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Reshoring of renewable energy manufacturing for regions and smaller nations: An exploration of offshore wind Northern Ireland

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Abstract

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Abstract: In order to combat climate change many nations have committed to reduce their carbon dioxide emissions with the development of renewable energy key in meeting these objectives. At the same time these nations see the development of renewables as and opportunity to 'reindustrialise for the 21st century' with many placing emphasis on the reshoring of manufacturing via the onshoring of parts of the renewable energy supply chains, to increase economic benefits from green investment. While this is a goal for nations of all sizes, due to the specialities needed in the development technologies, in reality reshoring is much easier for larger nations. Smaller nations are limited by their economic structures and labour force.

In this paper, using offshore wind in Northern Ireland as a case study, we investigate the issues around onshoring of renewables for small nations and regions. For this we use the particular case of Northern Ireland, a self-governing region of the UK; but the method we propose is general and could be carried out by decision makers in any small nation or region. We firstly carry out a structural analysis of the economy of Northern Ireland and identify synergies with the offshore wind supply chain, and then we model the economic impacts of onshoring key components of this supply chain. Overall, we find that there is the potential for sizeable economic benefits, in NI's case mostly in the onshoring of foundations;

but our results extend and in general many smaller regions will be able to identify their own specific opportunities in onshoring renewables manufacturing.

1. Introduction

Climate change is seen as one of the, if not the, biggest threats to humanity in the 21st century and as such the past 20 years has seen increased investment in climate change mitigation strategies. Because of the need for greener energy sources, and the potential resource, offshore wind is an industry which has seen significant growth in recent years with globally capacity increasing from just over 2GW MW in 2010 to over 75GW by the end of 2023 with expected capacity to around 450MW by 2032 (Global Wind Energy Council, 2024). While there is no doubt that the investment in offshore wind has the potential to bring both local (Arenas-López & Badaoui, 2022; Connolly, 2020) and global (Li et al., 2022) economic benefits there is expected to be difficulties in managing industrial growth.

One of the biggest challenges is with global supply chains and bottlenecks, potentially limiting both the positive national economic and environmental impacts from development. Supply chain bottlenecks are seen as significant issue for the offshore wind industry linked to the exponential increased in expected capacity over next decade and beyond. Several key areas exist where bottlenecks are prevalent, most notably in the manufacturing (Soares, 2022) and installation (Sarker & Faiz, 2017) of the turbine components. For installation, due to the limited number of available vessels , the focus of the literature has been on optimising strategies (McMorland et al., 2023) whereas there significant effort has been placed on the reshoring manufacturing capacity for renewables.

Over the past 50 years many developed countries have deindustrialised and shifted their economies to be more serviced based, as globalisation linked countries ever more closely, and lower labour costs in developing economies attracted the offshoring of tradeable goods production. Developments in the global economy and in geopolitics since the Financial Crisis of 2008-09 have seen moves towards economic nationalism, and if not a reversal then a slowing of the pace of development of globalisation. The onshoring of renewables manufacturing is seen as an opportunity to bring advanced manufacturing back, at the same time as growing the green economy (Di Stefano et al., 2023).

A key objective of many nations worldwide is for green sustainable growth where the economy grows at the same time as a reduction in emissions. Reshoring manufacturing capacity linked to renewables is seen as pivotal to this goal as with increased capacity there is the potential to grow the economy and the number of “green jobs” (MacKinnon et al., 2022). While some of the specialised components of offshore wind developments, like blades and drive trains, do not lend themselves easily to reshoring there are others components, such as foundations, which have synergies with other areas of the economy like the oil and gas industries (Van Der Loos et al., 2022) and because of this there has been renewed interest in reshoring of offshore wind manufacturing.

In addition to the local economy-wide benefits (De Bakcer et al., 2016) , reshoring of some offshore wind capacity builds supply-chain resilience (Bailey et al., 2018) by reducing the reliance on the global market. By developing a local supply chain, nations could see environmental benefits by being able to develop offshore wind capacity faster, reducing the output from fossil fuel generation in a shorter period of time than if fully reliant on external supply chains. Onshoring of manufacturing also brings the advantage of knowledge transfer (McCann, 2011) which can upskill the local work force impacting positively on the economy as a whole.

Additionally, the development of the supply chain could be beneficial for cost as there could potentially be a reduction in costs from the use of local components if the global supply-chain bottlenecks increase costs relative to the locally manufacturing components. Finally increased local production could allow for the higher level of co-ordination of between the different stages of development in offshore wind farms.

From the developers perspective there are many reasons for reshoring manufacturing capacity. (Kinkel, 2014) conducts a study of firms within Germany active in reshoring outlining the reasoning for reshoring with the majority responding that reshoring of manufacturing capabilities makes it easier to control quality of final products and to adapt to market conditions. Other key factors outlined where the ease of co-ordination with transport logistics and the relevantly larger availability of qualified personal. Building on this work Karatzas et al (2022) focus on firms' motivation for reshoring after the pandemic finding that a key driver being the company's future cash-flow notes that expectations of increased profits with reshoring.

Reshoring offshore wind manufacturing, as with many industries, is not a cheap endeavour as there is considerable upfront investment needed in building physical capacity and retraining the workforce. However, because of the identified potential benefits it would advantageous, in the long-run, for the national government to support the reshoring of offshore wind manufacturing capacity. An example of this is in the UK with the recently (2024) published offshore wind industrial growth plan (Renewables UK et al., 2024) which sets out priorities, objects, actions and investment needs to grow the UK offshore wind supply to maximise long term economy-wide benefits. The plan will create an industrial growth fund, national innovation hub and advanced turbine technology institute and will be supported by a new delivery body.

While the onshoring of offshore wind manufacturing is a key component of many nations' energy strategies, for a small nation or region, onshoring a high proportion of any very complicated supply chain is unfeasible Instead, a small nation or region should focus on those parts of the supply chain which link to their industrial specialisation. Such a specialisation strategy is likely to maximise potential growth, as specialisation linked to local production takes advantage of a home market effect (Krugman ADD CITATION), and the small nation or region can export its specialism to other locations (Boschma, 2015). Such an argument applies to the Offshore Wind industry, and in this paper we illustrate this argument by showing its potential as applied to the case of Northern Ireland.

This is an important issue from a policymakers specific as, while the environment and climate change is of the upmost importance, they also need to ensure that environmental policy does not come at the cost of economic development. Also focusing on a specialisation should hopefully alleviate some of the fears from smaller nations and regions that the move away from fossil fuel generation will only have negative impacts for the local area with most of the benefits of local investment being abroad.

In this paper, using Northern Ireland, we carry out an economic evaluation of a small self governing regional economy by first analysing current economic data to find the most important sectors of the economy in terms of employment and linkages with other industries. Using this information, we determine the links of these industries with development of offshore wind in Northern Ireland. Then, using a CGE model, we carry out an economic impacts analysis of if these components were reshored for the development of 1GW of offshore wind in Northern Ireland. The novelty in the paper lies in it being the first, to our knowledge, analysis of the economic analysis of potential benefits of reshoring offshore wind manufacturing for a small nation or region. We pay particular attention to the currently make-up of the small region's economy and synergies with offshore wind while carrying out a comparison of investment in different components.

The paper proceeds as follows: Section 2 outlines the structure analysis carried out for offshore wind in Northern Ireland with the economy-wide modelling methodology outlined in Section 3. Results and presented in Section 4 with discussion and wider context given in Section 5, Section 6 then concludes the paper.

2. Economic structure analysis

We take three separate analytical approaches in our analysis: firstly we conduct an analysis for the current employment and specialisation structure of Northern Ireland; secondly we investigate the industrial linkages, and finally we explore synergies between the local economic structure and the offshore wind supply chain.

2.1 Current economic structure analysis

The first approach taken is a simple investigation of the industrial employment proportions in Northern Ireland compared with the other three counties of the UK. In the second approach, we estimate the sectoral employment location quotients, which again are compared with the other countries of the UK. Both approaches are based on data from the UK Business Register and Employment (BRES) Survey (ONS, 2022).

The reasoning for the employment analysis is that this determines industries of the economy with relatively high concentrations of employment which can reveal a nations industrial specialities, and while this is a relatively simple calculation it goes some way to understanding a nations/regions make up and resilience (Giannakis & Bruggeman, 2020).

Employment proportions are calculated as the industry full time equivalent (FTE) employment in Northern Ireland as a percentage of the total Northern Ireland employment at a 4-digit Standard Industrial Classification (SIC) level. The employment percentages in Northern Ireland were compared to the same indicators for the other three countries of Great Britain, to identify industries where Northern Ireland has higher employment rates, and potential areas of specialisation. Table 1 outlines industries with linked to the offshore wind activities where NI either a significantly higher or lower concentration of employment than GB countries.

Table 1. Results of simple employment analysis of NI BRES data.

Industries linked to the offshore wind activities where NI has higher concentration of employment than GB countries.	• Manufacture of metal structures and parts of structures • Engineering activities and related technical consultancy • Freight transport by road; Construction of other civil engineering projects; NEC • Other research and experimental development on natural sciences and engineering • Wholesale of mining, construction and civil engineering machinery
Industries linked to the offshore wind activities where NI has significantly lower concentration of employment than GB countries.	• Manufacture of other electronic and electric wires and cables • Repair of machinery • Repair of electrical equipment • Manufacture of bearings, gears, gearing and driving elements • Sea and coastal freight water transport • Specialised design activities • Other construction installation • Technical testing and analysis • Development of building projects • Other specialised construction activities Not elsewhere classified • Other professional, scientific and technical activities Not elsewhere classified

The second approach is more analytical whereby instead of simple employment proportions we estimate the sectoral employment location quotients for Northern Ireland and the other three countries of Great Britain. Location quotients are one of the most common methods found in the literature to describe an nations or regions industrial specialities (Pereira-López et al., 2021) . We use Simple Location Quotients (SLQ's) calculated as:

$$SLQ_i^R = \frac{FTE\ employment\ of\ industry\ i\ in\ region\ R\ /\ FTE\ employment\ in\ region\ R}{FTE\ employment\ of\ industry\ i\ in\ national\ economy / FTE\ employment\ output\ in\ national\ economy}$$

Here R is either the Northern Ireland or an individual country within Great Britain. The numerator of the SLQ is sector i's proportion of employment in region R, while the denominator is sector i's proportion of national UK employment. SLQ's are interpreted as: an SLQ greater than one may be said to indicate that region R is more specialised in industry i than the nation as whole, whereas an SLQ less than one indicates that region R is less specialised in that industry.

Table 2 shows the headline results of this analysis. Northern Ireland has specialisations relative to the countries of Great Britain, indicated by SLQ>1, in a number of industries related to offshore wind activity, particularly in the 'manufacture of structural metal products' and 'manufacture of other special-purpose machinery'. However, Northern Ireland lacks specialisation in other industries that will play an important role in offshore wind activities, notably in the 'manufacture of wiring and wiring devices' and 'technical testing and analysis'.

Table 2. Location Quotients for SIC sectors related to the offshore wind industry

Industries in NI linked to offshore wind activities with high specification (SLQ >1)	NI SLQ	Industries in NI linked to offshore wind activities with little specification (SLQ <1)	NI SLQ
Manufacture of structural metal products	25.0	Manufacture of wiring and wiring devices	0.0
Manufacture of other special-purpose machinery	22.3	Technical testing and analysis	0.1
Construction of other civil engineering projects	15.5	Sea and coastal freight water transport	0.6
Manufacture of other general-purpose machinery	8.7	Architectural and engineering activities and related technical consultancy	0.7
Treatment and coating of metals; machining	8.1	Specialised design activities	0.9
Manufacture of other electrical equipment	6.6		
Freight transport by road and removal services	6.2		
Other professional, scientific and technical activities Not elsewhere classified	6.1		
Development of building projects	4.7		
Wholesale of other machinery, equipment and supplies	4.2		
Manufacture of other fabricated metal products	3.1		
Electric power generation, transmission and distribution	2.8		

Other specialised construction activities Not elsewhere classified	1.7		

2.2 Backward linkage Analysis

For the current industrial structure, a key sector analysis of the Northern Ireland Input-Output Table (IOT) with a particular focus on backward linkage estimates was completed. Backward linkages are the 'supply-chain' linkages of industries reflecting the purchases a industry makes from the output of others within the economy as an input into their own production process. Backwards linkages are used throughout a wide literature with two core applications being in the study of value chains (Antras & Chor, 2022) and embodied emissions in consumption (Wang et al., 2020). Backward linkages are key for understanding the industries in which reshoring would bring maximum economic benefits. The larger the backwards linkages the higher the economy-wide benefit with investment as these industries are more integrated into the nation's economy and supply chain. Different types of linkages are available with the focus of this paper on the normalised backward linkages (BPLi), calculated as (Miller & Blair, 2009) :

$$BPLi_j = \left[\frac{\frac{1}{n}\sum_{i=1}^{n} L_{ij}}{\frac{1}{n^2}\sum_{i,j=1}^{n} L_{ij}}\right] \quad (1)$$

Where n is the number of sectors, and $L_{I,J}$ are the values found within the Leontief inverse matrix, calculated from the Northern Ireland IOT. Using equation (1) backward linkage index for all 63 industrial sectors in the published IOT[1] is developed. In this index, a sector with a BPLi greater than one has an above average backwards linkage strength, whereas a value below 1 indicates a lower-than-average backward linkage. The index also allows for rankings of the sectors in the economy based on their linkages to the other industries.

Another way of thinking of this measurement is that sectors which have a high BPLi value have higher than average supply chain purchases from other sectors in the region's economy, thus you would expect investment in these sectors to induce higher total economy activity than investment in sectors with low BPLi values (which may rely on imports). In Figure 1 below we outline some of results from the backward analysis of the 2018 Northern Ireland IxI IOT.

[1] These 63 industrial sectors are based on the 4-Digit Standard Industrial Classification (SIC) which classifies companies based on their business activity.

Figure 1 - Backward linkage estimate for the Northern Ireland IOT

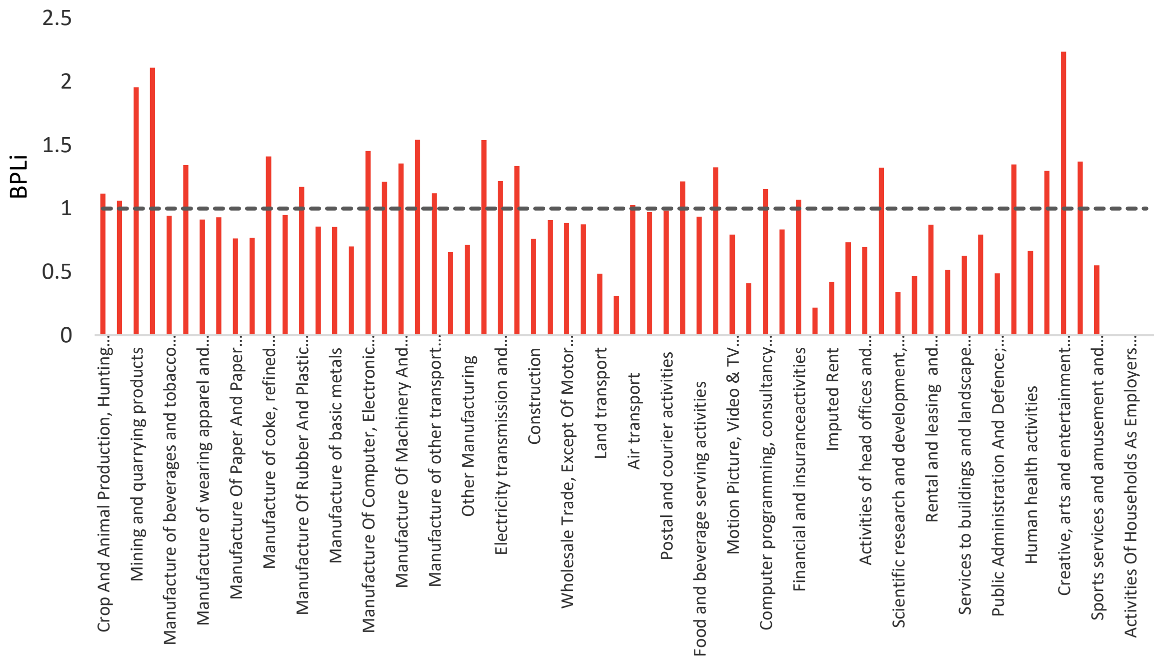


Figure 1 shows the BPLi ranking for each of the 63 sectors in the latest Northern Ireland IxI IOT. While it would be unnecessary to go through each of these values in detail, we can come to some general conclusions can be made. Firstly, we find that the Northern Ireland agriculture industry purchases (left part of Figure 1) many of the intermediates used in production locally as both the 'manufacturing of food products' and 'crop and animal production and hunting and related services' industries have large BPLi estimates of 2.11 and 1.96 respectively. The BPLi estimates for manufacturing industries (to the right of agriculture in Figure 1) vary significantly dependant on the products, for example the 'manufacturing of other transport equipment' index is 1.54 compared with 0.65 for the 'other manufacturing activities'. In general, services (right side of Figure 1) sectors have a lower-than-average BPLi with a notable exception being 'Gambling' and 'residential and care'.

2.3 Synergies with offshore wind

For any attempt of manufacturing reshoring to be successful a nation much have the specialisation to produce the goods and services needed here we focus on the economic analysis of the current Northern Ireland economy and how this matches with the development of offshore wind. There are a number of noted synergies between offshore wind with energy and existing industries, particularly these economies with oil and gas sector (Andersen et al., 2018) and those with significant infrastructure investment (Bento & Fontes, 2019). How a nation/regions offshore wind industry will evolve is dependant on a number of factors but core to this is the current structure and history.

A key take away from the economic data analysis is that Northern Ireland has a significant experience in the production of metal products. From the employment data, highlighted that Northern Ireland has a higher proportion of workers in the 'Manufacture of structural metal product's SIC (0.39% against 0.18% for the UK).

BVG Associates (BVGA, 2022) reports on the potential of an offshore wind supply chain in Northern Ireland. While BVGA take a more bottom-up survey approach to this paper we can compare their key results with our findings to determine if there are noticeable conclusions from both methodologies. Also, the 'Manufacturing of structural metal', which includes offshore manufacturing, has a relatively high SLQ of 1.82 indicating that this is an area of specialisation in Northern Ireland when compared with the Great Britain countries.

Northern Ireland has a storied history of offshore manufacturing with many ships being built in the nations in the last two centuries with Harland and Wolff (H&W) being identified as a key business in this area. BVGA (2022) notes that H&W has already fabricated offshore wind foundations for non-Northern Irish projects and is expected to be the main fabricator of foundations for planned capacity in Northern Ireland. This result closely matches with the analysis of Northern Ireland's economic data in Section 2.1.

Interesting though is that the backward linkage coefficient for the 'Manufacturing of metal products' is lower than the average at 0.84, ranking the sector 38 out of 63 sectors. So, while the sector is important in terms of speciality and employment, they are not as connected to the rest of Northern Ireland's economy as some other sectors. However, the cost of manufacturing offshore wind foundations amounts to a large proportion of total offshore wind Capital Expenditure (CAPEX) and thus might bring significant economic benefit.

'Electrical manufacturing' is notes as another potentially important industry the reshoring of Northern Ireland offshore wind supply chain, in particular the onshore electrical components of the developments (such as onshore substations). Our analysis also supports the notion that electrical manufacturing could be key to maximising economic benefits from Northern Ireland's offshore wind supply chain. On average, 'Manufacturing of electrical system equipment' in the UK accounts for 0.07% of employment but for Northern Ireland the value is near three times greater at 0.19%. Both Standard Industrial Classification (SIC) sectors ('Manufacture of electric motors, generators, transformers and electricity distribution and control apparatus') and ('Manufacture of other electrical equipment') have a high SLQ coefficient. This again suggests that the expertise is there in Northern Ireland for these sectors to become important in the supply chain of offshore wind developments. Unlike the metal fabrication sectors, electrical manufacturing is highly interconnected to the other sectors with a BPLi backwards linkage of 1.43.

Offshore wind is a large-scale infrastructure project requiring installation both off- and on-shore. While the offshore installation is highly specialised, much of the onshore construction is less specialised, such as cable cabling. 'Construction' is a core sector of most economies worldwide and in Northern Ireland this amounts to 35,063 FTE's. The sector also has a high backwards linkage score of 1.33, ranking 13th out of the 63 sectors.

Ports play a pivotal part in the operation of offshore wind farms, in particular as an Operation and Maintenance (O&M) base and for logistics. Belfast port is a major international hub for freight and leisure which, along with smaller satellite ports is expected to be the main base for many Northern Ireland offshore wind operations. However, investigating the BRES data it is difficult to estimate the proportion of employment and associated SLQ's of the ports in Northern Ireland. Many of the associated jobs in the port are registered to other industries due to their registered companies not part of the sea transport SIC. As a result of this, we cannot comment on the data analysis, but this will still be an important sector for Northern Ireland offshore wind thus we include it in the modelling.

3. Economy-wide modelling

To this point the focus has been how the links between a smaller nation's economy and the offshore wind supply chain with the goal of maximising the economic benefit from reshoring. This section builds on this by estimating the potential economic benefits arising from the reshoring of the individual supply chains from the components identified in the previous section. From a policymaker's perspective this is the most important issues as it shows how developing policy for separate areas of components can impact upon the economy differently.

For the purpose of economy-wide modelling we use a Computable General Equilibrium (CGE) model which have been extensively used in the economic analysis of investment decisions across nations and regions (Nejati & Bahmani, 2020; Rokicki et al., 2021). As the need for renewables has increased focus is placed on both the economic and environmental consequences from investment in renewables in a national and regional context (Jenniches, 2018; Oh et al., 2020; Yeo & Oh, 2023). For the reshoring of offshore wind the comparative advantage of using CGE over other economy-wide frameworks in the analysis of reshoring is that supply-side constraints, like labour force, are included which is key for policymakers and does not overstate potential impacts.

The model is a CGE model calibrated to the 2018 IOT for Northern Ireland. The model belongs to the A Model Of Scotland (AMOS) family of models first developed for Scotland in the early 1990s. These models have been extensively used in both the academic and policy literature to analyse the macroeconomic impacts of projects, policies, or shocks, with a particular focus on energy and environmental applications (Alabi et al., 2020; Allan et al., 2014). The particular strength of CGE modelling is that is goes beyond the standard IO/multiplier economic impact assessments by modelling the supply side along with demand side. This is important for large scale investment projects, which are likely to impact supply chain prices, as would be expected with offshore wind.

Fundamentally, the model assumes that producers minimise cost using a nested multilevel production function. Output is produced from a combination of intermediates (which can be sourced from NI, Rest of the UK, and Rest of the world), labour and capital. These inputs combine in a constant elasticity of substitution (CES) function to produce output, allowing for substitution in response to relative price changes. 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. Investment is based on the difference between current capital stock and the desired level of capital stock. Government expenditure in the model is constant, while exports are determined endogenously by relative prices.

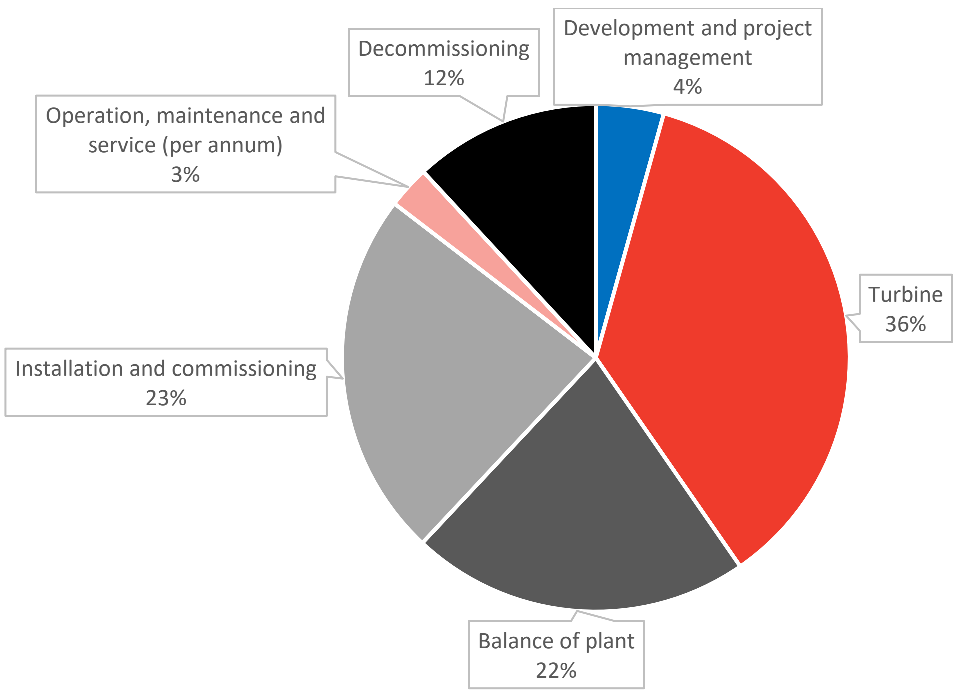
All simulations are run in a multi-period setting, with the periods interpreted as years as both the Social Accounting Matrix and behavioural relationships are benchmarked using annual data. The model is initially assumed to be in steady-state equilibrium, implying that with no exogenous disturbances, the model simply replicates the initial value over all subsequent time periods.

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. A single labour market with perfect sector mobility is imposed on the model whereby workers are free to move between different sectors.

3.1 Simulations

In order to analysis economy-wide impacts of component reshoring we must produce estimates for the potential investment in the key Northern Ireland offshore wind supply chain industries identified in Section 2. These investments are introduced into the CGE model as a demand shock. First and estimation of the cost per Megawatt (MW) of offshore wind capacity is needed. Of course, this varies depending on a number of factors such as: location, turbine type, developer etc, but for this paper we use the latest Offshore Renewable Catapult (2023) estimate a CAPEX £2.7 million per MW of capacity and £75,000 per year in O&M. Costs are then spread across the different stages of development, shown in Figure 2, based on the wind farm cost data again published by the Offshore Renewable Catapult (2023).

Figure 2. Breakdown of offshore wind farm expenditures[2]



Source (Offshore Wind Catapult, 2023)

For the purposes of this paper the stages (components) we are interested in are the turbine foundations, cables element manufacturing, installation of onshore components and port operations. Turbine foundations, on average, account for significant proportion of offshore wind investments. The Offshore Renewable Catapult (2023) estimates that turbine foundations cost around £280,000 per MW, which amounts to a total of £280 million if the 1GW of offshore wind capacity by 2030 was to be realised.

From the economic and synergy analysis and the fact that there are already Northern Ireland based companies producing offshore wind foundations, we could realistically assume that all Northern Ireland offshore wind foundation manufacturing could be carried out locally meaning a total reshoring. One of the key strengths of CGE modelling techniques is they allow for sensitivity analysis, which we take

[2] The costs have been aggregated to the six main stages of wind farm development for illustration purposes.

advantage of. We carry out three simulations for wind foundation manufacturing with local content[3] of 80%, 90% and 100%, respectively.

In Section 2, 'Electrical manufacturing' was identified as another sector in Northern Ireland which, on the surface, has links to a potential local offshore wind supply chain. This is not just because of the current size of the sector, but also because of its links with other industries. Many of the cables needed for use in offshore windfarms are high voltage, which requires specialised equipment and expertise to manufacture. Based on publicly available information BVGA (2022) the industry in Northern Ireland does not have. As a result of this, the 'local content' for electrical manufacturing is expected to be somewhat minimal.

There may be two areas of offshore wind farm developments which the 'Electrical manufacturing' sector in Northern Ireland can contribute to – cable protection and part of the onshore substation. Northern Ireland based companies are already involved with the manufacture of cable protection systems and similar to foundations, with regional expertise available we can reasonably assume that between 80-100% of these components could be produced locally. Cable protection, however, is only a small percentage [0.07%] of overall offshore wind CAPEX costs, with the total for 1GW of planned capacity amounting to £2 million. Again, based on the information from BVGA (2022), for the onshore substation there are certain components which cannot be manufactured in Northern Ireland. Therefore, for these components we assume that local companies may reasonably be involved in 40-60% of manufacturing on substation costs. Taking this information into account we estimate that between £10.4 and £15.2 million of investment could be made in the 'Electrical manufacturing' industry related to offshore wind development. Again, like the foundations, we carry out three separate simulations.

'Construction' was also identified as another local important industry for reshoring which may benefit from the investment in 1GW of offshore wind capacity in Northern Ireland. Wind developments require both offshore and onshore installation of components. Offshore install of wind farm components relies heavily on a limited number of specialised ships and as such, it is unlikely that any of this process could be carried out by companies based in Northern Ireland. The onshore components, however, are not specialised as there are many companies which could carry out this process. Thus, we assume that between 80-100% of the onshore install can be carried out locally. The reasoning behind this is that the construction related activities to these components is non-specialised and there are many companies locally which could carry out this process. These construction companies are more than likely cheaper than bringing in external labour thus developers are expected to use local companies for non-specialised construction, increasing local content at the same time as minimising cost. There are two main elements

[3] Local content is proportion of project contracts given to local (i.e Northern Ireland based) companies.

to onshore infrastructure related to this – the onshore substation and the land part of the electrical export cable. Overall, for 1 GW of offshore wind, this investment amounts to between £24-30 million.

The fourth and final industry we consider could play an integral part in the reshoring of Northern Ireland local offshore wind supply chain is in ports. Belfast is the largest port in Northern Ireland. Ports are key for offshore wind farms as they serve as bases for the O&M crews, which accounts for a non-trivial amount of total offshore wind cost. Unlike the other stages of development, the operation of offshore wind is a longer-term project and is likely to bring continuous benefits to the local area for the lifetime of the projects. Estimated to be around 25 years.

In our cost modelling, using data based on previous UK based offshore wind farms, we assumed that the majority, if not all, of the logistics could be carried out in ports based in Northern Ireland. For the other O&M areas (such as balance of plant and turbine manufacturing) an estimation of 40-60% was made. A key advantage for Northern Ireland is that there is already a large international port operating, which could serve the 1GW of offshore wind capacity. Currently ports could be the base for planned maintenance by specialised crews, however any unplanned maintenance may require specialised equipment would need to be carried out by non-local industries. An important issue here is capacity for ports, there may need to be investment made in local ports to bring to the level necessary for offshore wind. In this paper we have assumed a costless increase in port capacity to enable the operation of offshore wind capacity. This might not be the case but the costing the upgrade to the port is out of scope for this project. It would require higher levels of detail of the current port operations, costs and capacities. Overall, in our modelling, the increase in offshore wind capacity and local content estimates equates to between £31.2 and £46.2 million annually being spent in Northern Ireland based ports for the operation of 1GW of offshore wind.

4. Results and Discussion

The modelling finds that the economy-wide impacts related to the reshoring of offshore wind supply-chain in smaller nations like Northern Ireland highly sector specific, dependant on the size of potential investment and on the sector's links to the rest of the local economy. By far the biggest opportunity for local economic development in the CAPEX stage in Northern Ireland is in the manufacturing of the offshore wind foundations, with the results for the three simulations outlined in Table 3.

Table 3. Summary results for potential economy wide impacts producing of 1GW offshore wind fixed foundations in seven-year period until 2030.

	Low content-80%	Medium Content-90%	High content-100%
Gross Value Added (£m)	168.8	189.9	211.1
Employment (FTE)	3,435	3,864	4,293
Direct (FTE)[4]	1,744	1,962	2,179
In-Direct (FTE)	1,691	1,902	2,114
Investment (£m)	224	252	280

Source: Author's Calculations

As detailed in Section 2, there are already companies based in Northern Ireland, in particular Harland & Wolfe (H&W), which operate in the offshore wind foundation space. Therefore, we expect the vast majority of these structures for the 1GW to be produced in Northern Ireland. Table 5 shows the results for simulations if 80%, 90% and 100% of offshore foundations were manufactured locally. The total investment locally would be between £224 (low content) and £280 (high content) million. The investment related to the foundations, in the high content scenario, could lead to an increase overall in Northern Ireland GVA of £211 million and increase in employment of ~4,300 FTE over the seven-year period until 2030. This employment is split nearly equally between direct and indirect employment with 2,179 (50.8%) FTE in the metal manufacturing sector linked to the construction of offshore wind foundations and the remaining 2,114 FTE (49.2%) in other sectors of the economy. If we focus on only the 100% local content (High content from Table 4) we can explore how investment impacts on a range of economic variables in the long run, shown in Table 4.

[4] Direct employment is employment in the sectors directly related to the production of foundations (e.g fabrication of metal' whereas in-direct employment is employment is in other sectors either through the supply-chain or increase in household spending attributed to increase in employment.

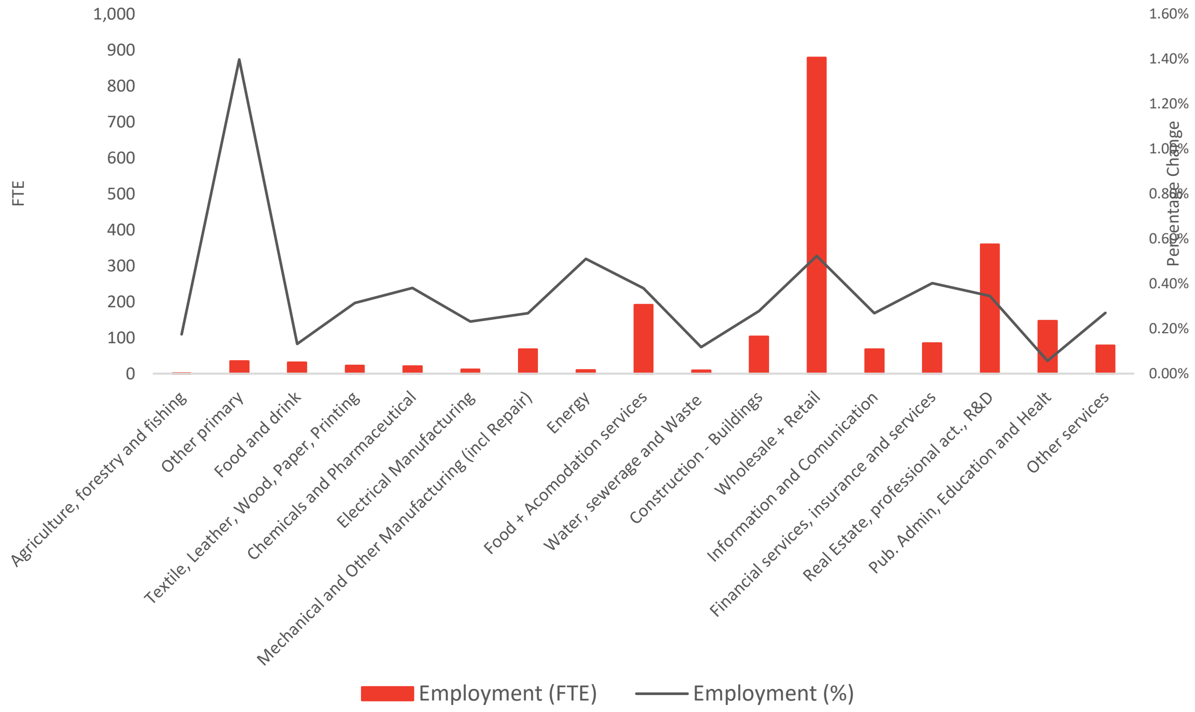
Table 4. Economy wide results if 100% offshore wind foundation is manufactured in Northern Ireland over the seven year period until 2030.

	Change from base economy[5]
GVA	0.55%
Household Consumption	0.39%
Capital Stock	0.49%
Indirect taxes	0.69%
Total Household Tax	0.60%
Unemployment Rate	-0.58%
Employment	0.60%
Government Revenues[6]	0.27%

In the period until 2030 we find an overall increase in national GVA of 0.55% combined with a decrease in the unemployment rate of 0.58%. Increased investment leads to an accumulation of capital stock over time and the increase in employment also leads to an increase in tax revenue, which the Government can then redistribute across the economy. Figure 3 illustrates the indirect employment change by sector.

[5] Baseline economy refers to the economy with no changes (i.e no investment in offshore wind)
[6] Change in total tax income

Figure 3 Indirect employment change by sector related to 100% local offshore wind foundation supply



Already noted was the increase in the manufacturing sector, Figure 3 focuses on the indirectly impacted sectors from investment in offshore wind foundation (100% local content). Focusing on the percentage changes, the analysis indicates that the 'other primary' (1.40%), 'energy' (0.51%) and 'wholesale & retail' (0.52%) sectors are the most indirectly impacted sectors. Manufacturing of metals is a resource and energy intensive industry so you would expect that the increase foundation manufacturing will lead to an increase in energy and materials (bought from both the primary and retails sectors). However, as both the 'Primary' and 'Energy' sectors are not labour intensive, we find that the 1.4% and 0.51% increase in employment in these sectors only leads to an absolute change in employment of 35 and 10 FTE's respectively. 'Wholesale & Retail', with a high labour intensity, does have a large increase in employment of 878 FTEs. Other large absolute increases in employment are 'Real Estate, professional act., R&D (358 FTEs) and' Pub. Admin, Education and Health' (146 FTEs).

Investment in the other sectors follows the same pattern with the increases in capital stock and GVA leading to an increase in employment and household consumption, albeit at a much-reduced scale. Table 5 outlines the summary economy-wide results for 'Electrical manufacturing' and 'Construction' sectors offshore wind developments.

Table 6. Summary results for electrical manufacturing and construction sectors over the period until 2030.

Electrical Manufacturing	Low Content – 80% cable protection; 40% onshore substation	Medium Content – 90% cable protection; 50% onshore substation	High Content – 100% cable protection; 60% onshore substation
GVA (£m)	9.1	11.2	13.4
Employment (FTE)	127	157	186
Investment (£m)	10.4	12.8	15.2

Construction	Low Content -80% onshore components	Medium Content- 90% onshore components	High Content -100% onshore components
GVA (£m)	21.8	24.5	27.2
Employment (FTE)	446	501	557
Investment (£m)	24.0	27.0	30.0

The results in Table 5 reinforce this and the difficulty in producing large economic benefits for Northern Ireland and other smaller nations from reshoring attempts. The opportunities for investment in the electrical manufacturing and construction sectors are significantly reduced when compared to the metal manufacturing, which already is involved in external offshore wind supply chains.

Over the period until 2030 the maximum estimated investment for electrical manufacturing of £15.2 million and £30 million for construction (high content values from Table 7). These will still bring economy-wide benefits in terms of increased employment (up to 186 FTE in electrical manufacturing and 557 for construction) and GVA (£13.4 & 27.2 respectively).

The direct and indirect employment benefits with investment in each of these sectors is also determined. For electrical manufacturing, we find that the direct employment accounts for 36.3% of the total FTEs created, with the remaining 63.7% indirectly created in other sectors. In the construction sector, the share of in-direct employment (54.0%) is also larger than that of direct (46.0%). While the investment in these two sectors is expected to be low, given the impacts are likely to be distributed across the wider economy. Table 6 contains the results for the economy wide impacts of port related expenditure.

Table 6. Economy-wide impacts of expenditure on port services[7]

	Low Content-40% O&M; 80% logistics	Medium Content -50% O&M; 90% logistics	High Content -60% O&M; 100% logistics
GVA (Yearly average) (£m)	28.7	35.7	42.6
Employment (Yearly average)(FTE)	832	1,034	1,235
Investment (yearly average) (£m)	31.16	38.71	46.25
GVA (Cumulative)(£m)	718.2	892.1	1,066.1
Employment (Cumulative) (FTE years)	20,803	25,841	30,878

Table 7 above reports both the yearly and cumulative economy-wide benefits of the operation of 1 GW offshore wind with lifetime of 25 years. On average, the yearly expenditure on the ports system is estimated to be between £31.2 and £46.3 million. This potentially increases Northern Ireland GVA by £42.6 million and adding 1,235 FTE annually. Cumulatively the operation of offshore wind in Northern Ireland could bring in excess of £1.07 billion GVA and 30,800 FTE years to the Northern Ireland economy over a 25-year lifetime.

5. Discussion and wider context

Although this paper focuses on offshore wind in Northern Ireland, the results are relevant to policymakers in smaller nations looking to boost economic activity by reshoring renewable energy manufacturing.

The key takeaway is that a nation's existing economic structure and its synergies with renewable energy manufacturing are crucial to maximizing economic benefits. Our structural analysis reveals that Northern Ireland has a strong metal and marine manufacturing industry, with a long-storied history, that aligns well with offshore wind foundation development. In fact, Northern Irish companies have already produced foundations for wind farms outside the region. Since these industries are already established, reshoring efforts can be streamlined, with the reasonable assumption that the majority of foundations for Northern Ireland based wind farms could be produced locally. Under the high-context assumption

[7] Cumulative is 25 years which is the expected lifetime of offshore wind farms

from the results, reshoring could generate upwards of £200 million in GVA and create nearly 4,300 jobs for 1GW of capacity.

However, when comparing these results to other industries like construction and electrical manufacturing, the limited synergies with the offshore wind supply chain reduce the economic benefits. For instance, reshoring in electrical manufacturing could yield only £13.2 million in GVA, and in construction, £27.2 million for 1GW of capacity. The main limitation is that much of the offshore components and installation are highly specialized, and Northern Ireland lacks the necessary expertise. While policy changes could support the development of these offshore industries, it would take time, and Northern Ireland would still struggle to compete with established players.

These findings highlight the importance for policymakers in smaller nations to assess their current economic structures and identify how they align with renewable energy development. Additionally, the country must have the capability to reshore parts of the supply chain. If there is a disconnect between the most environmentally favourable technologies due to resource (like offshore wind) and the existing economy, policymakers may need to reconsider their energy and reshoring strategies. In such cases, policy might focus not only on environmental and economy-wide benefits but also on others like improving energy security and potentially lowering energy prices.

Our results also emphasise how reshoring affects the types of jobs created. While manufacturing foundations offers significant benefits, the larger economic impacts come from reshoring the operation of offshore wind farms. Many reshoring efforts focus on manufacturing, which typically creates short-term jobs as offshore wind farms take around six years from pre-development to full installation. However, these farms operate for 25 years, so if smaller nations focus on building skills in renewable energy operations, the long-term economic benefits could be substantial.

Even when there is clear potential for reshoring renewable energy manufacturing, like offshore wind foundations in Northern Ireland, policymakers in smaller nations may face other challenges. For instance, it was recently announced that three new Royal Navy warships will be built in Northern Ireland. While this is beneficial overall, it may come at the expense of renewable manufacturing efforts. Warship construction competes directly with offshore foundation manufacturing, straining the labour force and likely pushing offshore developers to look abroad. Policymakers must therefore balance their overall economic strategy with the energy transition, a challenge faced by many smaller nations and regions.

6. Conclusion

The recent Climate Change Act (Northern Ireland Assembly, 2022) set statutory obligation of at least 80% of electricity consumption is from renewable sources by 2030 and also a net zero position in terms of greenhouse emission gases by 2050. This will require significant investment and diversification of the electricity sector, with offshore wind expected to play a key role in the future energy system. Up to 1GW of offshore wind capacity is expected to come online in Northern Ireland from 2030.

As well as reducing emissions an additional goal of the Energy Strategy is to grow the LCREE linked to the development of new technologies through reshoring of manufacturing. Offshore wind is a large scale infrastructure project with the total capital investment needed for 1GW of capacity expected to be between £2.7 billion- £3.3 billion (depending on foundations used), with a further £1.9 billion in O&M costs over an expected 25 year lifetime. However, while this is a large investment, the local economic benefit to Northern Ireland is uncertain due to the specialisation needed for the manufacturing and installation of many offshore wind components.

The purpose of this paper is to investigate the potential areas of the offshore wind supply-chain could be reshored in Northern Ireland and the associated economic impacts. For this We first analyse the current structure of the economy in Northern Ireland then determine if there are any synergies with the offshore wind development process. Using CGE modelling, we estimate the potential growth in these sectors and the economy-wide impacts of the investment.

In our analysis of the current economic structure, we identify four core sectors which have growth potential linked to offshore wind supply in Northern Ireland. The sector with by far the largest potential for growth (and by extension economy-wide benefits) in the construction stage is the 'Metal manufacturing' industry linked to the fabrication of the foundations for offshore wind farms. Companies, such as H&W, are already operating in the offshore wind and we expect these to be major players in the local Northern Ireland offshore wind supply chain. Due to their current penetration in the market, it would not be unreasonable to assume that all tier one offshore wind foundation contracts will be won locally. From our modelling, we estimate that these contracts could be worth between £224 million and £280 million. Through the linkages with the rest of the economy we estimate a total £280 million investment in the fabrication of fixed foundation for 1GW of offshore wind capacity could lead to an increase in economy-wide GVA of £211 million supporting ~4,300 FTEs.

The two other growth industries linked to the construction stage – 'Electrical manufacturing' and 'Construction'- do not have nearly the same potential for economy-wide benefits as the manufacturing of metals. While these sectors are important to the local economy, it will be difficult to penetrate the offshore wind supply chain due to specialised labour and equipment needed. As a result, the estimated maximum economy-wide benefits for Northern Ireland electrical manufacturing contracts with 1GW of offshore wind is only an increase in GDP of £13.4 million and an increase in employment of 186 FTEs. For the 'Construction' industry the economy wide benefit potential is only slightly better at increased GVA and employment of £27.23 million 557 FTEs, respectively. This is driven by only a small proportion of the installation process taking place onshore, most is offshore, which requires specialised labour and equipment that is not available in Northern Ireland.

Local ports are expected to play a pivotal part in the operation of Northern Ireland's offshore wind capacity with the economy-wide benefits expected to be much larger than the three sectors previously identified. On average annually, there is an expected to be an additional £42.64 million of GVA and 1,235 FTEs linked to the running of the 1 GW of offshore wind capacity. Over the 25-year lifetime, this amounts to a total GVA impacts of more than £1 billion and 30,000 FTEs – significantly larger than any of the other sectors analysed in this pape. While we have assumed the ports of Northern Ireland have the capacity from offshore wind operation, more analysis is needed into port capacity and investment requirements for offshore wind.

In conclusion, we have noted that while there will likely be large investment in offshore wind in Northern Ireland, there is only really one current industry (metal manufacturing) in position to be a significant player in the reshoring of manufacturing in the offshore wind. This is not an indictment of Northern Ireland's economy, but rather shows the difficulties for smaller economies to achieve green goals that are economically beneficial. Northern Ireland, like many other smaller economies, does not have the capacity to manufacture or install many of the specialised components needed for offshore wind. While Northern Ireland may develop these industries over time there may not be an incentive for companies to move into the space as it would cost money, there is only limited scope for growth in local offshore wind and it is usually only short term projects. However, to offset this, there may be opportunity for Northern Ireland to focus on the foundations as an area of excellence which could open the potential to export a large number of these to offshore structures worldwide, delivering more longer term benefits.

While it may be difficult to gain a local foothold in the construction and installation of offshore wind, there is great potential in the operation of the farms, particularly as this period lasts for at least 25 years. From a policy perspective the focus of the Energy Strategy maybe on areas of the green transition that are on the smaller scale but last for an extended period, bringing constant benefits which cumulate overtime. An example other than the operation of offshore wind is the construction sector bringing housing stock to the required energy efficiency level.

Even though we use Northern Ireland as a case study the results are relevant for smaller nations aiming to boost economic activity through reshoring renewable energy manufacturing. Northern Ireland's existing metal and marine industries align well with offshore wind foundation manufacturing, which could generate substantial economic benefits, including £200 million in GVA and nearly 4,300 jobs. However, other industries like construction and electrical manufacturing offer minimal economic benefits due to limited synergies with offshore wind.

Policymakers in smaller nations should assess their current economic structure and its compatibility with renewable energy development. If there's a mismatch between the most environmentally favourable technology and the local economy, energy policies may need adjustment to focus on energy security and price stability in addition to environmental goals.

The paper highlights the importance of reshoring not only manufacturing but also the operation of renewable projects for smaller nations and regions, as this offers long-term economic benefits. However, competition from other sectors, such as warship manufacturing in Northern Ireland, could divert resources away from renewable energy efforts. Policymakers must balance economic strategy with energy transition goals.

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