

The economic and environmental impacts of UK offshore wind development: the importance of local content

[Short title: Economic and environmental impacts of UK offshore wind development to 2029]

Grant Allan*, David Comerford*, Kevin Connolly*¹, Peter McGregor* and Andrew G Ross*

*Fraser of Allander Institute, Department of Economics, University of Strathclyde, 199 Cathedral Street, Glasgow, UK, G4 0QU

Abstract

We explore, through simulation of a purpose-built Input-Output model of the UK, the economic and emissions impacts of the likely future development of the UK's offshore wind sector, with a particular emphasis on the importance of local content. We explore six scenarios, including two illustrative simulations of the potential impact of Brexit on local content. We find that future offshore wind development does indeed generate a policy "double dividend" in the form of simultaneous and substantial reductions in cumulative emissions, which in each case exceed a year of the UK's total emissions, and improvements in economic activity (of nearly £30 billion cumulative increase in value-added when the 60% target for local content is achieved). It is also the case that, as anticipated, the scale of the economic stimulus arising from offshore wind development is directly and strongly related to the extent of local content. Future work could extend the modelling to relax the supply side assumptions of input-output modelling, disaggregate the analysis by regions and households to allow assessment of the impacts on the distribution of both economic activity across regions and income among household quintiles.

Highlights

- Changes in local content impact both the economy and environment
- With higher levels of content greater impacts
- Focus on installation implies higher level of territorial emissions
- Impacts of Brexit on UK content uncertain

Keywords: low carbon economy; industrial strategy; supply chain; offshore wind; economic impact; input-output analysis; Brexit.

¹ Corresponding author: Dr Kevin Connolly, Fraser of Allander Institute and Department of Economics, Strathclyde Business School, university of Strathclyde, 199 Cathedral Street, Glasgow, G4 0QU. Email: k.connolly@strath.ac.uk

1. Introduction

Fundamental to UK energy policy is the new ambition to reduce greenhouse gas (GHG) emissions in line with a net zero target by 2050. While the reduction of GHGs is of the utmost importance, the UK Government has stressed that this must not be at the expense of the economy; indeed, recently UK industrial policy has set the ambition to simultaneously grow the economy while reducing GHG emissions [1]. In addition, 2018's Clean Growth Strategy [2] focuses on developing industries which are key to both economic development and the reduction of GHG emission – identifying the offshore wind sector as having a key role to play (reflected in a “Sector Deal” arrangement between the industry and government as agreed in March 2019)[3]. This was anticipated to produce a policy “double dividend” as offshore wind has a beneficial impact on the key policy goals of economic activity and emissions reductions, which have traditionally been regarded as conflicting [4].

Several factors will impact upon the economic and emissions impacts of developments in UK offshore wind capacity. Primarily, the economic impacts on the UK of future offshore wind developments will depend on the level of capacity deployed, but also on the extent to which inputs to projects are sourced from UK firms, i.e. the degree of “local content”. Other countries have similarly adopted targets or ambitions for local content in project expenditures (see for instance Ettmayr and Lloyd [5] for South Africa or Matsuo and Schmidt [6] for the cases of Spain and Mexico).

Local content (in the UK context) has been defined as follows [7]:

“the percentage of the total undiscounted expenditure by the Wind Farm Asset Owner on a Wind Farm that is ultimately spent through Contracts awarded to companies operating in the UK. It excludes the value of Contracts to UK companies that is spent on Subcontracts to companies not operating in the UK. It includes the value of Contracts to non-UK companies that is spent on Subcontracts to companies operating in the UK”

Due to the complex nature of offshore wind developments, with the need for large specialised manufacturing, a considerable amount of local content is concentrated on the development and installation stages of projects. A 100% content target for offshore wind projects would likely be unrealistic as this could reduce competitiveness (substituting higher priced domestic inputs in place of cheaper imported inputs) and increase overall project costs.

There has therefore been much debate on the ‘ideal’ level of local content for offshore wind projects and how this may be achieved. There are several policy measures which can be implemented to support an increase in local content including the imposition of: local content requirements;

financial/tax incentives and favourable customs duties [8]. One aspiration of the recent UK Offshore Wind Sector Deal is to increase UK content in offshore developments from 50% to 60% by 2030 [9]. The impact of local content on delivering local (i.e. UK, in this case) economic impact has been less widely studied.

This paper explores the potential economic and environmental impact of developments in UK offshore wind capacity between 2019 and 2029. We use an Input-Output (IO) methodology, which allows us to link expenditure in different sectors of the UK economy to whole economy impacts, and has become the most widely used technique to estimating the ex-ante impact of changes in the renewable energy capacity. In total, we investigate six scenarios: two based on current local content and potential increases in the coming years; two where the 60% target for local content from the new Sector Deal is achieved; and a further two on the potential consequences of Brexit – the UK's departure from the European Union – where possible changes to the development of the offshore wind industry could lead to significant changes in UK content. However, such changes are at this stage highly uncertain. In each scenario, we vary the scale of local content, similar to how other papers have considered “sensitivity” around point estimates of local content (such as Williams et al. [10]).

There are three novel contributions of our paper. First, we use an electricity disaggregated Input-Output model of the UK in which we have separately identified the backward and forward linkages of the operational offshore wind sector. This permits us to explore the impacts with greater accuracy than using the aggregated electricity sector. The second is to incorporate into the same framework, the impact on environmental indicators. Typically, IO studies assume a fixed relationship between sectoral activity and environmental impacts through the use of emissions-output coefficients. Given the changes in technology within the electricity generation sector, we are able to expand the IO approach to create a time-varying matrix, and endogenously adapt emissions-output coefficients for the electricity generation sector. The third contribution – as introduced above – is our demonstration of the ability to link economic (and emissions impacts) to changes in local content, motivated by technological and policy changes.

This paper proceeds as follows: Section 2 outlines the IO methodology, and our novel contribution relative to previous studies employing this approach. Section 3 outlines the dataset used and our simulation strategy, while Section 4 then presents and discusses the results of the analysis across the six scenarios considered. Brief conclusions and directions for future research are given in Section 5.

2. Literature review

Input-Output modelling has been used extensively in the literature to investigate the economic impacts arising from the move towards a greener electricity network, with a wide range of technologies and geographical areas being modelled. Jenniches [11] provides a detailed literature review of assessing regional economic impacts of renewable energy sources, noting IO as prominent with 45 specific papers using the method between the years 1995 and 2017.

We highlight evidence from a number of recent studies. Mikulić et al [12] use an IO model to model the economic impact of wind development in Croatia focusing on the difference between direct, indirect and induced effects. Croatia being a small economy with little wind expertise, they find limited opportunities for direct impacts from the increase in wind installed capacity. However, the authors note that there is potentially significant indirect (from the supply chain) and induced impacts with continued development. Sanchez-Carrera et al [13] model the impacts of wind energy but focus on peripheral regions - with a study of the Spanish Galicia region – finding significant impact.

Outlined in [11] was the Jobs and Economic Development Impacts (JEDI) family of models, based on IO principles, used for the economic appraisal of various green policies across different regions of the USA. An example of this is Slattery et al [14], with the authors using the standard JEDI model to estimate the local² employment impacts of installing 1.3GW of on-shore wind capacity in Texas. Tegen et al [15] use a modified JEDI model to investigate the impact of installing offshore wind in four regions Of the USA (Mid-Atlantic, Great Lakes, Gulf of Mexico and the Southeast).

Ejdemo and Soderholm [16] investigate the impacts of increasing wind capacity in Northern Sweden by 4GW with a focus on (financial) benefit sharing (such as through a community-fund). With no benefit sharing the authors find modest employment impacts (with a multiplier of 1.4) however, they argue that significant impacts could be realised if even a small share of wind farm profits was allocated to the local government to redistribute. The added economic benefits from local ownership is also explored in Allan et al [17] in the case of the Shetland Islands. Hondo and Moriizumi [18] analyse the employment impacts of the construction and operation of nine different electricity generation technologies through the use of IO modelling. They find an employment multiplier for wind energy of 1.89 with 58.2% of the jobs created in the supply chain (i.e. indirect).

² 100 mile radius around the wind farms.

Similar to wind, there are many examples of IO modelling being used to determine the macroeconomic impacts resulting from investments (i.e. spending) in other renewable/green technologies. In Markaki et al [19] the authors estimate the economic consequences of the 'green' investment (largely spending on renewable electricity) need for Greece to meet the EU2020 energy and environmental targets. Also in the context of Greece, Mirasgedis [20] investigates the employment impacts from utilising renewable energy through the use of an IO framework, finding significant employment impacts with the implementation of energy conversion technologies in Greek buildings.

Both IO and computable general equilibrium (CGE) modelling are used in Allan et al [21] to investigate the potential economic impacts of an increase in Scottish marine energy (wave and tidal) on the Scottish economy, while Fanning et al.[22] and Bere et al [23] use IO methodologies to look at wave/tidal and small hydro in Wales respectively.

Our analysis differs from previous Input-Output economic studies of the consequences of spending on renewable energy developments as the IO database we use disaggregates the electricity sector to separately identify the operational offshore wind sector. There is considerable heterogeneity within the electricity sector – this single sector in the economic accounts includes firms whose primary business is in electricity generation, transmissions, distribution and supply (as well as electricity trading) [24]. This disaggregation promises significantly improved estimates of impacts, since it more accurately tracks the impacts of expenditures on the construction and operational phases of new windfarm investments.

In addition to economic impacts IO models can, through extension, be used to determine environmental impacts of policy changes. Suanmali and Limmeechokchai [25] use an IO model in assessing the economic and environmental impacts of a biofuel utilisation policy in Thailand. They find this could lead to increased economic output (especially in the agriculture sector) while simultaneously reducing CO₂ emissions by up to 10%. In Gemechu et al [26] the authors analyse the effects of a tax on carbon dioxide emissions using an IO model for Spain, finding an unavoidable trade-off among society, the environment and economy. Pascual-Gonzalez et al [27] use a multi-region IO model and optimization strategies to investigate a range of policies to effectively combat climate change in the US.

Other studies, using IO, focus on household consumption changes and how this may impact the economy and environment. Zhang et al [28] note that the recent sustained increase in Chinese consumption has had a positive impact on the economy but has led to increases in emissions. By separately identifying household types within the IO framework, the authors find that urban

residents have a CO₂ impact 1.8 times that of their rural counterparts. Allan et al [29] examine the potential benefits arising from reduced red meat consumption in Scotland, finding a “triple dividend” of increased economic activity, reduced CO₂ emissions and a healthier population.

In this paper we also analyse the emissions impacts resulting from the offshore wind developments in the UK. In doing so, we set out the extent to which the UK could see reductions in emissions alongside increases in the contribution to the generation mix from offshore wind technologies. In much of the previous IO literature environmental impacts have been estimated by using static (i.e. fixed across time) sectoral output-emissions coefficients (i.e. emissions per unit (e.g. £) of output for each sector in the economy). Jenniches and Worrell (2019) note that in the environmental analysis of renewable technologies the fixed coefficient method does not account for substitution away from emission intensive technologies (e.g. coal and gas) and thus underestimates the carbon reduction potential. To overcome this problem we extend the standard static IO emissions method, introducing a time-varying A matrix whereby, over time, the development of offshore wind replaces conventional fossil fuel generation thus reducing the emissions coefficient for the electricity sector.

3. Input-Output methodology and Data

3.1 Input-Output (IO) method

IO models are based on a set of simultaneous equations that record the sectoral linkages within an economy, producing the Leontief inverse matrix [31]. IO models are calibrated using the information from national (or regional) IO tables. These tables provide a snapshot of the economy within an area for a set period of time (normally a year) and represent the monetary value of all these transactions.

Describing the output of individual sectors within an economy, we can specify:

$$X_1 = a_{11}X_1 + a_{12}X_2 + \dots + a_{1n}X_n + f_1 \quad (1)^3$$

$$X_2 = a_{21}X_1 + a_{22}X_2 + \dots + a_{2n}X_n + f_2 \quad (2)$$

.....

$$X_n = a_{n1}X_1 + a_{n2}X_2 + \dots + a_{nn}X_n + f_n \quad (3)$$

Where X_i is the output of sector i and a_{ij} coefficients represents the output of sector i needed to produce one unit of output of sector j . F_i is the sales of sector i to final demand. In matrix notation this can be represented by:

³ This section follows the standard IO methodology detailed by Miller and Blair [31]

$$\mathbf{X} = \mathbf{AX} + \mathbf{F} \quad (4)$$

Which gives the following solution for X:

$$\mathbf{X} = (\mathbf{I} - \mathbf{A})^{-1}\mathbf{F} \quad (5)$$

$$\Delta\mathbf{X} = (\mathbf{I} - \mathbf{A})^{-1}\Delta\mathbf{F} \quad (6)$$

\mathbf{I} is an identity matrix, with $(\mathbf{I} - \mathbf{A})^{-1}$ the Leontief inverse matrix. Equation 6 can be used to explore the impacts on aggregate and sectoral outputs of changes in (exogenous) final demand. This “demand-driven” IO model can be used to estimate the effect of demand changes on different economic variables - including output, employment and GVA – through the use of multipliers⁴.

There are two main variations of the demand driven IO model (i.e. Type I and Type II), which differ in their treatment of households. For Type I the household sector is treated as exogenous to the model and as such is not included in the \mathbf{A} matrix, but within \mathbf{F} . A Type I multiplier captures the direct and indirect change resulting from a unit change in final demand for the output of a sector.

Type II models, with endogenised household consumption through expansion of the \mathbf{A} matrix, also measure the direct and indirect effects along with a third effect, the ‘induced effect’. An increase in final demand requires some increase in labour input, reflected in the increased payment to compensation of employees. This in turn generates additional increases in demand – due the workforce having an increased level of disposable income to spend - and thus output.

Demand-driven IO models make two key assumptions. The first is the assumption of fixed technical coefficients whereby output is always generated through the same share of sectoral inputs: IO models do not allow for substitution effects. Secondly, the supply side is assumed to be completely passive with changes in economic activity determined entirely by changes in demand. This assumes that the increase in demand is always met without increasing pressure on prices or wages; there are no resource constraints.

3.2 IO data

⁴ By calculating coefficients linking sectoral values for, e.g. employment, value added, emissions, to sectoral output we can explore the consequences on a range of indicators of the change in demand. For example, where m_i represents the employment-output coefficient (jobs per unit of output in sector i) we can calculate the change in employment from a change in demand as $\Delta\mathbf{M} = \mathbf{m}_i(\mathbf{I} - \mathbf{A})^{-1}\Delta\mathbf{F}$, where elements within \mathbf{M} reveal the impacts on employment at the sectoral level.

For our analyses, we use a set of 2010 IO tables for the UK as reported in [32]. These are the latest analytical (e.g. Industry-by-Industry (I×I)) tables available at the time of writing. The 2010 IO table is a symmetric I×I IO table with 98 industries defined at the Standard Industrial Classification (SIC) 2007. We disaggregate the electricity sector in these accounts into nine electricity generation sectors: Coal, Gas & Oil, Nuclear, Onshore Wind, Offshore Wind, Pumped, Hydro, Biomass, and Other. To match the information from the offshore wind matrix of cost components, we aggregate the full 98 sector table to 25 sectors, detailed in Appendix A [33].

Data in the IO tables also record socioeconomic characteristics in two dimensions. First, we link two indicators to sectoral output, so that we can explore the activity supported in more than purely economic (monetary) terms (see footnote 4). These are sectoral employment in full-time equivalents (FTE) and sectoral Gross Value Added (GVA). Employment is further broken down in the IO table, providing greater depth to this indicator by reporting (for each sector) employment across nine occupation categories, as given by Standard Occupational Classifications (SOC). We aggregate these to three categories that we term “High”, “Medium” and “Low” skilled for presentation purposes, following a standard approach of aggregation.⁵

Standard IO tables only report a single a single sector covering the electricity sector (SIC 35). As noted earlier, this sector contains firms mapped to the activities within this SIC, which include distinct elements – electricity generation (i.e. the production of electricity), transmission and distribution, as well as retail and trading. These activities are very distinct, meaning that the published (aggregate) electricity sector is unlikely to represent the purchases and sales pattern for any one of these activities. Second, the nature of generation technologies activities means that there is heterogeneity among the (backward) linkages of each technology. Third, the forward linkages of each technology are identical – each sells electricity onwards to retail and consumption uses across the economy. The generation mix therefore has major implications for the pattern of the purchases by the electricity sector in the national accounts. Furthermore, the activities of electricity retail and trading – counted as part of the electricity sector – comprise a major element of the employment within the sector, and so require disaggregation. Finally, disaggregation of the electricity sector is essential, as from the offshore wind bridge matrix (Appendix B), an increase in capacity directly impacts the offshore wind sector.

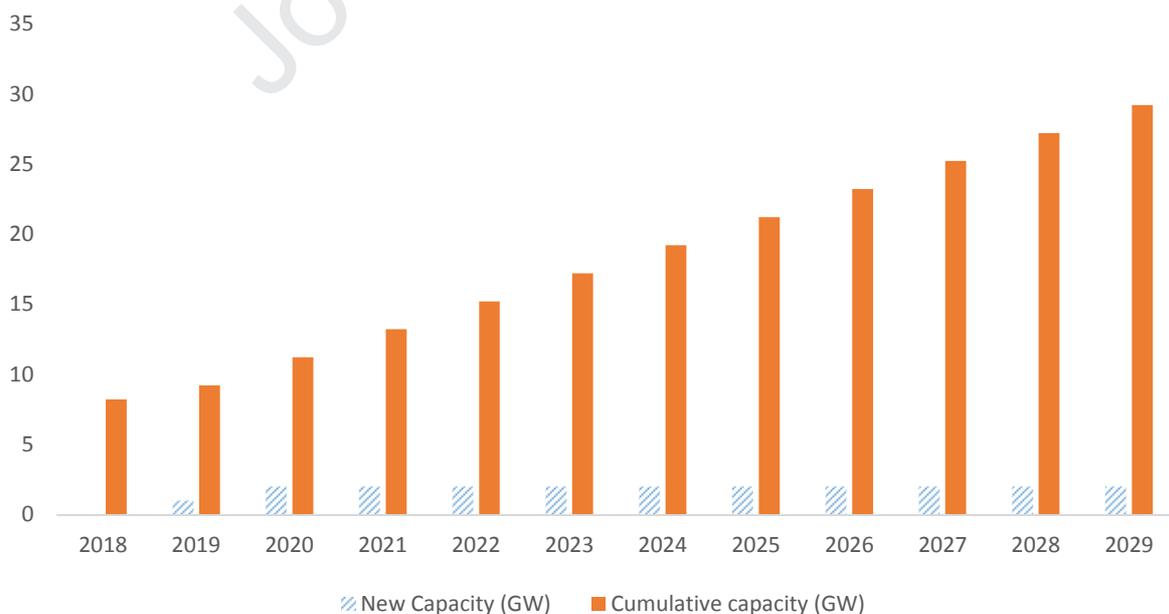
⁵ The nine categories are 1) “Managers & Senior”, 2) “Professional”, 3) “Associate Professional & Technical”, 4) “Administrative & Secretarial”, 5) “Skilled trades”, 6) “Personal service”, 7) “Sales & Customer Service”, 8) “Process, plant & machine operatives” and 9) “Elementary”. Categories 1 to 3 are classed in our later analysis as “High skill”, with categories 4 to 8 and 9 respectively termed, “Medium skill” and “Low skill”.

4. Simulation Strategy

To model the impact of developments in UK offshore wind capacity under our six scenarios, we first calculate, using information from the Offshore Wind Sector Deal, the expected capacity increase from 2019 to 2029 – which will also impact the 2030 UK emissions targets. From this, we estimate the component cost and breakdown for each MW of installed capacity. We then estimate the level of local content of each cost component, using the offshore wind bridge matrix that links cost components to the industrial classification used in our model. We convert yearly component expenditures - accounting for local content, and so with varying expenditure under each category for each scenario – into a set of demand disturbances which are then introduced into an IO model.

4.1 Capacity projections

As outlined in the Offshore Wind Sector Deal, the UK has a clear objective to grow offshore wind capacity by 2030. For all the scenarios in this paper, we assume that the capacity follows the sector deal whereby throughout the 2020s 2GW of capacity is added to the grid each year. This is essentially a linear increase between current capacity and the target for 2029. Figure 1 outlines the increment to capacity each year as well as cumulative capacity.



Source: Authors calculations based on BEIS (2019a,c).

Figure 1: New and cumulative UK offshore wind capacity 2019-2029 implied by the sector deal

4.2 Expenditures

Beginning with capital costs for offshore wind, expenditures on devices can be assigned to a number of different categories. The breakdown of these costs varies depending on a range of factors with location and technology being key. For the cost breakdown of UK offshore windfarms, we consult the information available from [34] [35]. We estimate turbine costs to be around 39% of CAPEX, which is in line with the other studies in the literature [36]. Overall we assume a CAPEX cost per MW of £2.1 million [37].

Along with the cost breakdown there is also a timing issue as capital costs are typically distributed over a number of years. Through investigating several EIA reports [38][39][40][41][42] we estimate that a full development of a ‘generic’ UK farm, from pre-development to full installation and operation takes six years, with the capital expenditures allocation across years summarised in Table 1.

Year 1 (operation minus 6)	Year 2	Year 3	Year 4	Year 5	Year 6 (operation minus 1)
0.37	1.82	16.43	32.12	27.13	22.11

Table 1: Yearly breakdown of CAPEX costs, in %

We also have to estimate operations and maintenance (O&M) costs which support wind farms during their lifetime operation to ensure optimum output. In each of the simulations, we assume that each MW of capacity will be operational for 25 years at a cost of £66,229 per MW per year [43].

4.3 Allocation of spending to industrial sectors

Each of the capital and O&M expenditures are allocated to an appropriate SIC code using the bridge matrix reported in Appendix B to match the UK classification of sectors. Note that the direct impact of installation is heavily concentrated in just two sectors, Iron and steel and Transport.

4.4 Local content

With the focus of this paper on the economic impacts of local content changes we explore six scenarios with different local content assumptions, but the same increase in capacity. The first two scenarios (2019 low and 2019 high⁶) are based on publicly available information for the East Anglia wind farm, outlined in Table 2.

Components	2019 Low content	2019 High content
Pre development costs	80	90
Turbine supply	19	29
Turbine Installation	16	26
Foundation design	50	50
Foundation and pile fabrication	25	53
Foundation installation	5	10
Array cable installation	14	28
Array cable supply	16	26
Grid Transmission	13	29
CAPEX (Weighed average)	22	35
OPEX	71	80
Lifetime total	40	52

Source: Scottish Renewables [44]

Table 2: Local content of different components of offshore windfarms, in %.

In the first scenario, there is an overall a lifetime local content of 40%, there is little manufacturing activity (turbine/array/foundation) cable supply. CAPEX activity that does have significant UK content is Foundation design reflecting the fact that UK expertise in designing offshore oil platforms can be transferred to wind turbine foundation.

⁶ In the low content scenario the developer is passive in its procurement process, while in the high content case the developer is seen as 'active' with its supply chain to maximise the participation of UK companies.

Under the second scenario with a more “active” attempt to increase local content within the supply chain, current offshore wind farms have the potential for an overall UK content increase of 12 percentage points to 52%. In this scenario, there are significant increases in UK content for the electrical infrastructure and foundation fabrication – with more than double previous content. Rather than based on current developments, we make estimates on the local content for the other four scenarios, outlined in Table 3.

Both scenarios 3 and 4 use 2019 high content assumptions as a baseline. In scenario 3, we assume that the 60% content target is met through the turbine supply category⁷ whereas scenario 4 assumes that the target is achieved through installation activities.

Scenario	Local content total	Description
2019 low (Scenario 1)	40%	2019 local content with developer “passive” approach to procurement
2019 high (Scenario 2)	52%	2019 local content with developer “active” approach to procurement
Increased content manufacturing (Scenario 3)	60%	Meet 60% target with focus on installation of components
Increased content installation (Scenario 4)	60%	Meet 60% target with focus on supply of components
Brexit low (Scenario 5)	30%	Brexit leads to relocation out of UK. UK content of activities decrease.
Brexit high (Scenario 6)	70%	Brexit leads to relocation into UK. UK content of activities increases.

Table 3: Simulation scenarios in brief

Scenarios 5 and 6 relate to the potential impact of the UK leaving the EU on offshore wind developments. While the precise timing, shape and implications that Brexit will have is not known at the time of writing, we can speculate that UK energy activities are impacted in a number of ways. Most critical are any implications of Brexit for the stated policy objectives around energy and low carbon policy. Second are the consequences for economic activity, and government revenues, which will be reflected in the scope for government to expand financial support for renewable energy technologies. As a more mature technology, offshore wind may conversely benefit from reduced funding for technological development of renewable energy.

⁷ Turbine manufacturers have already begun to invest heavily in the UK.

Two factors combine to create what is known as the Home Market Effect [45]: returns to scale mean that the industry will agglomerate, while trade costs mean that this agglomeration will occur in the largest market (the Home market). Brexit will likely increase trade costs, and the UK is a very significant market for the offshore wind industry. The Brexit related increase in trade costs could incentivise the location of the supply chain within the UK to avoid trade costs associated with imports from the EU. Alternatively, Brexit related increase in trade costs could incentivise the location of the supply chain in the rest of the EU if this is deemed to be the most important market. The supplementary material sets out how we might formulate a simple model to explore the trade-offs which could exist.

Our two scenarios cover alternative possibilities coming from Brexit. In the first scenario, labelled ‘Brexit low’, we assume Brexit leads to multinational companies moving operation from the UK resulting in lower local content for offshore wind. In the second Brexit scenario (‘Brexit high’) the assumption made is that developers use a higher level of local content to avoid trade costs associated with imports from the EU.

4.5 Varying the A-matrix IO model and carbon emissions

A key objective of increasing offshore wind capacity is to reduce greenhouse gas emissions through the replacement of fossil fuel generation. In the standard IO framework outlined in Section 3.1 this replacement of capacity would not be captured due to the static \mathbf{A} matrix. In our modelling, we adapt the IO framework by introducing a time varying \mathbf{A} matrix in which the increase in offshore wind capacity replaces fossil fuel generation, which is particularly useful for the calculation of emission impacts.

First, the potential power output (in MWh) arising from the increase in offshore wind capacity (in MW) is estimated. We use input information from BEIS [46] and develop a power-to-capacity coefficient for UK offshore wind.

$$pf = \frac{\text{Output (GWh)}_8}{\text{Capacity (MW)}} \quad (7)$$

⁸ We take power coefficient as the average over the last 5 years

Applying this power coefficient to the capacity information presented in Figure 1 generates the level of UK electrical output, per year and cumulative, that is replaced by offshore wind. The assumption made here is that the offshore wind capacity will initially replace coal generation then gas, in line with UK energy policy. Using this information we adapt the offshore wind and fossil fuel generation coefficients within the **A** matrix as:

$$a_{fossil,eled}(T) = a_{fossil,eled}(2010) * \frac{\text{cumulative of offshore wind output (MWh)}(T)}{\text{fossil fuel generation (2010)}} \quad (8)$$

$$a_{offshoreW,eled}(T) = a_{offshoreW,eled}(2010) + a_{fossil,eled}(2010) - a_{fossil,eled}(T) \quad (9)$$

$$a_{offshoreW,eled}(T) + a_{fossil,eled}(T) = a_{offshoreW,eled}(2010) + a_{fossil,eled}(2010) \quad (10)$$

With equation (8) the a coefficient of inputs to the electricity distribution sector (*eled*) from the fossil fuel at time t is determined by scaling the 2010 a coefficient by the ratio of offshore wind generation at time t and fossil fuel generation in 2010. The increase the a coefficient of inputs to the electricity distribution sector from the offshore wind (*offshoreW*) at time t is the difference between the fossil fuel a coefficient in 2010 and time t . Equation (10) ensures overall the totals of the **A** matrix remain unchanged, with only the offshore wind and fossil fuel elements updating. These are then introduced at each time-step of the modelling in Equation 6.

We use this model to account for the change in emissions through the increase in offshore wind capacity. In this paper, we recognise two sources of changes in carbon emissions attributable to the increase in offshore wind. First, emissions are generated throughout the economy by the construction and operation of offshore wind capacity. Second, however, the increase in offshore wind capacity replaces fossil fuel generation, affecting the electricity mix and so reducing emissions; indeed this is a key part of the motivation for policies encouraging the substitution in favour of renewables. We estimate the change in emissions arising from both sources, using emissions multipliers calculate from ONS [47].

5. Results/Discussion

5.1 Economic impacts

Table 4a reports the economic impacts of increasing UK offshore wind capacity to 2029 with 2019 low local content assumptions, separated into 'direct', 'indirect' and 'induced' effects, as well as two

distinct time periods. The first column, labelled 2014-2029, is the construction stage during which all capacity is constructed, while the second column - labelled 2030-2054 - is the operational stage of the wind farms (i.e. in which no further construction/installation is assumed to take place).

	2014-2029	2030-2054	Total
Direct			
<i>Output</i>	13,799	19,012	32,810
<i>GVA</i>	4,814	7,925	12,740
<i>Employment</i>	66,900	76,700	143,600
Indirect			
<i>Output</i>	10,035	15,814	25,849
<i>GVA</i>	4,432	7,179	11,611
<i>Employment</i>	75,700	126,200	202,000
Induced			
<i>Output</i>	15,967.	22,073	38,041
<i>GVA</i>	4,135.	5,716	9,851
<i>Employment</i>	77,200	106,700	183,900
Total			
<i>Output</i>	39,802	56,899	96,701
<i>GVA</i>	13,382	20,820	34,202
<i>Employment</i>	219,900	309,600	529,500

Note: Output in £ million, GVA in £ million, and Employment in FTE

Table 4a: Potential cumulative economic impacts of UK offshore wind to 2029 with 2019 low local content (scenario 1) (Non-discounted)^{9,10}

Table 4a illustrates that cumulatively the economic impacts are larger during the operational stage of the project than the construction stage, due to the larger spending (direct) occurring at the operational stage¹¹. There is larger average investment during the construction stage in this scenario, but the operational stage is much longer, thus the higher direct expenditure. Also we find from Table 4a that the sum of indirect and induced impacts – that occur through the UK offshore wind supply chain - are much larger than the direct effects, with the combination of indirect &

⁹ Results have been rounded to the nearest 1 for monetary value and 100 FTE

¹⁰ In this paper we focus only on the impacts arising from the increase in offshore wind capacity. Likely previous IO analysis 'net' impacts are not modelled.

¹¹ In other Scenarios, this may not necessary be the case as an increase in local content at the CAPEX stage will increase capital investment at the construction stage.

induced impacts accounting for 63% and 73% of the cumulative total impacts on GVA and employment totals respectively.

In Table 4b we report the economic impacts found in Table 4a in present value terms (i.e. using a discount factor of 3% to calculate the value of impacts “today”). With the operational stage occurring much further in the future, we find that (for scenario 1) with discounting, the construction stage impacts are now larger than those for the operational stage. In addition, we find that for output and employment during the construction stage, induced impacts are larger than direct.

Table 5 summarises the cumulative (i.e. the sum of all economic impacts across all time periods, in present value terms) aggregated results of our simulations¹². As expected, the macroeconomic impacts increase with the proportion of local content. This occurs as a larger proportion of spend is on outputs produced by UK-based companies. Comparing the two 2019 scenarios (Scenarios 1 and 2), for example, we find that with a local content of 40% the expected increase in GVA and employment of £19.9 billion and 311,800 FTEs respectively. With a 12 percentage point increase in local content to 52%, the Type II GVA and employment impacts increase to £26 billion and 414,200 FTEs.

Although both Scenarios 3 and 4 have 60% local content, the results differ slightly – though both have significantly greater impact than the previous two scenarios. If the increase in content is focused on manufacturing of components (Scenario 3) we find there is a cumulative GVA increase of £28.9 billion and increase of 465,100 FTEs. However if the content is focused on installation of components we find that the impacts are greater, with GVA increasing to 29.8 billion and employment 478,300 FTEs, £877 million and 13,200 FTEs larger than in Scenario 3. Recall, there has been no change in the overall scale of offshore wind capacity between these scenarios; these differences in GVA and employment occur as the sectors involved in the installation of wind farm components have a higher GVA- and labour-intensity than those involved in manufacturing.

¹² We focus on the Type II results, which reflect the combination of direct, indirect and induced changes. See Emonts-Holley et al [48]) for a detailed discussion of calculation methods of Type II multipliers.

	2014-2029	2030-2054	Total
Direct			
Output	10,958	9,472	20,430
GVA	3,845	3,949	7,794
Employment	53,200	38,200	91,400
Indirect			
Output	6,893	7,022	13,916
GVA	3,056	3,205	6,262
Employment	54,010	57,900	111,900
Induced			
Output	12,001	10,45	22,456
GVA	3,108	2,707	5,815
Employment	58,000	50,546	108,600
Total			
Output	29,853	26,948	56,801
GVA	10,010	9,861	19,870
Employment	165,200	146,600	311,800

Note: Output in £ million, GVA in £ million, and Employment in FTE.

Table 4b: Potential cumulative economic impacts of UK offshore wind to 2029 with 2019 low local content (scenario 1) (discounted)

	2019 low (Scenario 1)	2019 high (Scenario 2)	Increased content manufacturing (Scenario 3)	Increased content installation (Scenario 4)	Brexit low (Scenario 5)	Brexit high (Scenario 6)
Output	56,801	75,999	85,891	87,027	40,418	101,882
GVA	19,870	25,998	28,876	29,753	14,291	34,405
Total Employment	311,800	414,200	465,100	478,300	224,500	556,400
- High skill	132,400	174,600	195,000	200,600	95,700	232,800

- Medium skill	139,700	187,200	211,600	218,000	100,100	254,200
- Low Skill	39,700	52,300	58,500	59,700	28,700	69,400

Note: Output in £ million, GVA in £ million, and Employment in FTE.

Table 5: Summary cumulative results for all six simulations, Type II (present value)

The final two scenarios relate to the potential impact of Brexit on local (i.e. UK) content in the offshore wind sector. To recall, in 'Brexit low' we assume that multinational companies move operation from the UK resulting in lower local content for offshore wind, and in 'Brexit high', we assume that developers use a higher level of local content to avoid tariffs. In Table 5 we show that in the 'Brexit low' scenario the economic impacts are the lowest out of all six scenarios with an output £40.4 billion, GVA £14.3 billion and 224,500 FTEs. In the 'Brexit high' case where there is an expansion of this sector within the UK, the economic impacts are the largest with an increase in an output of £101.8 billion, GVA £34.4 billion and 556,400 FTEs

The IO framework allows for separation of employment by skill level (high, medium, low). We find that both current content scenarios favour high skilled labour. Scenario 1 has both the largest proportion of high skill (42 %) and low skill (13 %) employment, indicating the lowest proportion of medium skill employment at 45% of total. Scenario 2 has a slightly lower high skill employment proportion of (42%) than Scenario 1 but has a smaller percentage of low skilled employment (13%). Comparing Scenarios 3 and 4 we find that for both the proportion of high skill employment is the same at 42%, however there are difference in medium and low skill employment proportions. Medium skilled employment represents 45.58% of total in Scenario 3 compared with 45.50% in Scenario 4, indicating that employment supported by growing UK content through increasing wind farm manufacturing sector jobs are (marginally) lower skilled than when local content is increased in installation activities.

Comparing Scenarios 3 and 4, we find that for both the proportion of high skill employment is the same at 42%, however there are difference in medium and low skill employment proportions. Medium skilled employment represents 45.50% of total in Scenario 3 compared with 45.58% in Scenario 4, indicating that wind farm manufacturing sector jobs are slightly lower skilled than installation.

For the Brexit scenarios, the lower content has a higher level of high skilled employment that with the Brexit high scenario – 42.61% compared with 41.83%. However the there is also a higher level of low skilled employment, 13% and 12% for the Brexit low and high scenarios respectively.

Figure 2 reports the annual impacts on output and GVA for each of the six scenarios over the period from 2019 to 2032, illustrating that the general distribution of impacts over time is the same for each scenario; they differ only in terms of their scale. From 2019 to 2025 there is a steady increase in output and GVA, occurring as there is increasing capacity in development with peak output and GVA impacts being reached in 2026. This peak occurs as a large proportion of capacity is in the construction stage (years 2-6) at this time (see Table 1). After 2026, the impacts steadily decline as the CAPEX stage is coming to an end in 2029 with the installation of the last additional capacity. From 2030 onwards, as we reach the stage in which only O&M expenditures are incurred, we find that the impacts are constant as the O&M cost per MW per year is kept constant. At year 2045, due to the capacity beginning to be decommissioned, the GVA and output impacts start to gradually decrease until 2054 when the last of the operational capacity lifetime ends.

In addition to impacts on aggregate economic activity and employment, the IO model generates estimates of sectoral impacts. Figure 3 displays the changes in sectoral Type II GVA associated with each scenario for the peak year, 2026.

The sectors which benefit the most from the development of UK offshore wind capacity are: services, other transport, manufacturing, construction and the offshore wind sector itself. The Service and the Other Manufacturing sectors not only benefit from a direct demand increase but also from very strong linkages with the other sectors directly stimulated, notably the Iron & Steel sector and Non-ferrous Metals sector (which receive a large direct increase).

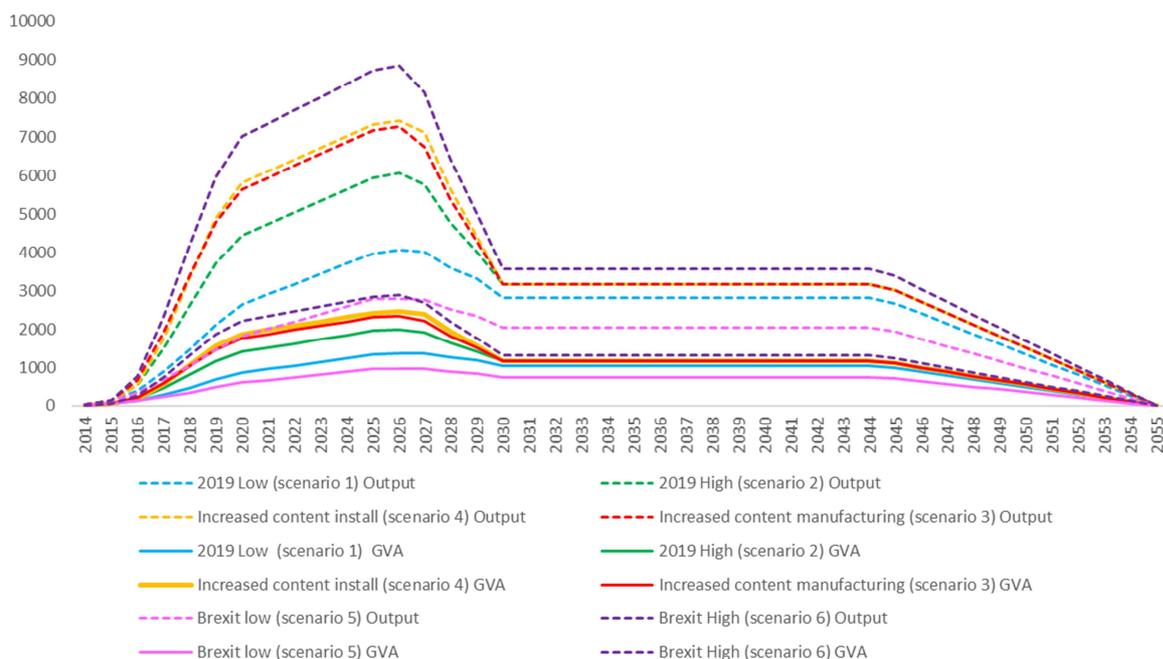
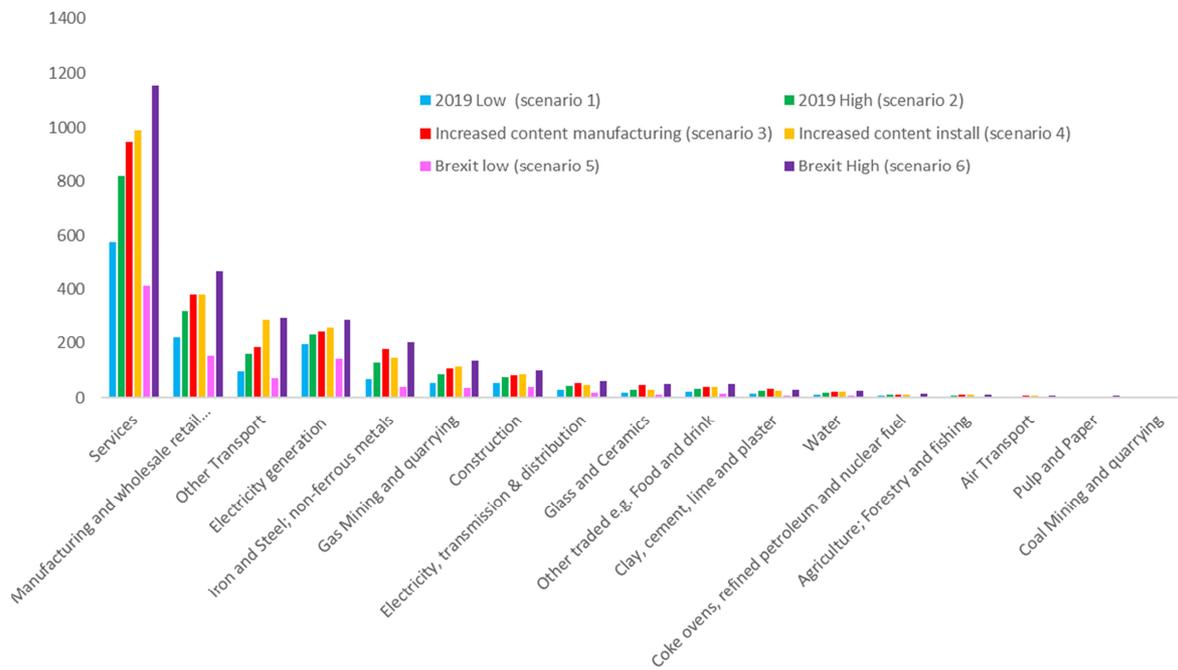


Figure 2: Output and GVA timing impacts, in £million**Figure 3: Sectoral GVA results for 2026, in £million**

5.2 Environmental impacts

Table 7 shows the cumulative emissions resulting from the construction and operation of UK offshore wind capacity to 2029. The first column provides estimates of the increase in emissions associated with the construction and operation of the increased wind capacity using the 2010 **A** matrix, whilst the second column provides estimates using the time-varying **A** matrix model. The third and final column provides estimates of the emissions that are saved as a consequence of the displacement of fossil fuel generation.

As would be expected, the increase in UK offshore wind local content leads to an increase in UK territorial carbon emissions due to the associated increase in demand throughout the economy. We find that the using the base modelling framework results in larger construction emissions, as would be expected as there is still large coal generation. However when using the time varying **A** matrix, accounting for offshore wind replacing fossil fuel generation, we find significant reduction in the construction emissions.

	2010 Base construction	Time-Varying A matrix construction	Total replacement
2019 low (scenario 1)	26,787	23,432	-645,722
2019 high (scenario 2)	40,888	36,295	-632,859
Increased content manufacturing(scenario 3)	48,382	42,982	-626,172
Increased content installation (scenario 4)	56,837	51,997	-617,158
Brexit low (scenario 5)	18,660	16,357	-652,797
Brexit high (scenario 6)	63,763	57,742	-611,412

Table 7: Cumulative changes in emissions resulting from the construction of UK offshore wind, 2019 to 2054, in Mt CO₂e

Overall, we find in all scenarios, over the lifetime of the projects, substantial carbon emission replacements - of between 611,410 and 652,790 Mt CO₂e – which accounts for more than a year worth of current overall UK carbon emissions (BEIS 2019d). Comparing Scenarios 3 and 4, where local content increases to 60%, we find that if the increase in local content occurs through the installation processes then this would lead to greater territorial emissions than if the focus was on manufacturing (because the former is associated with the greater stimulus to economic activity). This occurs as installation relies heavily on transport sectors, which are oil-intensive activities.

As outlined previously, the increase in offshore wind capacity is being driven by UK policy ambition to significantly reduce carbon emissions with there being two current targets – a 57% reduction in emissions by 2030 (compared with the 1990 level) and Net Zero carbon by 2050. We have modelled the increase in capacity to 2029 which will contribute to meeting the 2030 intermediate target. For each scenario in 2030 (when all turbines are operational) the increase in capacity will replace 21.34 Mt CO₂e of emissions from conventional generation (2.76% of 1990 base emissions). There will however be, emissions associated with the operational wind farms which we calculate, depending on scenario, to be between 0.37 and 0.42 Mt CO₂e. It is also clear from our results that there is considerable potential for the further development of offshore wind to make significant additional contributions towards the net zero target, beyond 2030, in combination with other policy initiatives (for example, to encourage EV adoption).

6. Conclusions

In this paper we explore, through simulation of a purpose-built input-output model of the UK, the economic and emissions impacts of the likely future development of the UK's offshore wind sector,

with a particular emphasis on the importance of local (i.e. UK) content in the necessary goods and services required to install and operate offshore wind capacity. This allows us to assess the extent to which the future development of offshore wind is likely to both stimulate economic activity and make a significant contribution to the Government's net zero target for emissions, creating a policy "double dividend". Furthermore, our modelling provides a systematic assessment of the potential importance of local content in these future developments.

Our model simulations explore the economic and emissions impacts of a number of possible alternative futures for offshore wind. We explore six scenarios. Two of these are based on publicly available information for the East Anglia windfarm. Even on the local content assumption implied by a developer with a comparatively passive approach to procurement, there are substantial GVA and employment effects, with cumulative effects on value added of over £19 billion and employment of over 310,000 full time equivalents (FTEs). However, under a more pro-active procurement policy that raises average domestic content from 40% to 52% the cumulative economic impacts are increased significantly (to £26 billion and over 410,000 FTEs). While more active procurement reduces the savings in cumulative displaced territorial emissions slightly (by around 14 thousand Mt CO₂e), total emissions savings remains very substantial, at 633 thousand Mt CO₂e.

Two further simulations explore alternative ways in which the sector might meet the 60% sector deal target for domestic content. Naturally, successful achievement of the 60% target – stated in the Offshore Wind Sector Deal - further augments the economic impacts, to over £28 billion GVA and employment of over 465 thousand FTEs in both cases. However, it transpires that achieving the target through improving the domestic content of installation activity has a bigger economic impact, raising GVA by £877m and employment by 13 thousand FTEs). Territorial emissions are less favourably impacted in this case (they fall by 11 thousand Mt CO₂e), but overall emissions savings remain substantial at 617 thousand Mt CO₂e) than if the target is attained through increasing the domestic content of turbine supply. The composition, as well as the scale, of the domestic content of inputs matters for both economic and environmental impacts

The final two scenarios relate to the possible impact of the UK leaving the European Union (Brexit) on our results. Theoretical considerations suggest that the direct impacts of Brexit on the offshore wind sector are ambiguous. Brexit-induced increased trade costs could incentivise location of the supply chain in the UK, an important market for the sector, to avoid higher costs associated with imported inputs from the EU. On the other hand, the increased costs could lead to the supply chain being incentivised to move to the EU if it is regarded as the most important market. In the former case, the result is comparatively good news for the industry in the UK (abstracting from the

macroeconomic spillover effects resulting from the impact of Brexit on other sectors, which are very likely to be negative). Otherwise, Brexit is likely to adversely affect the UK economic impact of offshore wind development by reducing domestic content.

Naturally, the further investment in offshore wind capacity associated with the more optimistic Brexit scenario involves some additional emissions, but this effect is swamped by the savings in emissions that result from substituting wind for coal in the generation of electricity.¹³ Overall, there is a very substantial cumulative saving in emissions across all scenarios - of between 611,400 and 653,800 Mt CO₂e – which accounts for more than a year's worth of current overall UK carbon emissions.

Overall, we find that future offshore wind development does indeed generate a “double dividend” in the form of simultaneous and substantial reductions in emissions – a major contribution to net zero - and improvements in economic activity. It is also the case that, as anticipated, the scale of the economic stimulus arising from offshore wind development is directly and strongly related to the extent of local content, providing supportive evidence for the emphasis of the Offshore Wind Sector Deal. While increases in local content do also increase territorial emissions these are modest relative to overall emissions reductions and decline through time as renewables penetration increases. Future research could explore the consequences of: relaxing the assumptions underpinning the input-analysis (and, in particular, allow for non-passive supply); disaggregating the analysis to provide an assessment of impact on the regions of the UK given recent policy emphasis on “levelling up”; incorporating households by income quintile to allow an assessment of impacts on the distribution of income.

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¹³ Note also that, if offshore wind capacity is required to reduce global emissions, the new capacity has to be located somewhere, in which case the emissions associated with construction, installation and operation are unavoidable.

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Highlights

- Changes in local content impact both the economy and environment
- With higher levels of content greater impacts
- Focus on installation implies higher level of territorial emissions
- Impacts of Brexit on UK content uncertain

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Declaration of interests

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests:

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