's reports and ELEXON's Portal. UK carbon intensity data from NESO was also checked against the UK's official Carbon Intensity API [23], with results found to be fully aligned. In addition to these external comparisons, internal consistency checks were conducted following each step of the data handling and processing mentioned earlier. After all preprocessing steps were completed, each criterion was reviewed against the original sources to ensure no discrepancies had been introduced during cleaning. This ensured the consistency and reliability of all data used in the analysis.

4.3 Calculation Methodology

4.3.1 All-Island Analysis

4.3.1.1 Emissions Embedded in EWIC & Moyle Imports

To estimate emissions from imports, quarter-hourly EWIC and Moyle flow data were multiplied by the GB grid carbon intensity at each corresponding time. This was summed to find the cumulative emissions associated with electricity imported to the island of Ireland via these interconnectors. Only positive (import) flows were included, with negative values excluded to avoid offsetting imported emissions with domestic exports. A national average GB intensity was applied to both interconnectors, as the specific origin of electricity within the UK was unknown.

$$E_I^{AI} = \sum_t I_{GB} \times \left[{F_{EWIC}}^{+} + {F_{MOYLE}}^{+} \right] \tag{1}$$

Where:

- All variables are evaluated at time t
- E_I^{AI} is the combined carbon emissions of the EWIC and Moyle imports (tCO_2)
- I_{GB} is the GB carbon intensity (tCO_2/MWh)
- ${F_{EWIC}}^{+}$ is the positive energy flow (imports) through the EWIC (MWh)
- ${F_{MOYLE}}^{+}$ is the positive energy flow (imports) through the Moyle (MWh)

Note: x^{+} denotes the positive value of x (i.e. value has a bottom bound of zero)

4.3.1.2 Counterfactual Emissions from Domestic Generation

To assess the emissions that would have occurred in the absence of interconnector imports, a counterfactual scenario was created in which imported electricity was instead generated domestically. It was assumed that this electricity would have been produced at the average carbon intensity of the all-island system at each time step. The domestic counterfactual emissions were calculated as:

$$E_D^{AI} = \sum_t I_{AI} \times \left[{F_{EWIC}}^{+} + {F_{MOYLE}}^{+} \right] \tag{2}$$

Where:

- All variables are evaluated at time t
- E_D^{AI} is the combined carbon emissions of domestic generation replacing EWIC and Moyle imports (tCO_2)
- I_{AI} is the all-island carbon intensity (tCO_2/MWh)

4.3.1.3 Emissions Abated by Interconnectors

The emissions abated for the Island of Ireland through the use of interconnectors was calculated as the difference between the emissions that would have occurred from domestic generation and those embedded in imported electricity. This was done for each time step and summed over the year:

$$E_A^{AI} = \sum_t E_D^{AI} - E_I^{AI} \tag{3}$$

Where:

- E_A^{AI} is the combined carbon emissions abated by the Moyle and EWIC interconnectors (tCO_2)

4.3.2 Republic of Ireland Analysis

4.3.2.1 Emissions Intensity of Tie-Line Imports

To estimate the carbon intensity of electricity imported into the ROI via the North–South tie-line, a weighted average approach was used. At each time step, the Moyle interconnector flow and NI's generation surplus (generation minus demand) were used to calculate the relative contributions of each to tie-line imports. These were then weighted by their respective carbon intensities, to derive the blended tie-line intensity. All negative values were clipped to zero to ensure only Moyle imports and NI generation surplus' were considered. The resulting value represents the time-varying emissions intensity of tie-line imports into the ROI:

$$I_{TL} = I_{GB} \times \left[\frac{{F_{MOYLE}}^+}{(G_{NI} - D_{NI})^+ + {F_{MOYLE}}^+}\right] + I_{NI} \times \left[\frac{(G_{NI} - D_{NI})^+}{(G_{NI} - D_{NI})^+ + {F_{MOYLE}}^+}\right] \tag{5}$$

Where:

- All variables are evaluated at time t
- I_{TL} is the blended carbon intensity of tie-line imports to ROI (tCO_2/MWh)

- I_{NI} is the NI carbon intensity (tCO_2/MWh)
- G_{NI} is NI generation (MWh)
- D_{NI} is NI Demand (MWh)

4.3.2.2 Emissions Embedded in EWIC & Tie-Line Imports

To quantify the emissions associated with imported electricity to the ROI, flows through the EWIC and North–South tie-line were assessed independently. For EWIC, positive (import) flows were multiplied by the GB carbon intensity at that time, while for the tie-line, imports were multiplied by the time dependent tie-line carbon intensity calculated in Section 4.3.2.1. Negative or reverse flows were excluded from both calculations. The total embedded emissions were then found by summing both sources over time, yielding a cumulative estimate of the carbon content of all electricity imported into the ROI:

$$E_I^{ROI} = \sum_t \left(I_{GB} \times F_{EWIC}{}^{+}\right) + \left(I_{TL} \times F_{TL}{}^{+}\right) \tag{6}$$

Where:

- All variables are evaluated at time t
- E_I^{ROI} is the combined carbon emissions of the EWIC and Tie-Line imports (tCO_2)
- I_{TL} is the Tie-Line carbon intensity (tCO_2/MWh)
- $F_{TL}{}^{+}$ is the positive energy flow (imports) through the Tie-Line (MWh)

4.3.2.3 Counterfactual Emissions from Domestic Generation

To estimate the emissions that would have occurred in the absence of imports, a counterfactual scenario was developed where the imported electricity was instead generated domestically within the Republic of Ireland. At each time interval, the combined volume of EWIC and tie-line imports was multiplied by the ROI's carbon intensity. This produced an estimate of the emissions that would have been associated with meeting the same demand using local generation, serving as the baseline for calculating abatement:

$$E_D^{ROI} = \sum_t I_{ROI} \times \left[F_{EWIC}{}^{+} + F_{TL}{}^{+}\right] \tag{7}$$

Where:

- All variables are evaluated at time t
- E_D^{ROI} is the combined carbon emissions of domestic generation replacing EWIC and Tie-Line imports (tCO_2)

4.3.2.4 Emissions Abated by Interconnectors

The emissions abated for the ROI through the use of the EWIC and tie-line was calculated as the difference between the emissions that would have occurred from domestic generation and those embedded in imported electricity. This was done for each time step and summed over the year:

$$E_A^{ROI} = \sum_t E_D^{ROI} - E_I^{ROI} \tag{8}$$

Where:

- E_A^{ROI} is the combined ROI carbon emissions abated by the EWIC and Tie-Line (tCO_2)

4.4 Tools & Software

All datasets were stored and managed in Excel workbooks, which were used for data collection, organisation, and some calculations. Using Google Colab, Python was used for handling data-intensive tasks and generating graphs that would have been impractical to produce in Excel. Calculations were carried out using a combination of Excel and Python, depending on the scale and complexity involved.

5 Results and Analysis

5.1 All-Island Results

5.1.1 Carbon Intensity Trends

Electricity imported from GB was consistently cleaner than that generated on the island of Ireland throughout 2024. GB recorded an annual average carbon intensity of 124 gCO_2/kWh, typically remaining between 100 gCO_2/kWh and 150 gCO_2/kWh across all hours of the day, as shown in Figure . In contrast, generation in the ROI and the all-island ranged on average between 200 gCO_2/kWh and 250 gCO_2/kWh during most hours, with a yearly average of 216 gCO_2/kWh for ROI. Northern Ireland recorded the highest overall intensity, averaging 250 gCO_2/kWh, with periods such as 04:00 averaging up to 326 gCO_2/kWh.

Monthly variations in intensity, shown in Figure , reflect similar trends. GB remained the cleanest producer throughout the year, dipping to a low of 92 gCO_2/kWh in April. NI and ROI exhibited seasonal peaks during summer months, likely due to reduced wind generation. ROI remained cleaner than NI overall, though from October to December, NI outperformed ROI, reaching a monthly low of 167 gCO_2/kWh in December.

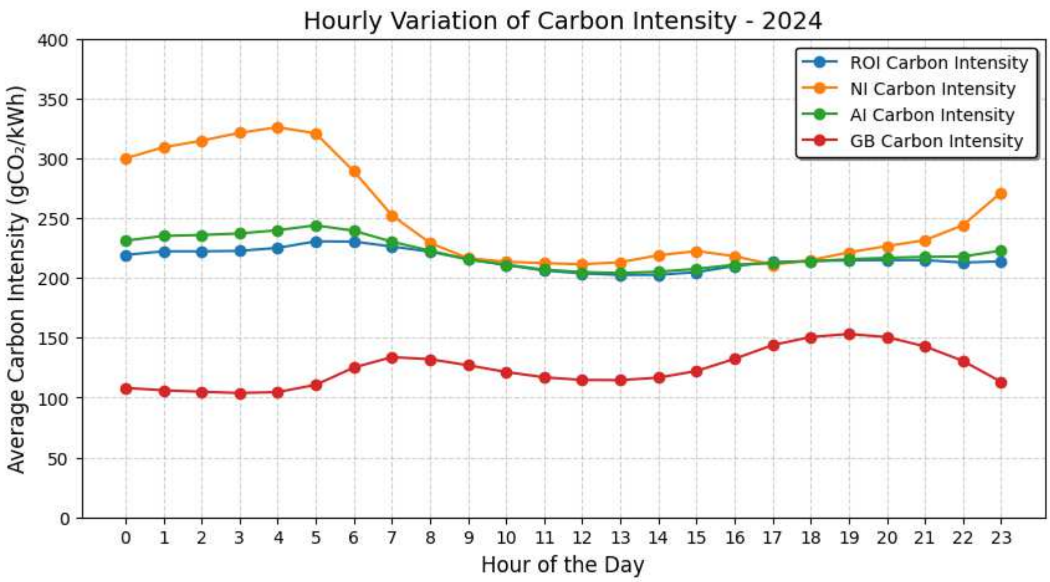

Figure 8: Hourly Variation in Regional Carbon Intensities – 2024

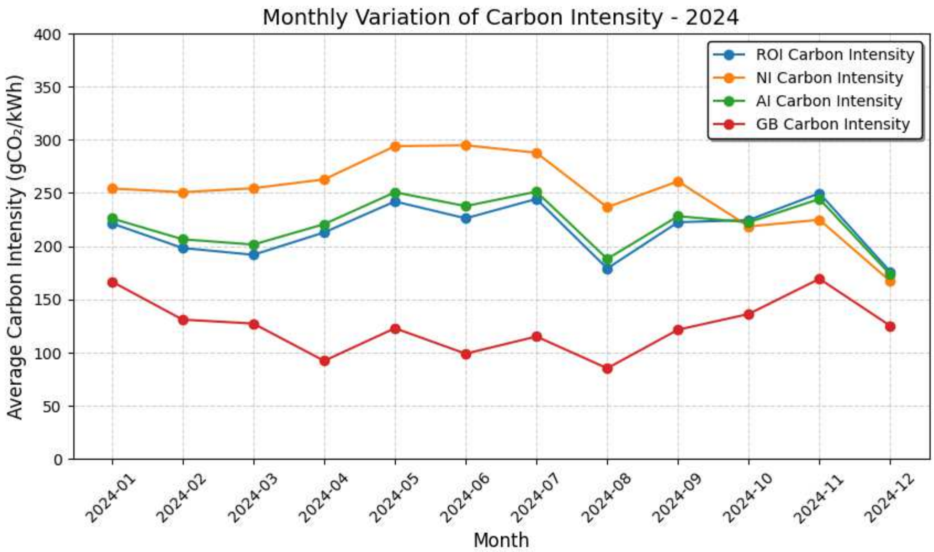

Figure 9: Monthly Variation in Regional Carbon Intensities – 2024

5.1.2 Emissions Embedded in EWIC & Moyle Imports

The emissions embedded in electricity imported via the Moyle and EWIC interconnectors were calculated using GB's carbon intensity. As shown in Figure , this resulted in 344.8 ktCO_2 of emissions from Moyle imports and 359.9 ktCO_2 from the EWIC, giving a combined total of 704.7 ktCO_2 embedded in interconnector imports in 2024. This illustrates the carbon emitted by GB to generate electricity consumed in Ireland. Monthly variation is also significant, with November alone accounting for 80.7 ktCO_2 of embedded interconnector emissions.

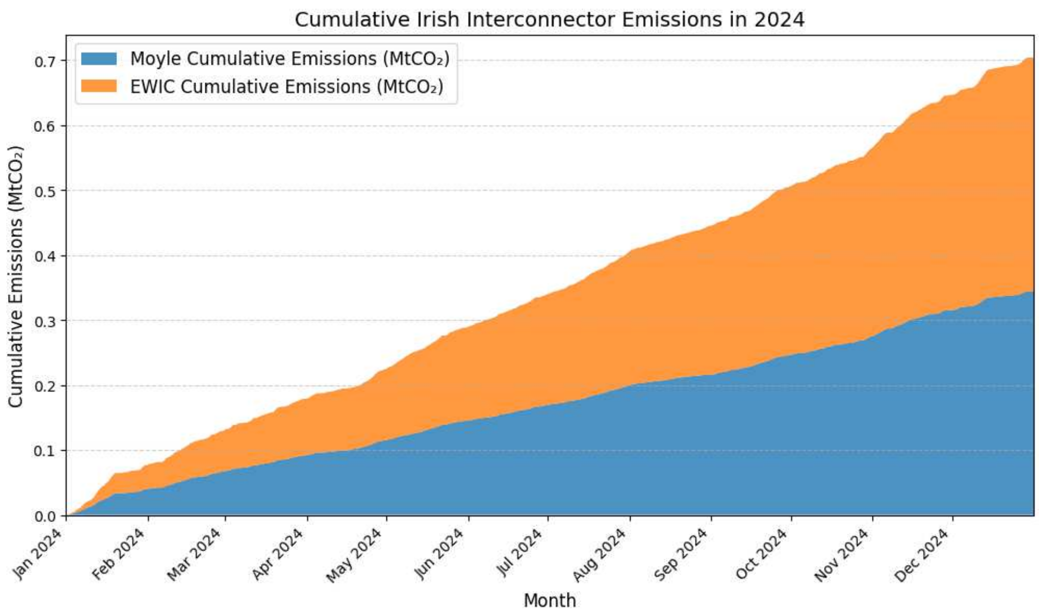

Figure 10: Cumulative Emissions Embedded in EWIC and Moyle Interconnector Imports - 2024

5.1.3 Emissions from Counterfactual Domestic Generation

Following the calculation of emissions embedded in imports, a counterfactual analysis was carried out to estimate the emissions that would have occurred had all imported electricity been generated domestically. Replacing Moyle imports with NI domestic generation would have produced 664.6 ktCO_2, while replacing EWIC imports with ROI generation would have emitted 674.4 ktCO_2. In total, domestic generation of the imported electricity would have resulted in approximately 1.34 million tonnes of CO_2 emissions. In essence, this represents the emissions avoided through interconnector use, from a carbon accounting perspective.

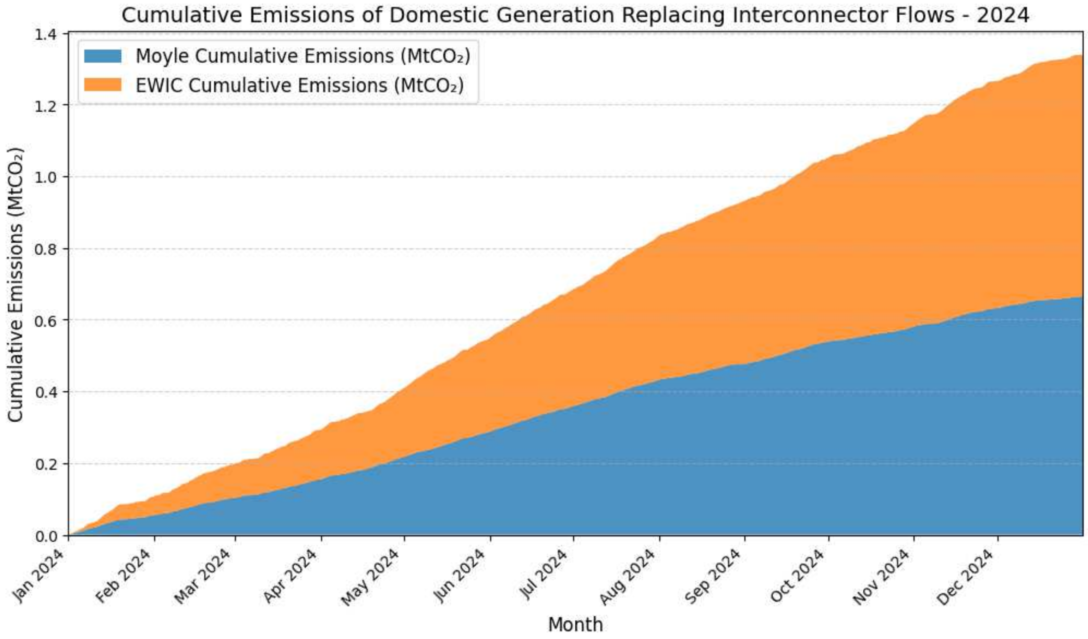

Figure 11: Cumulative Emissions in Counterfactual Scenario Where EWIC and Moyle Imports are Replaced with Domestic Generation - 2024

5.1.4 Emissions Abated by EWIC & Moyle Imports

Combining the current findings, the net emissions abated by Irish interconnector imports in 2024 were calculated by comparing embedded import emissions with their respective domestic generation counterfactuals. The Moyle interconnector abated approximately 319.9 ktCO_2 when compared to equivalent generation in NI, while the EWIC abated 314.4 ktCO_2 relative to ROI domestic generation. From an environmental perspective, this means that Irish electricity imports prevented over 634 thousand tonnes of CO_2 from being released into the atmosphere in 2024. This demonstrates a substantial environmental benefit from interconnection.

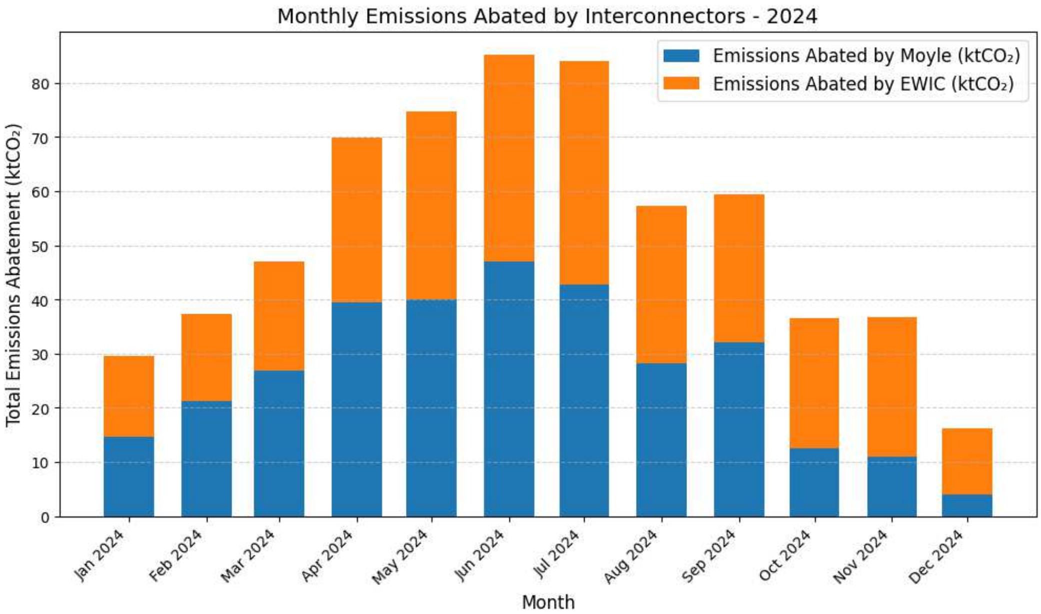

Figure 12: Monthly Emissions Abated by EWIC and Moyle Interconnectors when Compared to Counterfactual Scenario Using Domestic Generation – 2024

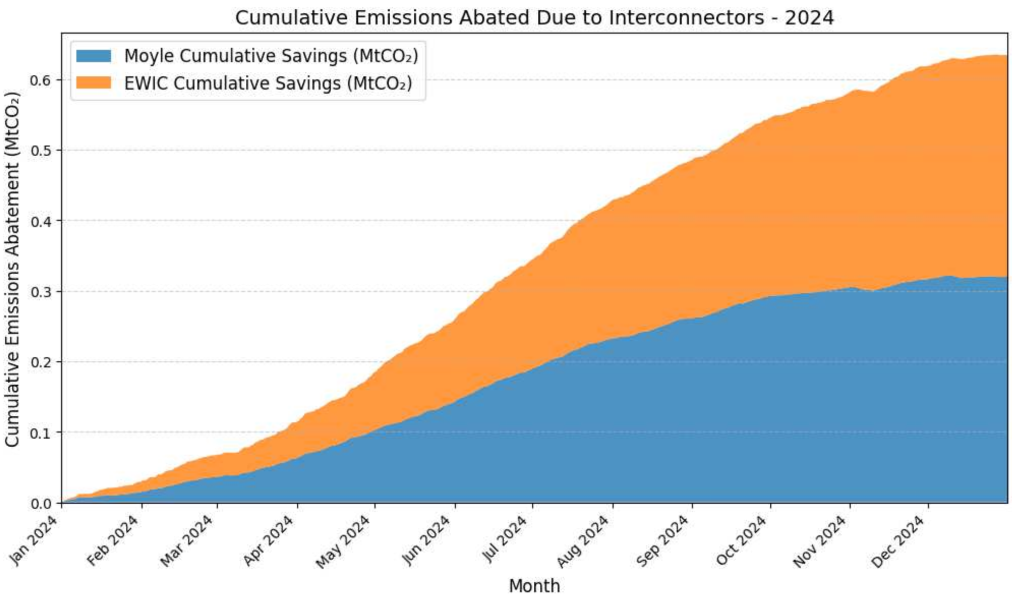

Figure 13: Cumulative Emissions Abated by EWIC and Moyle Interconnectors when Compared to Counterfactual Scenario Using Domestic Generation - 2024

5.2 Republic of Ireland Results

5.2.1 Emissions Embedded in EWIC & Tie-Line Imports

The emissions embedded in ROI electricity imports were calculated by multiplying positive EWIC flows by the GB carbon intensity at each time step, and positive tie-line flows by the estimated tie-line intensity. The cumulative results are presented in Figure , showing that tie-line imports accounted for 360.2 $ktCO_2$, while EWIC imports produced 359.9 $ktCO_2$ of emissions.

Interestingly, the tie-line supplied 2.41 TWh of electricity, while the EWIC delivered 2.69 TWh, meaning the tie-line produced approximately the same quantity of emissions despite supplying approximately 13% less electricity. In total, 720.1 $ktCO_2$ of emissions were embedded in ROI interconnector imports in 2024. This is the true carbon footprint of the ROI's imported electricity, though unreported under production-based emissions accounting. Notably, this figure is even higher than the all-island total of 704.7 $ktCO_2$ reported in Section 5.1.2, reinforcing the Republic's dominant share in cross-border electricity imports.

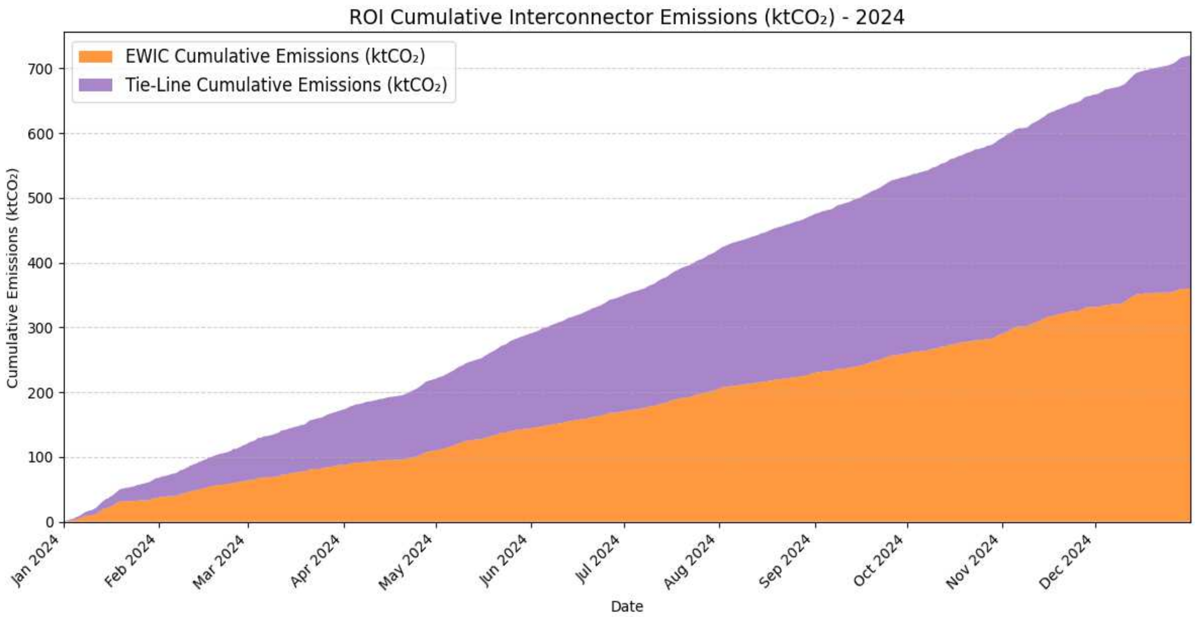

Figure 14: Cumulative Emissions Embedded in EWIC and Tie-Line Imports - 2024

5.2.2 Emissions from Counterfactual Domestic Generation

In line with the all-island analysis, a counterfactual scenario was again completed to estimate the emissions that would have occurred if ROI imports had instead been met by domestic generation. In this case, all positive (import) flows from both the tie-line and EWIC were combined and multiplied by the ROI's grid carbon intensity at each time step. The resulting cumulative emissions are shown in Figure 15.

From this analysis, it was found that replacing tie-line imports with domestic generation would have produced 526.9 $ktCO_2$, while replacing EWIC imports would have resulted in 674.4 $ktCO_2$, as previously calculated. Combined, domestic generation of the electricity imported via interconnectors in 2024 would have resulted in just over 1.2 million tonnes of CO_2 emissions. This figure is particularly significant in the context of Ireland's sectoral emissions ceilings. As outlined in Section 2.1.2, the electricity sector has a strict emissions budget under Ireland's Climate Action Plan. Had Ireland not imported this electricity in 2024, the additional 1.2 $MtCO_2$ from domestic generation would have placed substantial pressure on the sector's emissions ceiling.

Tie-line imports abated approximately 166.7 $ktCO_2$, while EWIC imports abated 314.4 $ktCO_2$, leading to a total of 481.1 $ktCO_2$ of emissions abated through interconnector use in 2024. This figure represents the environmental benefit of importing electricity instead of generating it domestically.

Notably, the emissions savings from the tie-line are considerably smaller than those from the EWIC. As illustrated in **Error! Reference source not found.**, tie-line abatement is low at the start and end of the year. In the first and last three months combined, the tie-line only abated 46.6 $ktCO_2$, while the EWIC avoided 113.5 $ktCO_2$ over the same period, which is almost 2.5 times more. This suggests that from an emissions abatement perspective, prioritising EWIC imports may be more beneficial than relying on the tie-line.

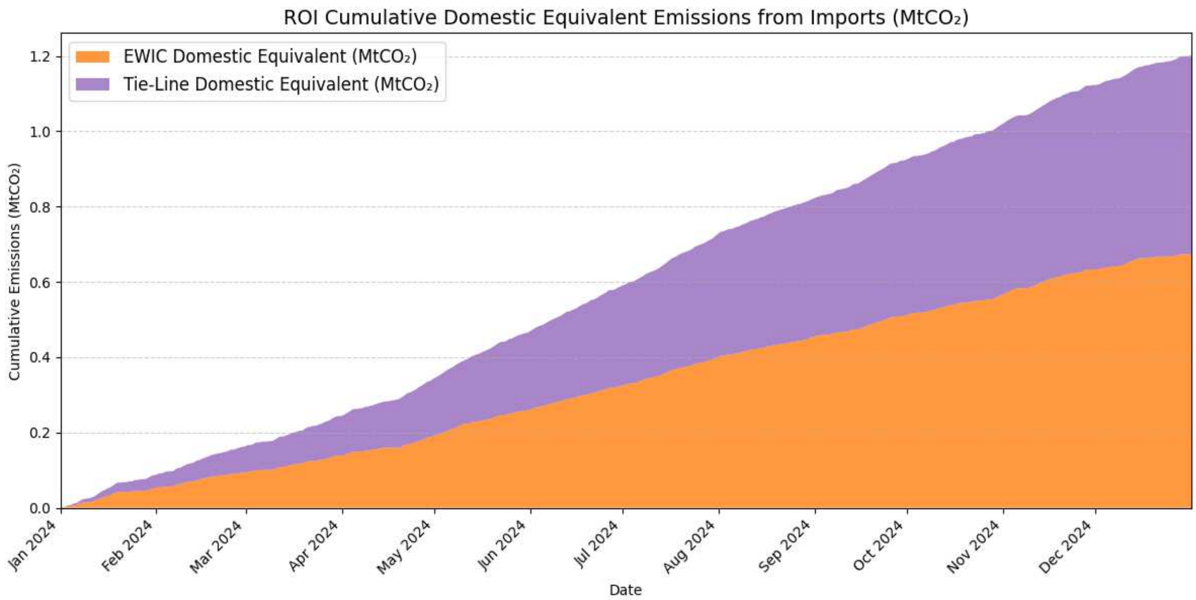

Figure 15: Cumulative Emissions in Counterfactual Scenario Where EWIC and Tie-Line Imports are Replaced with Domestic ROI Generation – 2024

5.2.3 Hypothetical Scenario: Replacing Imports to ROI with Unused Renewables

A hypothetical scenario was developed in which curtailed and constrained renewable energy from ROI was used to offset interconnector imports when possible. Given the complexities of grid constraints and power plant dispatch this not a realistic scenario but instead serves to understand the environmental implications of dispatch down. Given that the tie-line was shown to abate significantly fewer emissions than the EWIC, renewable dispatch-down was first allocated to replace tie-line flows, with any surplus replacing EWIC imports. This approach prioritises the displacement of higher-intensity NI imports first, maximising emissions savings.

Monthly emissions avoided under this scenario are shown below. In total, using dispatch-down renewables would have avoided 94.5 $ktCO_2$ from the tie-line and a further 12.7 $ktCO_2$ from the EWIC, resulting in combined emissions savings of 107.2 $ktCO_2$. These savings are visualised in Figure 17, where the red dotted line represents the original interconnector emissions. This outcome emphasises the value of prioritising domestic renewables where possible, as a method of lowering overall emissions.

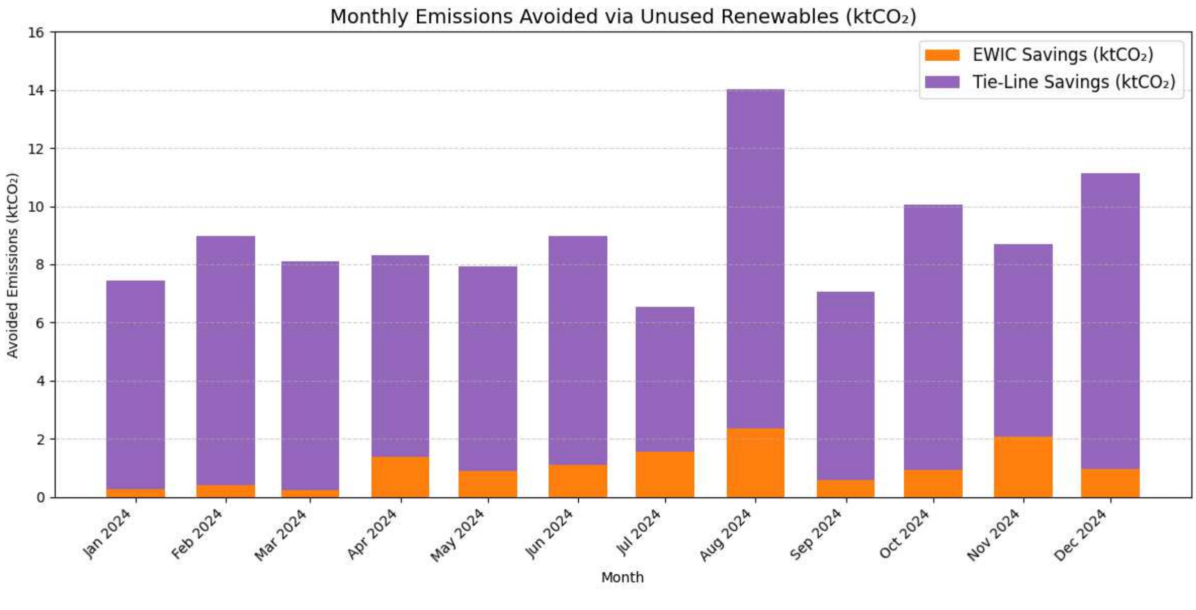

Figure 16: Monthly Interconnector Emissions Avoided By Using ROI Constrained and Curtailed Renewables to Replace Tie-Line Flows, Using Any Surplus to Replace EWIC Flows – 2024

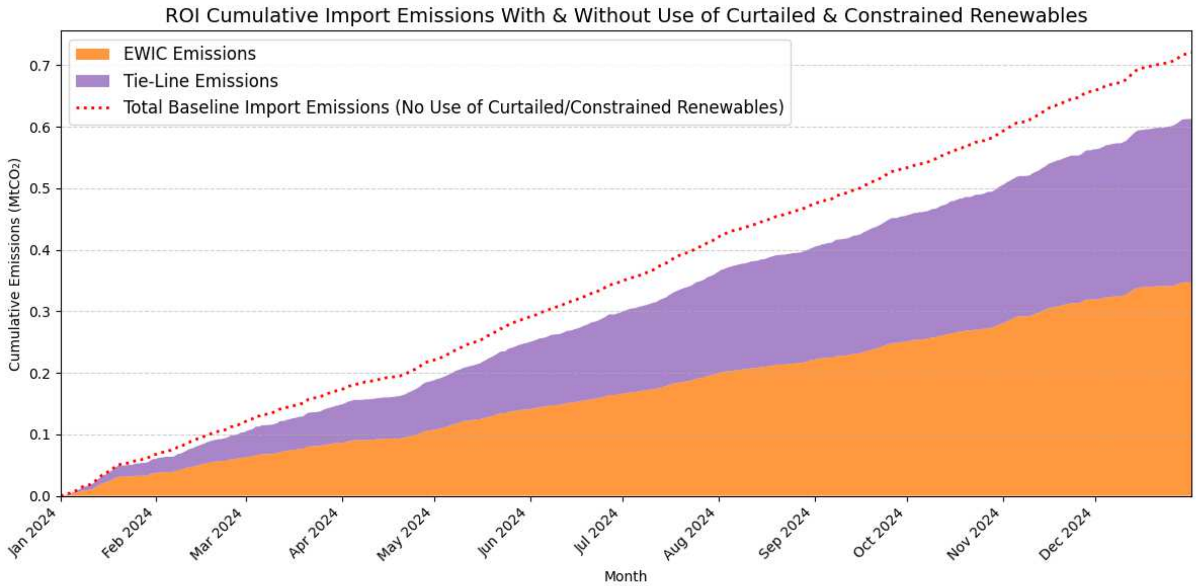

Figure 17: Monthly Interconnector Emissions in Scenario Where ROI Constrained and Curtailed Renewables are used to Replace Tie-Line Flows, Using Any Surplus to Replace EWIC Flows – 2024

6 Discussion and Conclusion

6.1 Emissions Impact of the Interconnectors

6.1.1 All-Island Emissions Impact

The interconnectors delivered a net environmental benefit in 2024, abating over 634 thousand tonnes of CO_2 that would have been emitted had the same electricity been generated domestically. This confirms as hoped that as a whole, the EWIC and Moyle interconnectors contributed positively from an emissions perspective in 2024. However, this benefit must be properly contextualised. While the flows were cleaner than Irish domestic generation, they were not clean. More than 700 thousand tonnes of CO_2 was still embedded in imported electricity through these interconnectors. This underscores a key point, acknowledging that the environmental case for interconnection should be based on carbon footprint, not hinged on emissions comparisons.

In Ireland's case, the interconnectors are a net benefit because the domestic generation mix remains carbon intensive. However, if a country with a lower grid intensity such as Norway, were importing similar volumes of electricity from GB, the interconnectors would likely result in further emissions. Thus, a more nuanced outlook should be adopted, rather than simply celebrating the emissions savings from Irish imports. In short, Irish interconnectors currently abate emissions because Irish electricity is not clean enough, meaning the long-term solution lies in decarbonising domestic supply, not relying further on imports.

6.1.2 ROI Emissions Impacts

Similar emissions savings were observed for the Republic of Ireland, where the combined use of the EWIC and North–South Tie-Line abated over 480 thousand tonnes of CO_2 in 2024, as mentioned earlier. However, the more significant figure is the 1.2 million tonnes of CO_2 that would have been emitted had domestic generation replaced these imports. This would have expended a substantial share of the electricity sector's carbon budget; a budget Ireland is already struggling to stay within, suggesting that there may be potential financial and compliance benefits from imported electricity. From a carbon accounting perspective, this significantly lowered Ireland’s reported electricity sector emissions. Yet, the imported electricity still carried 720.1 $ktCO_2$ in embedded emissions, as much as the total for the island of Ireland.

The Tie-Line is a disproportionately large contributor to these embedded emissions, primarily due to Northern Ireland’s higher average carbon intensity,

One limitation of the analysis completed in this report is a lack of flow tracing, meaning the specific origin of imported electricity is unknown. For instance, GB imports may be dispatched by low carbon wind, or higher carbon gas plants, but this cannot be distinguished. As such, a national average GB grid intensity was applied across all EWIC and Moyle imports. The same approach was used for Northern Ireland, with imports assumed to carry NI’s average grid intensity. No marginal intensity data was available for either region. If this analysis were to be repeated, incorporating marginal emissions data or flow tracing models could significantly improve accuracy.

The tie-line intensity methodology also involves several simplifying assumptions. While Moyle flow enters the NI system, the path it takes and how it mixes with domestic generation is unknown. It is assumed here that NI first meets its own demand, and that any surplus is blended with Moyle imports into a single homogeneous intensity that supplies ROI across the tie-line. This approach may not reflect the true dynamics of system dispatch, but it offers a practical estimate of the likely carbon intensity of tie-line imports.

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Supplementary Files

This is a list of supplementary files associated with this preprint. Click to download.

- DataSheetQuantifyingtheNetCarbonDioxideEmissions.xlsx