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Comparing the macroeconomic demand-side v supply-side impacts of offshore renewable energy

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ABSTRACT

This paper evaluates the deployment of offshore wind in Northern Ireland, focusing on the economic outcomes when considering supply-side factors. Traditional economic analyses typically focus on the direct demand impacts linked to the development, construction, and operation of offshore wind projects. However, recent research highlights a crucial connection between offshore wind capacity and reductions in electricity prices.

The novelty of this paper lies in its approach: to the authors' knowledge, it is the first study to model and compare the economy-wide impacts of investment in offshore renewable energy while incorporating the effects of electricity price changes. Using a CGE model, we find when adjustments in electricity prices are considered, Gross Value Added (GVA) over the 60-year simulation period rises from £1.83 billion to £8.6 billion — nearly 4.7 times higher. Employment also increases, growing from 15,860 to 47,750 person-years.

These findings are not only valuable for academic researchers but also carry significant implications for policymakers globally as current frameworks underestimate scale and length of economy-wide impacts and industry dynamics. The study suggests that future appraisals will need to adapt accordingly. While our focus is on floating offshore wind in Northern Ireland, the results are pertinent to other technologies and regions.

1. Introduction

Northern Ireland, akin to numerous other nations globally, has plans to decarbonise in the coming decades. Central to the nation's decarbonisation strategy is the Climate Change (Northern Ireland) Act, which mandates that Northern Ireland generate at least 80 % of its electricity from renewable sources by 2030, with the ultimate goal of achieving net-zero carbon emissions by 2050. By the end of 2023, 45.8 % [1] of electricity was generated from renewable sources, with onshore wind power contributing the majority. While the increase in onshore wind energy signifies a notable accomplishment, future growth potential is constrained by technological and societal challenges. With these limitations, there is an acknowledged necessity to diversify the renewable energy portfolio and invest in innovative solutions to overcome these obstacles.

As part of the British Isles, Northern Ireland possesses some of the most favourable offshore wind resources globally, with numerous potential development areas experiencing wind speeds exceeding 10 m per second [2]. Given this substantial resource and the imperative to diversify the electricity system, the Department for the Economy in Northern Ireland initiated a consultation on the draft Offshore Renewable Energy Action Plan (OREAP) as a preliminary step towards expanding offshore renewables in the region. Through this consultation, five key themes were identified:

Sustainability and Co-existence: Offshore wind developments in Northern Ireland should aim to achieve the highest standards of environmental, social, and economic sustainability, in alignment with the Department of Agriculture, Environment, and Rural Affairs' draft Marine Plan. Where feasible, innovative approaches to co-location and co-existence within the marine environment will be implemented [3]:

1. **Enabling Frameworks:** A coordinated and coherent process for the development of offshore renewable energy projects should be established, encompassing marine licensing, development consent, planning permission, and generation and transmission licensing.
2. **Electricity Network**: Government departments, regulators, and relevant bodies will collaborate to implement the Energy Strategy for Northern Ireland's long-term ambitions, which includes the integration of offshore renewable energy.
3. **Sustainability and Co-existence:** Offshore wind developments in Northern Ireland should aim to achieve the highest standards of environmental, social and economic sustainability in line with

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Department of Agriculture, Environment and Rural Affairs' draft Marine Plan and, where possible, innovative approaches should be taken to co-location and co-existence within the marine environment will be practiced.

4. **Economic Growth:** Certainty and assurance of a route to market for offshore wind should be provided. Northern Ireland should strive to maximise the economic return from investments in offshore wind.
5. **Legislation and Regulation:** Existing legislation and regulations will be reviewed to ensure they are conducive to achieving the Energy Strategy's offshore wind and low carbon objectives.

The focus of this paper is on Theme 4: Economic Growth, specifically examining how investment in offshore renewables can generate employment and promote economic sustainability in Northern Ireland. This theme is not only a critical objective within energy policy but also aligns with the broader global perspective that regards offshore wind as a key technology for advancing a green economy. Numerous countries recognise offshore wind energy as essential for stimulating economic growth and achieving long-term environmental and economic sustainability. For example both Norway [4] and Canada [5] identify offshore wind as a key core technology in their low carbon economic transition.

In this paper, we analyse the macroeconomic impact of investment in offshore wind, using Northern Ireland as a case study. The novelty of this research lies in its comprehensive investigation of both demand-side (linked to the investment) and supply-side impacts linked to the change in electricity price of such investments. While the focus of numerous studies has been examine the economic effects of offshore renewable energy investments, the focus is primary on the economic activity generated by the construction and operation of offshore renewables. However, recent research has demonstrated that investment in offshore wind positively influences electricity prices, resulting in lower consumer prices compared to business-as-usual scenarios [6].

This reduction in prices is fundamentally driven by increased energy security, as offshore wind replaces fossil fuel generation in the electricity mix. This transition reduces reliance on natural gas and coal imports, which are subject to significant price fluctuations due to geopolitical situations, such as the 2022 Ukraine-Russia conflict. Given that nearly all industries rely on electricity, any decrease in wholesale electricity prices can lead to lower production costs, thereby stimulating economic activity. Additionally, considering that offshore wind farms have an expected operational lifetime of approximately 25 years, the economic benefits from lower electricity prices extend well beyond the development and construction phases, which typically last around 5–6 years.

The primary research question is to analyse and compare the scale of the economy-wide impacts of investment in offshore wind when accounting for the changes in electricity prices compared to the standard appraisal which only model impacts from the construction and operation of offshore wind projects (demand-side). A key objective of this paper is to assist policymakers in understanding the mechanisms by which offshore wind can drive economic activity across various industries, considering both supply-side impacts linked to electricity price changes and traditional demand-side factors.

National and regional policymakers worldwide see offshore and other renewable energy sources as avenues for economic growth. However, their focus to date has been primarily on economic gains from increased investment in manufacturing, construction, and operations. This paper adds to the literature by highlighting the need to look beyond these direct investments and consider the broader economic impacts of renewable energy on electricity prices, which can further stimulate growth. This perspective is largely overlooked in current policy and academic discussions. Policy literature on offshore renewables primarily focuses on the economic impact of demand-side investment, employing standard appraisal techniques such as multiplier analysis or Input-Output modelling (e.g. Ref. [7]). However, by neglecting the supply-side, policymakers risk underestimating or overestimating the economic impacts of offshore renewables. This paper seeks to address this gap Although our study uses Northern Ireland as a case study, the findings are relevant for policymakers and researchers globally, as the green transition increasingly emphasises offshore renewables. This paper proceeds as follows: the next section outlines the existing literature on the economy-wide impact of offshore renewables. Section 3 details our methodology. Section 4 presents the key results of our modelling. Section 5 provides a discussion of these results and their policy implications. Finally, Section 6 concludes the paper.

2. Literature review

As outlined in the introduction, there is a significant body of academic literature investigating the economic impacts of offshore wind. However, much of this literature focuses predominantly on the demand side of the economy. Input-Output (IO) modelling is the primary methodology employed in the economic analysis of demand-side disturbances, and this is reflected in the offshore wind literature, where IO is the most commonly used method. For instance, Brelik et al. [8] utilised this method in their investigation of offshore wind in Poland, focusing on the gross impacts—specifically, the new or additional economic impacts—of investment in offshore wind, including cost estimations for development, construction, and decommissioning of planned capacity. Similarly, Aponte et al. [9] conducted a study for Norway using IO modelling.

In typical IO modelling of any investment decision, the gross impacts are usually the primary focus, as most investment decisions are new and add additional benefits to an economy. However, for offshore wind or other green electricity investments, new renewable electricity investments often replace older fossil fuel capacity to meet decarbonisation targets. Consequently, some researchers focus on the net impacts of offshore wind replacing fossil fuel generation in the electricity system using IO methodologies. For example, Mardones [10] conducted a study in Chile, estimating both the economic and environmental impacts of replacing fossil fuel generation with offshore wind and solar. Using a mixed IO method with partially exogenous production, Mardones [10] found that while the environmental benefits are positive, the economic results are mixed, with an increase in output but a decrease in employment, indicating that fossil fuel plants are more labour-intensive than their green counterparts.

Allan et al. [11] also analysed the economic and environmental impacts of replacing fossil fuel plants in the UK with offshore wind capacity. Similar to Mardones [10], they used an augmented IO model with a time-varying A-matrix methodology, finding economic and environmental benefits from the replacement. An additional focus of their paper was on local content, conducting sensitivity analysis around different scenarios concerning the value of offshore wind goods and services procured within the UK. The theme of local job creation through offshore wind investments was also explored by Kahouli et al. [12] for France.

There has also been an effort to integrate IO models with other types of technological and economic analysis. Varela-Vazquez & Sanchez-Carreria [13] use IO within the context of a lifecycle assessment to quantify the benefits of offshore wind to the Spanish economy, finding significant economy-wide impacts. Bianchi & Fernandez [14] outline a novel method in which IO models are combined with supply-chain analysis and location quotients to estimate the local economic impacts arising from offshore renewables.

While IO modelling is a powerful tool utilised by many researchers, it has limitations. In the context of offshore wind, the main issues are the assumptions of constant prices and the exclusion of supply-side impacts. Large infrastructure projects like offshore wind are likely to cause supply-side constraints, affecting prices and having additional supply-side impacts linked to electricity prices. Therefore, some researchers have adopted other modelling frameworks to address these issues, with Computable General Equilibrium (CGE) models being another methodology used to analyse the economy-wide impacts of offshore wind development.

Similar to IO frameworks, CGE models are often used to investigate the gross impacts of offshore wind, without considering the replacement of fossil fuel capacity. Graziano et al. [15] conducted an investigation into the economic impacts of offshore wind in the UK, focusing on foreign investment and how economic outcomes vary depending on investors' expectations. They found that economies with more forward-looking investors had lower economic impacts from offshore wind investments compared to those with reactive tendencies. Connolly [16] used a similar CGE framework to analyse the economy-wide impacts of planned offshore wind developments in Scotland, comparing the results of the CGE model with those of an IO model and finding differences through various stages of development. Bachner et al [17] uses a multiregional approach in their analysis of their analysis of the economy-wide impacts of offshore wind taking a more top-down approach based on LCOE calculations.

CGE models can also investigate supply-side consequences of offshore wind, as seen in the literature. Lecca et al. [18] used a CGE framework to examine the link between the levelised cost of energy (LCOE) of offshore wind and economy-wide impacts, finding that a significant increase in offshore wind capacity in the UK would require a larger-than-expected reduction in generation costs. Yang et al. [19] used a CGE model for Scotland to explore the impact of offshore wind development on the energy-food nexus, specifically modelling the most recent Contracts for Difference (CFD) and their implications for food poverty. Qu et al. (2021 [20]) development an ecosystem services CGE model in their analysis of the energy-food nexus focusing on offshore renewables and fisheries. Their focus is on how the development of offshore wind can impact upon fish prices and how this flows through the rest of the economy.

In addition to IO and CGE frameworks, other methodologies have been used to analyse the economic impact of offshore wind. Kandrot et al. [21] used a value chain analysis to evaluate the potential economic benefits of local companies supplying the development of offshore wind in Ireland, related to 2.5–4.5 GW of capacity, finding significant economic impacts. Glasson et al. [7] conducted an ex-post evaluation of the local economic impact of two recently completed offshore wind farms, one in Scotland and one in England, finding that environmental statements tend to overestimate social and economic benefits during the construction stage but underestimate impacts at other stages. Ortega-Izquierdo & del Rio [22] carry-out an ex-post analysis of the offshore wind investment across the EU finding significant emissions abatement, fossil fuel saving, jobs creation as well as increased public support.

While much of the literature focuses on fixed offshore wind, the emerging competitiveness of floating offshore wind also warrants investigation. Schallenberg-Rodriguez and Inchausti-Sintes [23] conducted the first demand analysis of the economic impact of floating offshore wind, using a 200 MW floating offshore wind farm in Gran Canaria as a case study.

The existing literature shows that the economy-wide impacts of offshore renewables are well-researched, with a range of innovative approaches. However, most studies focus on demand-side impacts related to investment, while only a few explore supply-side effects, such as learning curves and ecosystem services. This paper contributes to the literature by modelling and comparing both demand and supply-side impacts—particularly in relation to changes in electricity prices—-stemming from investment in offshore renewables, and discussing their implications for policymakers.

3. Methodology

In this paper, we employ a multi-sectoral CGE "macro" model of the economy, which provides a detailed description of the economy by capturing the key interlinkages between the private sector, households, government, international trade, and the labour market. Such models allow for extensive simulations of scenarios to assess the impact of a wide range of policy interventions and are frequently used by researchers and governments to evaluate the merits of alternative policy choices and model the impact of changes to a baseline economy.

We utilise the standard Northern Ireland version of the modelling framework A Model of Scotland (AMOS), calibrated on a 30-sector Social Accounting Matrix for Northern Ireland based on the 2018 published Northern Ireland Input-Output (IO) Table. The primary focus of our modelling is the increase in demand for goods and services for industries linked to offshore wind investment and the pricing impact of more offshore wind on the system. Alongside the 30 sectors within the model, there are three internal institutions—households, firms, and governments—and two external entities, the rest of the UK (RUK) and the rest of the world (ROW). As Northern Ireland is a small, open, regional economy, external RUK and ROW prices are not impacted by changes in the Northern Ireland economy.

This AMOS framework has been extensively applied in a wide range of applications (For example [16,24]) and this specific version of the CGE model was developed for the Department for the Economy for policy analysis, a complete listing of the Northern Ireland AMOS model, please see Appendix A. The model offers flexibility in the choice of assumptions regarding economic setup and reactions to changes. The version used in this paper assumes that industries and households within the model have no future expectations of prices and are only reactive to changes in demand, supply, or prices.

The model assumes that producers minimise costs using a nested multilevel production function. The combination of intermediate inputs with RUK and ROW inputs is based on the Armington function Output is produced from a combination of composite intermediates and value-added, where labour and capital combine in a constant elasticity of substitution (CES) function to produce value-added, allowing for substitution between these factors in response to relative price changes.

$$Y_{y,t} = \left(\alpha[EK]_{j,t} K_{j,t}^{\frac{\sigma-1}{\sigma}} + \beta[EL]_{j,t} L_{j,t}^{\frac{\sigma-1}{\sigma}} \right)^{\frac{\sigma-1}{\sigma}} \quad [1]$$

Where Yj,t is the value added of sector j at time t and K and L are the stocks of labour and capital respectively. σ is the elasticity of substitution between labour and capital with α the share parameter and β the shape parameter ($\beta = 1 - \alpha$). [EK] and [EL] are the efficiency parameters for capital and labour, which are equal in the initial equilibrium. When we improve productivity in the simulations later, we are directly changing the value of EK in the relevant sectoral production function.

There are four components of final demand in the model: household consumption, investment, government expenditure, and exports. Household consumption is a linear function of real disposable income. Real government expenditure is constant in the model, while exports are determined through an Armington function and depend on relative prices. Investment represents the change in physical capital (such as machinery, infrastructure, and cash) needed to sustain economic output.

The model is dynamic with All simulations are run in a multi-year setting. The model is initially assumed to be in steady-state equilibrium, implying that with no exogenous disturbance, the model simply replicates initial values over all subsequent time periods (which in our set up is years).

The supply side of the economy determines the use of capital and labour in the model. Capital is fixed in the first period, but in subsequent periods, each sector's capital stock is updated through investment, which responds partially to the gap between the desired and actual (adjusted for depreciation) levels of capital stock, in line with the neoclassical investment formulation Capital is immobile between sectors.

We assume no migration in the model. The labour market is characterised by the presence of imperfect competition, where workers' bargaining power is inversely related to the rate of unemployment, as outlined in equation (2). There is substantial international evidence supporting the wage curve, and evidence suggests it is an appropriate aggregate characterisation of the labour market in Northern Ireland.

$$ln\frac{w}{cpi} = c - 0.113\ ln(u)_{-} \qquad [2]$$

where w is the net of tax nominal wage in Northern Ireland, *cpi* the Consumer Price Index, *u* the unemployment rate in, and *c* is a calibration parameter.

A core advantage of CGE modelling over other appraisal methods, such as Input-Output analysis, is that both the demand and supply sides of the economy are explicitly modelled. This is particularly relevant for large-scale investments like offshore wind. In CGE models, increased demand affects prices, which industries throughout the economy react to with changes in demand, potentially resulting in "crowding-out" effects where some industries may lose out due to rising prices. Additionally, the presence of the labour force in CGE models can impact prices through changes in wages.

In this paper, we choose to run the model under the assumptions of wage bargaining, no migration, and myopic dynamic capital adjustment. The model also allows for alternative closures, such as fixed real or nominal wages, rest-of-UK migration, and forward-looking expectations. However, the novelty and focus of this paper are in comparing the economy-wide impacts of offshore wind investment alone with those that occur when supply-side pricing is included rather than a full impact assessment. This approach is intended to illustrate the differences brought by incorporating pricing rather than conducting a full sensitivity analysis on the model's assumptions. For.

3.1. Simulation strategy

This paper simulates two main scenarios: the first scenario examines the demand impacts associated with 2 GW of offshore wind capacity being produced by 2040 (Scenario 1), while the second scenario evaluates both the demand linked to investment and the impact on electricity prices (Scenario 2). Fig. 1 outlines the mechanisms in which both scenarios drive economic impacts.

In Scenario 1, direct investment in offshore wind stimulates economic activity through the supply chain and increases demand in industries related to offshore wind. These industries are also connected to others through their own supply chains. Furthermore, the overall increase in employment leads to additional spending in non-offshore wind-linked industries across the economy. In Scenario 2, these impacts are also observed, with the added effect of the reduction in electricity prices, which influences the supply chain and other industries. The 2 GW capacity target by 2040 was estimated using a combination of publicly available information and analysis of expected future electricity demand and supply in Northern Ireland. The Offshore Renewable Energy Action Plan (OREAP) sets a goal of delivering 1 GW of offshore wind capacity by 2030 to help achieve the target of generating 80 % of electricity from renewable sources by that year. Additionally, a report by BVG Associates [25] suggests that an additional 0.5 GW of offshore wind capacity will be operational by 2032 in Northern Ireland, bringing the total to 1.5 GW by that time. However, there is a lack of information regarding the total expected capacity of offshore wind in Northern Ireland by the 2050 net zero deadline. Using data from the Department for Energy Security and Net Zero [26] on current electricity consumption and generation and future energy scenarios identified by the DfE we estimate the further capacity needed to decarbonise the electricity sector in Northen Ireland by 2040.

This demand-supply model is a simplified framework that uses the current electricity system as a baseline and forecasts changes up to 2050. It incorporates the goals outlined in Northern Ireland's energy strategy, including reductions in fossil fuel generation, increases in energy efficiency, and the anticipated electrification of heat and transport Additionally technology advancements, to account for changes overtime, can be incorporated into the model as changes in efficiency, i. e producing more MWh per MW of capacity per year for current technologies or introducing new generation such as hydrogen. As previously noted, offshore wind is expected to play a pivotal role in decarbonising Northern Ireland's electricity supply due to the region's abundant wind resources. Consequently, a substantial increase in capacity is required.

There are various technologies and future scenarios for Northern Ireland's energy sector. For this paper, using the simplified model, we estimate a 35 % reduction in electricity demand, with current fossil fuel generation replaced by offshore wind. In this scenario, we project that 2 GW of offshore wind capacity will need to be operational by 2040, with an additional 0.5 GW, to planned development, added between 2032 and 2040. This estimate was discussed with developers in Northern Ireland to confirm its feasibility. Over time, as the industry and policy landscape evolve, this capacity assumption may change, which would, in turn, affect the economic results. For instance, an increase in capacity would likely lead to significant employment and GVA impacts. In addition to changes in capacity there may be changes in direction of government policy in which focus moves to another type of technology in the green transition. If this was the case the demand-supply electricity

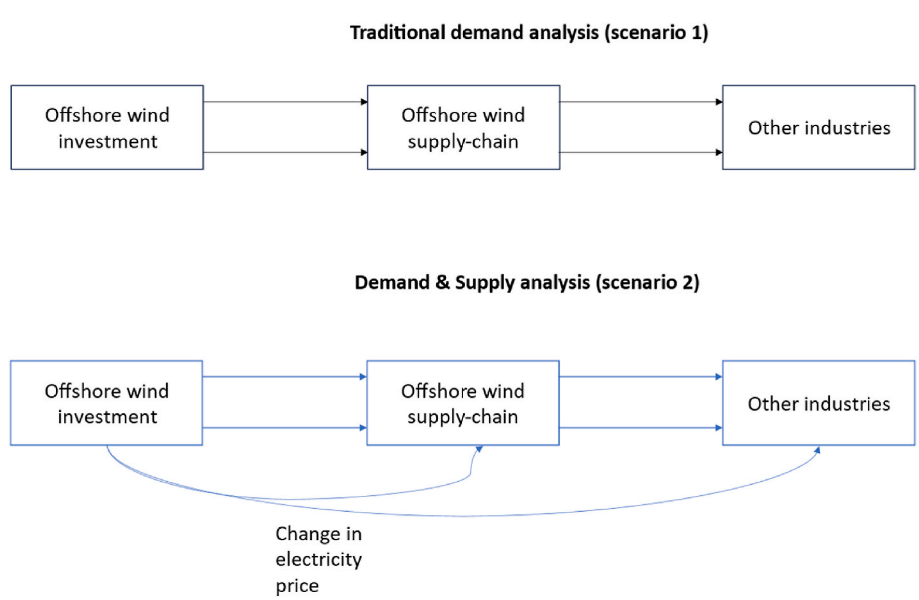

Fig. 1. – Mechanism for economic impacts.

model could be adapted to account for the change in policy. For this all that is needed is some estimations on the potential growth and resource of the technology in Northern Ireland, for example for solar a calculation of the yearly output per MW in Northern Ireland and expected growth in the industry. Similar the model could be adapted for policy with priority on demand what is needed is the level of energy efficiency and no of households retrofitted per year.

While these alternative policy and capacity scenarios could be explored within this framework. We emphasise that the scenario in this paper is a purely illustrative simulation; the paper's focus is not on forecasting future energy scenarios for Northern Ireland, but on analysing the economic impacts of offshore wind when accounting for electricity price changes, in contrast to existing literature that primarily examines investment impacts. While variations in offshore wind capacity would quantitatively alter results, the qualitative insights on economic differences and dynamics when considering electricity price changes would remain consistent.

Regarding costs, there are currently no offshore wind farms in Northern Ireland, and information on the costs of wind farms currently in development is sensitive. Therefore, we use publicly available information on the costs of generic UK-based offshore wind farms. For this case study, we assume all capacity is floating. The Offshore Wind Catapult recently published a detailed breakdown of expected costs for a floating offshore wind farm in the UK (Offshore Wind Catapult, 2023). It is estimated that the capital expenditure (CAPEX) for a floating offshore wind farm in the UK will be £4.2 million per MW (around 20 % higher than a fixed-bottom farm) with an operations cost of approximately £85,000 per MW per year. Again, as with capacity, if this was an economic impact assessment rather than comparison of supply and demand impacts then sensitivity around these values would be required but our qualitatively results still hold.

In addition to the total cost for floating offshore wind, estimations are made regarding the timing of the development of each component for each wind farm type. The timing of investment in offshore wind is highly dependent on key variables such as location, size, and type of foundations. Although there is no single document providing agreed-upon timescales, we estimate from literature and supply chain reports that both floating and fixed offshore wind projects in Northern Ireland will take a total of 5 years from pre-development to full operation. Each wind farm is unique, but for our modelling, we assume that both floating and fixed offshore wind farms follow the same development timeline, with year 0 being when the wind farm becomes fully operational. The pre-development costs, such as surveying and environmental services, are assumed to occur over years −4 and −3, with costs evenly split across both years. Fabrication of foundations is assumed to span years −2 and −1, with costs evenly distributed. Operation costs are spread over a 25-year period from installation (year 0). Table 1 provides the assumed timeline of development, with key spending areas outlined.

The development of floating offshore wind projects entails significant costs, and each phase of this process demands a high degree of expertise. However, not all investments in this sector will directly benefit businesses in Northern Ireland, potentially limiting the economic impact on the region. To address this, we need to estimate the level of 'local content'—expenditures within Northern Ireland—for each stage of development.

In a prior study [27], four sectors within the Northern Ireland economy were identified as pivotal in the development of fixed offshore wind capacity: metal manufacturing for foundations, onshore electrical systems, onshore construction, and ports and harbours for operation and maintenance (O&M). We presume a high degree of local content in these sectors, as suggested by FAI [27], for both wind endeavours.

In addition to the FAI [27] identified industries, BVG Associated [25] also carried out a survey on the current set up of the offshore wind supply-chain in Northern Ireland, which we gather some baseline estimates from. Using this BVG associates [25] we anticipate that most development stages, such as surveys and sensor installations, will be conducted by Northern Ireland-based companies. However, highly specialised components such as offshore wind turbines and offshore cabling systems are expected to have minimal local content. Nonetheless, components like offshore substation foundations may offer opportunities for local development. Although specialised ships are required to install large offshore components, local companies are likely to handle logistical operations during installation. Overall combining our local content estimates by development stage with the cost breakdown from Offshore Renewable Catapult [28], we calculate that around 34 % of the total costs for floating offshore wind projects will contribute to the local economy, primarily driven by the fabrication of offshore foundations within Northern Ireland. While this is only a baseline estimate using publicly available information on Northern Ireland (which can be refined if more data is made available) the 34 % local content similar to that for other regions with economies with comparable structures. For example, Tait et al [29] notes that the local content for offshore wind Scotland is 38 %. Scotland does have a larger economy than Northern Ireland, but also does not have much of a specialised offshore wind industry, thus (like Northern Ireland) the majority of local content comes from manufacturing.

The 34 % local content value is estimated using publicly available information on offshore wind in both Northern Ireland and the UK, along with consultations with developers. Local content may vary depending on several factors, but for the purposes of this study, we use 34 % as the baseline. This allows us to compare the demand-only simulations with those that account for supply-side impacts. Similar to capacity changes, variations in local content will quantitatively affect the economic outcomes. However, qualitatively, the overall narrative remains consistent: accounting for the supply-side significantly influences economic estimates. A sensitivity analysis was conducted around the local content figure. In this analysis, instead of floating offshore wind, we assume the capacity will be fixed, which reduces local content from 34 % to 27 %. The results of this analysis can be found in Appendix B.

The first scenario of our study examines the overall impact of developing and operating offshore wind projects in Northern Ireland. Utilising data on costs and local content, we simulate the introduction of offshore wind-related investment within a computable general equilibrium (CGE) model. This model reflects the standard impact of offshore wind found in the literature and has been extensively researched.

Recently, there has been a growing recognition that increasing offshore wind capacity could influence electricity prices. By replacing fossil fuel generation technologies, expanding offshore wind capacity in Northern Ireland is expected to reduce electricity prices compared to business-as-usual scenarios, thus reducing dependency on volatile fuel prices. Since electricity is a crucial input for nearly every business in Northern Ireland, a reduction in its price could have economy-wide impacts, including reducing the prices of goods and services, increasing consumption, and driving economic activity.

While specific data on expected price differences in Northern Ireland are not available, we can reference existing literature for estimates. Hosius et al. [6] conducted a study on the impact of offshore wind energy on Northern European wholesale prices, using the UK, Western Denmark, and Germany as case studies. They found significant effects, with a reduction in electricity prices ranging from 0.66 % to 6.91 % for every additional 1 GW of offshore wind capacity installed.

Given the similarity in population between Western Denmark and Northern Ireland, we utilise the estimate of a 6.91 % reduction in electricity prices for the first 1 GW of offshore wind capacity. Hosius et al. [6] also provided estimates for the marginal reduction effect for each additional 1 GW of offshore wind capacity, which we apply to derive an estimate of an 11.83 % reduction in electricity prices from the base price with 2 GW of capacity.

While this scenario assumes that only Northern Ireland will experience a decrease in electricity prices, other nations pursuing net zero goals may also witness reductions. To account for this, we conduct sensitivity analysis around these assumptions.

Table 1
Yearly breakdown of cost components for and offshore wind farm in Northern Ireland.

Year minus 4	Year minus 3	Year minus 2	Year minus 1	Year 0
• Environmental assessments • Resource assessments	• Environmental assessments • Resource assessments • Manufacturing of array cables • Manufacturing of export cables	• Manufacturing of turbine • Manufacturing of foundations • Manufacturing of array cables • Manufacturing of export cables	• Manufacturing of turbine • Manufacturing of foundations • Construction of onshore substation • Installation of array cables • Installation of export cables	• Installation of turbine • Installation of foundations

4. Results

4.1. Demand only (scenario 1)

In the demand-only scenario, our estimates indicate that the introduction of 2 GW of floating offshore wind capacity in Northern Ireland could lead to a notable increase in Gross Value Added (GVA) by approximately £1.83 billion and employment by 15,860 person-years. Table 2 outlines the percentage increase across various economic variables during the period spanning from 2029 to 2036, representing the years with the most significant demand stemming from offshore wind investment.

Investment in floating offshore wind, as expected, leads to a notable increase in employment, which we estimate to be around 1790 person-years for the year 2029, just before the completion of the first 1 GW of capacity. As depicted in column two of Table 3 for the same year, this rise in overall employment translates into a higher level of disposable income across Northern Ireland, resulting in a 0.67 % increase in household consumption. However, this surge in household consumption, coupled with the investment in offshore wind, contributes to a rise in prices, reflected in a Consumer Price Index (CPI) increase of 0.47 %. Concurrently, with increased bargaining power, workers negotiate a real wage increase of 0.64 %. Consequently, production costs escalate due to rises in wages and CPI, thereby driving a modest reduction in net exports due to their less competitive position in the global market.

By far the biggest sectoral contributors to GVA and employment are those which are directly linked to the offshore wind investment. For example, in 2029 the manufacturing of metal structures is responsible for 89.76 % of the total GVA increase, other personal services 9.03 % and construction 4.41 %[1]. Other key industries which contribute significantly to the change in GVA, and employment are financial services, wholesale and retail and manufacturing of electronics and electrical equipment.

Across Table 2, we observe a consistent pattern where economic activity increases in tandem with rising prices. While, overall, the increase in floating offshore wind stimulates economic activity in Northern Ireland, this phenomenon does not hold true for every industry in the economy, as we identify some crowding-out effects associated with the aforementioned price increases. Fig. 2a &b illustrates the sectoral changes in output (the value of all goods and services produced in £m) for the year 2029.

The most significant change in output is observed in the manufacturing of metal structures, with a notable increase of 19.73 %, as shown in Fig. 1). This surge is directly linked to the fabrication of offshore wind foundation structures. The "Manufacturing of Metals" industry classification includes the specialised offshore fabrication businesses in Northern Ireland. With a strong history and expertise in offshore fabrication, particularly in shipbuilding, these businesses also operate in offshore foundation manufacturing. Due to this expertise, we expect a substantial increase in output from this industry during periods of foundation manufacturing, as illustrated in Fig. 2.

Additionally, increases in output are noted in sectors such as electronics and electrical equipment, electricity, construction, wholesale and retail, accommodation and food services, as well as financial services and other professional services. The majority of these increases can be attributed to direct investment stemming from floating offshore wind activities.

However, for other sectors of the economy, there is a slight decrease in output due to the general increase in prices across Northern Ireland, which is linked to the rise in production and labour costs. Among these sectors, administrations and building services experience the highest reduction in output at 0.42 %, while the public services sector sees the least change in output compared to the business-as-usual case (i.e., no changes in the economy). This discrepancy is an important consideration in economic appraisals it is evident that not all industries will benefit; some may suffer due to changes in prices. Nevertheless, as seen overall, there is an expansion in the economy, as illustrated by the increase in GVA and employment.

Focusing on employment and GVA we can track the impacts over the full lifetime of the 60-year period of the simulation.

From Fig. 3a, both Gross Value Added (GVA) and employment exhibit similar trends to Northern Ireland investment, albeit with some slight variations overall. Investment follows the breakdown in Table 1, with the total development period for a wind farm—spanning from pre-development to operation—taking five years. As shown in Fig. 3a, initial investments in offshore wind in Northern Ireland are modest, supporting the first 1 GW of capacity by 2030. However, a major surge in investment occurs in 2028 and 2029, driven primarily by foundation manufacturing, as outlined in Table 2, with investment peaking in 2029. After this peak, investment decreases slightly in 2030 and 2031 but remains over £200 million annually, largely due to foundation production for an additional 0.5 GW by 2032. From 2032 to 2035, investment levels remain steady, supporting the operation of the first 1.5 GW. Investment rises again in 2036 as the final 0.5 GW is developed, reaching a second peak (year −1) before the final capacity becomes operational. Thereafter, investment is primarily for the ongoing operation of the offshore wind farms.

Between 2023 and 2026, there is no increase in either GVA or employment, as there is no investment in offshore wind during this period. However, in 2026, the pre-development costs for the first 1 GW of wind capacity incur, resulting in a modest increase in both GVA and employment. This increase becomes more pronounced in 2029, with peaks reaching £182.5 million in GVA and 1792 person-years of employment, primarily associated with the manufacturing of foundations. Following these peaks, there is a slight decline in both variables as the demand for goods and services diminishes. Unlike simpler appraisal models such as Input-Output (IO), where economic activity is solely driven by demand, our model reflects the influence of both demand and supply, thus explaining the disparity in the decline rates between GVA and employment.

Between 2032 and 2035, there is a sharp decrease in economic activity, as the only investment linked to offshore wind is the operation and maintenance (O&M) cost for 1.5 GW of capacity, amounting to approximately £22.7 million annually spent in Northern Ireland. As capital expenditure (CAPEX) investment ramps up in 2036 for the last 500 MW of capacity, we observe another increase in both variables, with secondary peaks occurring in 2039. After 2040, all offshore wind capacity is operational, with yearly local Northern Ireland O&M

[1] These add to more that 100 %, as demonstrated in Fig. 1, some industries see a reduction in output

Table 2
Percentage increase in economic variables compared with Business As Usual (BAU) case in demand scenario for years 2029–2036.

	2029	2030	2031	2032	2033	2034	2035	2036
GVA	0.34 %	0.22 %	0.23 %	0.11 %	0.09 %	0.08 %	0.07 %	0.08 %
Employment	0.23 %	0.14 %	0.14 %	0.06 %	0.05 %	0.04 %	0.04 %	0.05 %
Household Consumption	0.67 %	0.32 %	0.34 %	0.09 %	0.08 %	0.08 %	0.08 %	0.12 %
Investment	0.88 %	0.15 %	0.21 %	−0.16 %	−0.10 %	−0.06 %	−0.03 %	0.07 %
Real Wage	0.64 %	0.39 %	0.39 %	0.16 %	0.13 %	0.11 %	0.10 %	0.13 %
Capital Stock	0.13 %	0.22 %	0.21 %	0.21 %	0.16 %	0.13 %	0.11 %	0.09 %
Total HH Tax	1.45 %	−0.01 %	0.13 %	−0.51 %	−0.36 %	−0.25 %	−0.17 %	0.03 %
CPI	0.47 %	0.20 %	0.20 %	0.01 %	0.01 %	0.01 %	0.01 %	0.05 %

Table 3
Overall results for GVA and Employment increase over the two simulations.

	Demand modelling only	Demand plus supply modelling
GVA (£billion)	1.83	8.6
Employment (person-years)	15,860	47,750

expenditure around £30.3 million. Unlike IO models, the supply-side of the economy influences the gradual decrease in employment and GVA, rather than a sudden drop-off. The first 1 GW of capacity is decommissioned in 2055, followed by another 500 MW in 2057. Although the final year of planned operation for the last 500 MW is in 2065, Fig. 3a indicates continued economic activity beyond this period. This can be attributed to the legacy effect of offshore wind investment, where capital stock and employment accumulated over time persist even after operations cease. However, as capital stock depreciates and operational expenditures cease, wages gradually decrease, slowing the need for reducing employment.

Fig. 3b illustrates the cumulative impact over time. Similar to the yearly investment, GVA and employment impacts follow a comparable pattern. During the initial three years, there is little to no investment; however, as manufacturing and installation ramp up, so too do GVA and employment. By 2031, cumulative investment reaches 50 % of the total. In contrast, GVA and employment do not achieve 50 % of their cumulative impacts until 2038 and 2037, respectively. This indicates that economic impacts are distributed more evenly across the years compared to investment. This difference arises because economic impacts are driven by the accumulation of capital stock and labour, which do not change as immediately as investment but over time.*4.2 Demand & Supply (Scenario 2)*.

For the second simulation, where we account for the impact of changes in prices, the overall impact is significantly larger. Over the 60-year period, we estimate that for the pathway of 2 GW capacity of floating offshore wind, Gross Value Added (GVA) could increase to £8.6 billion, with an employment of 47,750 person-years. This represents an increase of 4.7 times in GVA and 3 times in employment compared to the demand-only case in scenario one. Fig. 4 illustrates the evolution of the GVA and employment impacts over the 60-year period with the development of 2 GW of floating offshore wind capacity.

The evolution mirrors Fig. 2a, which only considers the demand side, but with significantly amplified impacts. For instance, in 2034, the GVA increase is £41 million for the demand only case, compared to £182 million for when both supply and demand are modelled. This pattern persists throughout the scenario, reflecting the substantial scale of the impacts. Similar to Fig. 3a there are two peaks in the GVA and employment impacts which match with the investment with the first peak linked to the manufacturing of the offshore foundation structures for the first 1 GW of capacity. Again after this initial peak there is a reduction in economic activity, but it is not as pronounced as in the demand-only simulation as there is the additional positive impact from the electricity price. The second peak again occurs in 2039 link to the ramp up in investment for the last 0.5 GW of offshore capacity by 2040.

With the reduction in electricity prices, goods and services in Northern Ireland become cheaper to produce, thereby driving up domestic consumption and enhancing competitiveness in the export market. In the demand only modelling, we highlighted the "crowding-out" effect on industries not directly linked to offshore wind. However, the decrease in electricity prices offsets this crowding-out, allowing more industries to increase output over the 60 years by being more competitive globally. This is highlighted in Fig. 5 where we see that accounting for the lower electricity prices impacts the output of most industries increases, again showing the positives compared to Fig. 2 where only offshore wind industries are seen as winners.

Initially, we adopt the conventional approach, assuming that only Northern Ireland's electricity prices are impacted by the increases in offshore wind capacity, while prices elsewhere remain unchanged in

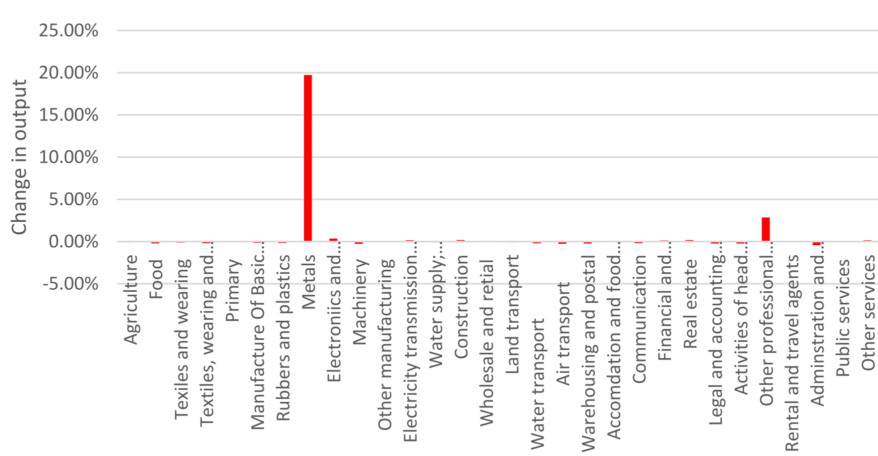

Fig. 2a. Sectoral change in output in 2029 for 2 GW of floating wind (Demand only). Manufacturing of metals included.
Source: author's calcuation

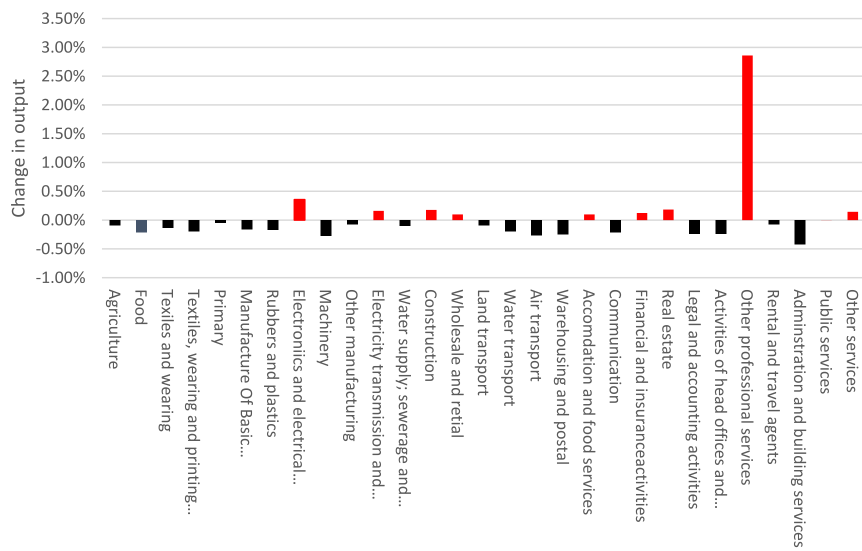

Fig. 2b. Sectoral change in output in 2029 for 2 GW of floating wind[21](Demand only). Manufacturing of metals omitted.
Source: author's calcuation

other regions and nations. Consequently, in relation to the rest of the UK and the rest of the world, prices in Northern Ireland are lower, which has positive economic implications. Goods and services developed in Northern Ireland become more affordable and are likely to be in greater demand beyond the region. However, this assumption may not hold true globally, as the transition to offshore renewable electricity is a worldwide phenomenon. Therefore, electricity prices across the world may fall compared to what they would have been without the green transition.

While a comprehensive analysis would require a multi-regional CGE framework and detailed information on nations' plans for renewable electricity generation over the next 60 years, this is beyond the scope of this paper. However, we can conduct sensitivity analysis on our results by fixing Northern Ireland's exports to the rest of the UK and the rest of the world. This assumes that the move towards renewables does not enhance Northern Ireland's competitiveness in the global market, as increasing renewable electricity capacity is a worldwide trend. Table 4 presents the key GVA and employment results for demand and supply modelling with fixed exports.

From Tables 4 and it's evident that while fixing exports does introduce some variation, the primary driver of economic activity remains the reduction in electricity prices resulting from the development of offshore wind. The purpose of this sensitivity analysis is to demonstrate that our results remain robust, even when we exclude the positive competitiveness effects typically seen in price reduction simulations. Overall, accounting for supply-side impacts still shows a significant positive economic effect compared to demand-only simulations. This finding holds not only for Northern Ireland but is also generalisable to other nations and regions.

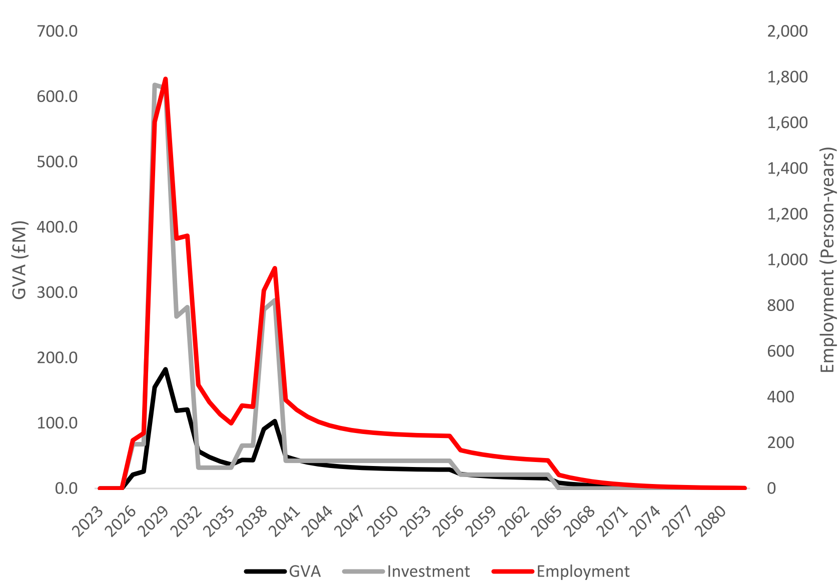

Fig. 3a. Timing of yearly gross economic impacts linked to the investment of 2 GW of floating offshore wind[31] (scenario one).
Source: authors calculation

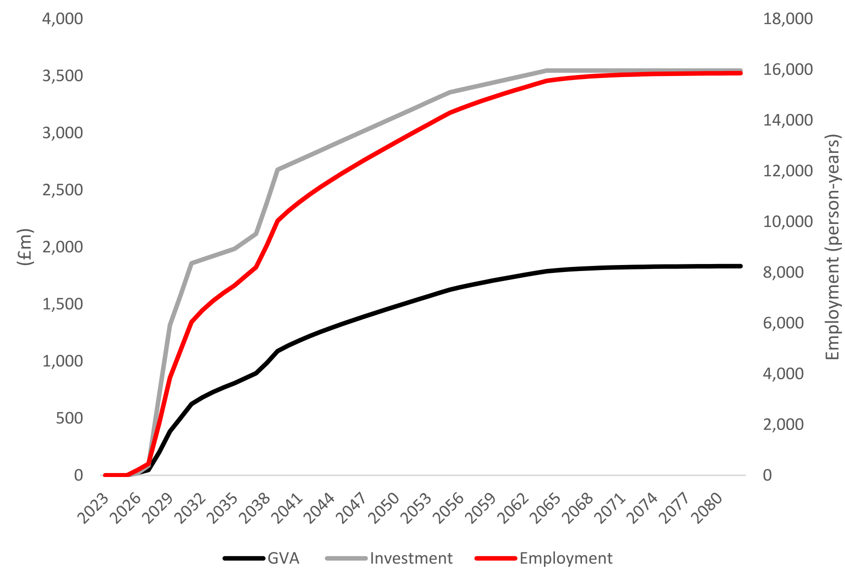

Fig. 3b. Timing of cumulative gross economic impacts linked to the investment of 2 GW of floating offshore wind (Scenario one).
Source: author's calcuation

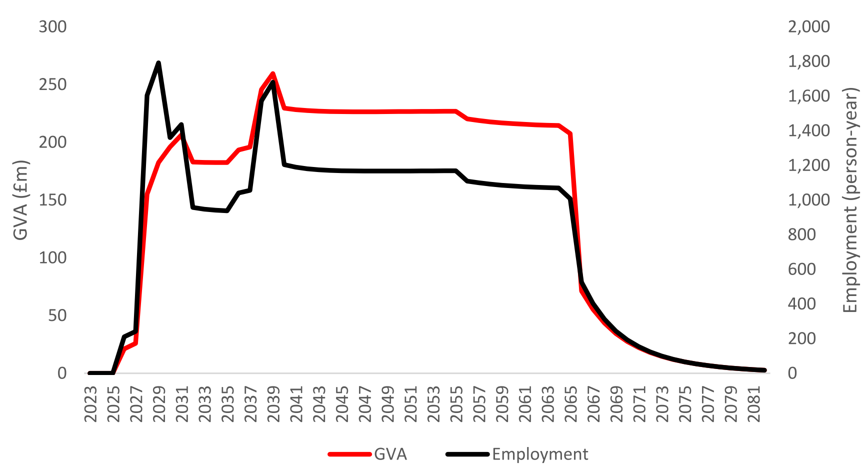

Fig. 4. Timing of yearly gross economic impacts linked to the investment for a 2 GW capacity pathway of floating offshore wind with price changes.
Source: author's calcuation

5. Discussion

The findings presented above underscore the broader impact of considering the pricing effects associated with transitioning to offshore renewables, extending beyond the traditional scope of demand-focused economic analysis prevalent in existing academic and policy literature. This insight holds significant implications for policymaking, and while we use the Northern Ireland as a case study, the results and policy outcomes can be generalised to other nations and regions globally where there is a push towards offshore renewables.

Historically, policymakers have emphasised the development of offshore renewables, particularly offshore wind, as a means of creating employment opportunities through investment. The conventional perception often revolves around large-scale investment projects, involving material development, structural construction, cabling systems, and asset operation. However, our results indicate a far-reaching impact attributable to the pricing effects of offshore wind, contrasting with the conventional analytical approach. Recognising this broader impact could potentially bolster support for renewable energy initiatives among policymakers.

Furthermore, the concept of a "green just transition" is central to many countries' sustainability agendas, aiming to ensure that the growth of the green economy is inclusive and equitable. In traditional analyses focusing solely on investment-related jobs, we observe industries experiencing losses during the construction phase due to increased Consumer Price Index (CPI) and reduced competitiveness in the Rest of the UK (RUK) and Rest of the World (ROW) markets. However, the price reductions resulting from offshore wind development mitigate these effects, leading to positive outcomes across all industries. This underscores the importance of considering not only direct investment impacts but also broader economic consequences in policy formulation.

Another critical consideration for policymakers is the nature of job creation. When focus is solely on investment, the majority of jobs, aside from those in operation and maintenance, tend to be short-term, typically lasting during the Capital Expenditure (CAPEX) phase of offshore wind development. While these jobs may offer high remuneration, their transient nature poses challenges for sustained green growth. However,

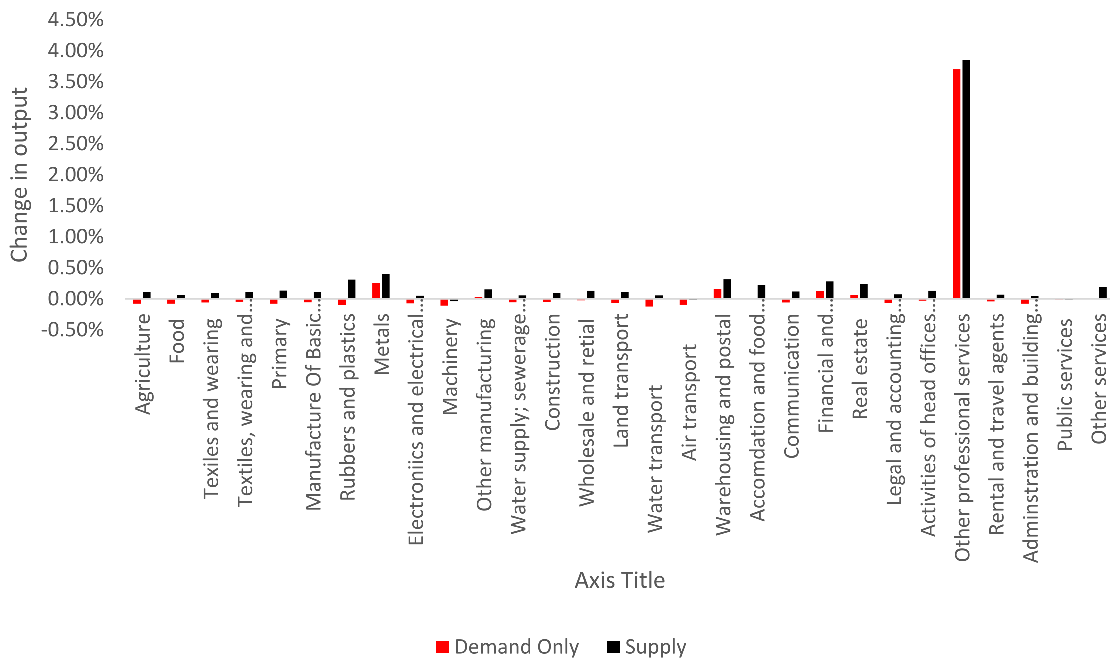

Fig. 5. Sectoral change in output in 2030 for 2 GW of floating wind[41](Demand & Supply).
Source: author's calcuation

Table 4
Sensitivity around fixed exports.

	GVA (£m)	Employment (Person-years)
Floating foundations (Standard model)	8550	47,750
Floating foundations (exports fixed)	8320	46,490

by incorporating supply-side considerations, the longevity of jobs significantly increases, aligning more closely with the notion of sustained green growth. Our simulations show that this holds true for regions with high offshore wind resources. However, for regions with limited offshore resources or different energy mixes, the results are more difficult to generalise. A limited resource makes it challenging to realise the full benefits of offshore wind and the associated changes in electricity prices. Nevertheless, many renewable technologies, such as solar, continue to see a decrease in prices, making them at least cost-competitive with fossil fuels in many regions. As prices decrease and fossil fuel costs are expected to rise, regions with a mix of renewables should experience similar dynamics to those with offshore wind, where changes in electricity prices lead to economy-wide benefits. The scale of these effects, however, falls outwith the scope of this paper, however if you were calculating these scales for regions reliant on other renewables (for example solar) you could follow a similar method as outlined in the paper. First you would need an econometric analysis of the impact increasing the capacity of solar has on a region's electricity price compared with other areas without the solar capacity – similar to the work of Hosius et [6]. You would then need to set up an electricity model with expected changes increase in demand for electricity and supply solar, estimating a capacity to meet the regions electricity/climate goals. These capacity estimates along with costs breakdown, local content and timelines could be used to development an investment scenario for a CGE model as is done in this paper. The model can then calculate the regions economic impacts for both the demand only and supply-side scenarios to determine the impact these have.

Additionally for policymakers, the sustained green growth observed when accounting for electricity price changes can also contribute to achieving broader societal benefits linked to sustainability. The ongoing increase in economy-wide employment resulting from lower electricity prices can help reduce poverty, as more people are employed. This can also improve both the physical and mental health of populations in regions investing in renewables. Additionally, when considering electricity price changes, employment growth occurs across a wide range of industries, not just in offshore wind. For example, from Fig. 4, there is an increase in the accommodation and food which has no direct relationship to offshore wind. However, the change in electricity price has a positive impact on their supply-chain costs which then feeds to an increase in output showing their diverse benefits from increase in offshore wind capacity. From a policy perspective, this broader distribution of benefits helps reduce inequalities, unlike models that focus solely on demand-driven investment impacts.

In summary, the key recommendation for is for policymakers across the globe to adopt a more comprehensive approach in their economic modelling and planning of offshore renewables, by either developing a CGE or other framework, that encompasses both demand and supply-side dynamics when formulating policies related to offshore renewables. The development of a more comprehensive modelling framework may initially be resource intensive however, as outlined above, there will be many benefits in the long-run as demonstrated above. By using Northern Ireland as a case study but with generalised results, we show that policymakers can better address the broader economic implications of offshore renewable investment and promote inclusive, sustainable green growth.

6. Conclusions

The primary objective of this study was to assess the economy-wide impact of offshore wind, utilising Northern Ireland as a case study. While the economic ramifications of offshore wind have been extensively explored in existing literature, this study offers a novel approach by comparing both the demand and supply-side effects associated with offshore wind investments. Traditionally, both academia and policy circles have predominantly focused on the demand impacts pertaining to investments in the development, construction, and operation of offshore wind. However, recent research has shed light on the positive impact of increased offshore wind on electricity prices, prompting an exploration of the broader economy-wide implications in this study.

To evaluate these impacts, a custom-built Computable General Equilibrium (CGE) model calibrated to the 2018 Input-Output table for Northern Ireland was employed. Two separate simulations were conducted. The first simulation focused solely on the economy-wide impacts associated with the investment in 2 GW of floating offshore wind capacity by 2040 and the second simulation which also accounts for, the effect increasing offshore wind capacity has on electricity prices compared to the business-as-usual scenario.

Overall, the 60-year period, in the demand only simulation, we find:

- An increase in GVA of £1.83 billion and 15,860 person-years of employment.
- Industries directly or indirectly linked to the offshore wind sector experienced the largest increase in economic activity, such as the fabrication of metals.
- Not all industries across Northern Ireland experienced positive impacts from the offshore wind investment, as some faced reductions due to price increases affecting their competitiveness in the Rest of the UK (RUK) and Rest of the World (OW) markets.

When including supply-side pricing impacts.

- Economic impacts are much larger with an increase in GVA of £8.6 billion and 47,750 person-years of employment over the 60-year period – an increase of 4.7 and 3 times increase, respectively.
- Reduction in electricity prices attributable to offshore wind drove further economic activity in both domestic and global markets

The novelty in this paper lies, not in being a standard economic analysis of economic impacts of offshore wind which has been researched extensively, but rather in the comparison of impacts of the traditional demand analysis with those when the supply-side are included. Using Northen Ireland as an illustrative case study our findings hold crucial implications globally for policymakers. As many regions globally seek to simultaneously grow their economies while reducing greenhouse gas emissions, offshore wind emerges as a key technology. While policymakers often highlight offshore wind as a means to revitalise industry, through such ideas such as supply-chain plans and reshoring manufacturing, it is important to note that the impacts, as demonstrated by the demand modelling, may be significant but short-term. Globally policymakers may thus be overlooking the supply-side impacts associated with electricity price, which are crucial for fostering sustained green growth and positively influencing public opinion.

We use illustrative simulations based on several assumptions regarding capacity, price, and model closure. Future research should focus on other areas of the economy and explore how these factors impact the results. A key area of interest would be the labour market, specifically how changes in labour supply and the types of labour available might influence the macroeconomic outcomes associated with electricity price reductions. Another important area to explore would be supply chain constraints and how other environmental and economic policies could affect the benefits of offshore renewable investment and the associated impacts on electricity prices.

While this paper focuses on the economic benefits, the development of offshore renewables also offers additional advantages that policymakers could consider. The primary objective of renewable energy is to achieve sustainability and reduce carbon emissions in electricity generation. An extension of this work could involve incorporating environmental variables, such as emissions, into the CGE modelling framework. Another key component of energy policy is the just green transition with an additional extension of the work being incorporating social impacts, such as impacts by income. This would allow for an assessment of how supply-side impacts influence overall sustainability goals. However, this falls outside the scope of the current study.

Declaration of competing interest

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests: Kevin Connolly reports financial support was provided by Northern Ireland Department for the Economy. If there are other authors, they declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.renene.2025.122625.

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