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ECONOMIC ACTIVITY SUPPORTED BY OFFSHORE WIND: A HYPOTHETICAL EXTRACTION STUDY

BY

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Economic activity supported by offshore wind: a hypothetical extraction study

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Abstract

Given public investment in renewable energy technologies, it is important to understand the contribution these make to the economy. Various methods have been used to quantify impacts, such as job counts, surveys and measures based on economic statistics. Economic modelling approaches on the other hand appear to offer an ability to both provide metrics of interest to policy makers, and crucially an understanding of the activities which support that contribution. In this paper, we implement a "hypothetical extraction" of UK activities related to renewable electricity generation – specifically focusing on offshore wind – to identify the contribution that they make to economic activity as well as job quality, and emissions. Undertaking the partial extraction of offshore wind from an aggregated IO table, and then subsequently from one in which we have separated out the offshore wind electricity sector, we highlight the value of more disaggregation and technology-specific detail in economic accounts. We find that a significant portion of activity supported by offshore wind is supported by expansions in capacity, in addition to the operation of existing offshore wind activity, giving policymakers important information on the likely path of economic impacts related to renewable energy activities.

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

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1. Introduction

Renewable energy activities are crucial in contributing to UK climate change targets, such as the recent committed to reduce greenhouse gas emissions to *net*-zero by 2050 (Committee on Climate Change,

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2019). A key policy focus is to strengthen activities on the supply of low-carbon electricity. For example, the UK has set out a renewed direction for offshore wind – building on its 2017 Industrial Strategy (HM Government, 2017). This strategy also set in motion the process of Sector Deals, though which government and representatives of industry across the economy negotiated a set of objectives and agreements, laying out actions and responsibilities for both to deliver against the government's industrial objectives. Specifically, the Industrial Strategy identifies that "The move to cleaner economic growth… is one of the greatest industrial opportunities of our time" (HM Government, 2017). This has ushered in a new phase of energy policy where the wider (national) economic benefits are acknowledged as a specific objective of policy (Watson, 2019).

The major economic outcome from the Offshore Wind Sector Deal in addition to up to 30GW of capacity, and increased exports of UK knowledge in offshore wind, is unambiguously stated in terms of spending in the UK economy, and the creation of jobs (HM Government, 2019). It is clear that more (offshore) wind, rather than less, is implied by the current policy stance so that wind energy will be increasingly important for UK energy production.

Measuring the economic impacts of low-carbon energy policies ex-ante and ex-post must therefore be a top priority. Measuring and defining the contribution of the "offshore wind" sector, however, is a difficult business. Common approaches are first, the use of surveys of businesses, asking if they are active in a particular activity (e.g. HM Government, 2013; ONS, 2019), or second, the identification of specific industries from economic accounts to track developments in economic statistics for a particular group of activities over time. The Scottish Government's (2018) characterisation of its "growth sectors" uses this second approach, for example.[2]

We argue that multisectoral economic accounts and the hypothetical extraction method (HEM) can be useful in identifying the economic contributions of renewable energy activities. This is a widely used method in industrial analysis (Dietzenbacher & Lahr, 2013) and has been applied to consider the economic and environmental impacts of a wide range of individual sectors in a number of countries/regions. In essence, the HE approach developed from "key sectors" analysis, to show the contribution of individual activities and to compare different sectors' economic impacts. Its typical use is to show the effect of full closure of an individual sector, with the loss of its own activities plus the activities which are supported by that sector's sales to and purchases from all sectors in the economy. The sector's impact is measured by the effect of its (hypothetical) extraction from the economy as a whole. We show how the economic activities associated with the renewable energy sector can be captured within the HE approach, to generate estimates of their economic and environmental (emissions) contribution.

A second contribution is empirical. We show how the HE technique can be used to consider the economy-wide impacts of closure of the offshore wind industry in the UK. Whilst we use the UK offshore wind sector as a case study, the general issues identified and methods employed, have wide applicability to renewables as a whole and to other nations and countries engaged in low carbon electricity generation. Our application has an additional empirical novelty in that use an IO table with a disaggregated "electricity sector". While this is currently treated as a single sector in UK IO accounts, disaggregation of the electricity sector is of considerable importance for policy given that a major thrust of energy policy is to alter its composition in favour of renewables. This allows us to compare partial HE of offshore wind from the aggregated electricity sector as it appears in current IO accounts – the best

[2] See Allan et al. (2017) for a review of such counts of employment related to low carbon and renewable energy activity for Scotland.

estimate that can be obtained using that database - with HE applied to the electricity-disaggregated IO table.

Third, by looking at impacts beyond output – specifically emissions and employment (including the 'skill' classification of jobs) we move the conversation of economic impact beyond the use of a single metric, namely jobs (Connolly et al, 2016), and closer to the concept of "green jobs". While the focus on job counts associated with renewable energy are still important for policy, there is growing interest in the "quality" of employment supported by renewable energy (e.g. the UK's recent Offshore Wind Sector Deal (HM Government, 2019) outlines ambitions to raise the economic contribution to 27,000 *skilled* jobs by 2030). Of course, extension to consider the contribution of renewables to emissions, as well as to the economy, further enhances the policy relevance of the analysis.

The paper proceeds as follows. Section 2 outlines existing techniques used to explore employment impacts of renewable energy, principally those using surveys (e.g. ONS, 2019), economic statistics (e.g. Scottish Government, 2018) and those which use spending approaches and multipliers from Input-Output tables (e.g. Slattery et al, 2011; Eurobserv'ER, 2018; Kaček et al, 2019). Section 3 sets out our multisectoral modelling approach, including how we extend and apply the HE method to assess the full economic contributions of the offshore wind sector. Section 4 presents the results, while Section 5 concludes.

2. Measuring the offshore wind sector

Measuring the economic contribution of the renewable energy sector is challenging. We illustrate our approach with a specific application to the offshore wind sector to make this question more specific and tractable. There are three approaches to measure the impact of offshore wind:

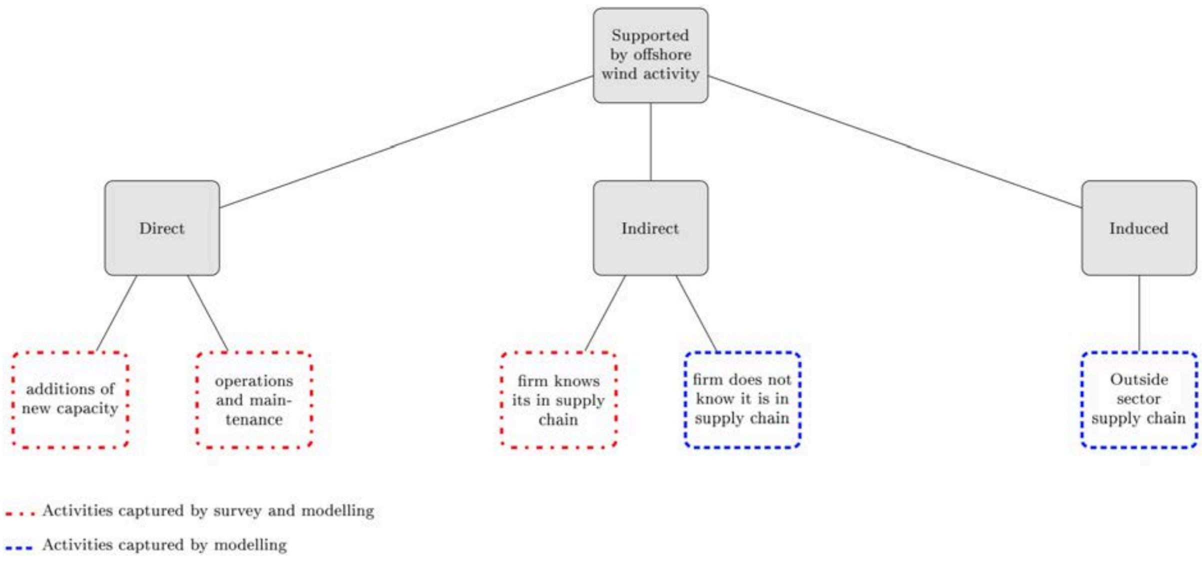
- activity by firms identifying themselves as active in offshore wind energy;
- activity concerned with the production of electricity from offshore wind technologies;
- activity supported by spending on offshore wind energy;

The first option is perhaps the metric that users of the estimates of economic contribution of the offshore wind energy sector expect a count to measure. In the UK, the ONS's "Low carbon and renewable energy economy" survey – sent to firms across the economy – asks firms across the economy to identify if they undertake activities relating to the use of the good/service they provide across seventeen different categories relating to renewable energy or low carbon activities. For offshore wind, the survey asks firms if they are involved in, "The production of electricity from offshore wind renewable sources and/or the design, and/or production, and/or installation of infrastructure for this purpose, including operations and maintenance".

It is instructive to define two commonly used terms: first, the "direct" effect – i.e. those activities which the spending supports in those activities where the spending is made. For example, spending on turbine blades will support activity in the production of turbines. Second, the "indirect" or "induced" effects – i.e. those activities which are supported elsewhere in the economy by the direct expenditure, through supply chain links (for the former) and additional income and consumption effects for the latter. In both, the notion of the "multiplier" is central: the direct expenditure supports further activity through intermediate demand (the supply chain for the activities experiencing the direct effect) and through higher income generating additional consumption. The total economic activity attributable to the renewable energy expenditure is thus identified as the sum of direct, indirect and induced effects.

There is a clear issue here with the identification of renewable activities through such surveys, which we use Figure 1 to identify. Of the activity (e.g. number of firms, turnover or employment) supported by offshore wind: the survey identifies firms which undertake activity for new additions of capacity, operations and maintenance, plus those companies who "know" that their products are used in offshore wind (in either O&M or new capacity). Consider the example of a firm producing parts which are used in a gearbox, for instance: The gearbox producer would clearly answer "yes" to the question above, and if the parts company (supplying the gearbox producer) know that their products are used in that (offshore wind) activity they would also respond positively. Firms who do not know that their products are used in offshore wind would not respond positively, and so would be missing from the reported count. This is identified in Figure 1 as those jobs which would be supported by offshore wind through "indirect" links, but where the firms are not known to be the supply chain.

Figure 1: Classification of jobs supported by offshore wind activity



A final group of survey respondents would be those whose activity is supported by the "induced" activity of the offshore wind sector. For instance, those firms receiving spending from workers in direct and indirect activity would likely be unaware that a portion of their activity can be traced back to offshore wind. An example of retail or accommodation providers illustrates a portion of activity which would be omitted.

The second option – activity concerned with the production of electricity from offshore wind technologies - would be straightforward to identify were such activities identified in economic accounts. The production of electricity has a Standard Industrial Classification (SIC) code (35.11) and so the Input-Output (IO) accounts could identify the purchases and sales for whom this is their predominant activity. The "direct" activity would be readily identifiable, and updated each year (or more frequently) with the release of official statistics.

This approach however has two disadvantages. First, there will be activity in the economy, related directly to offshore wind activity, which does not feature within the SIC related to electricity production. For instance, the construction of new turbines or production of equipment for the addition of capacity would not be considered[3]. Second, the accounts are not sufficiently detailed to identify the production of electricity from different technologies within SIC 35.11 (such as offshore wind).

The third approach examines spending on offshore wind energy (this is crucially important given the commitment to further capacity, not just in the UK). This expenditure could be captured in the IO tables as the production of goods for investment – a category of final demand, rather than production. Spending-derived estimates of the activity supported by renewable electricity are becoming more common. Jenniches (2018) finds that IO modelling of expenditure related to renewable energy is a commonly applied technique. EurObserv'ER (2017) sets out an example of this approach – employed in Eurobserv'ER (2018) - through which activity supported by additions to capacity and Operation and Maintenance (O&M) can be estimated. A spending-driven assessment would identify the activity related to offshore wind spending. Identifying that which is supported by expenditure related to new additions of capacity, this would be the "direct" activity supported by offshore wind. Additional activity in the firms supply chain (and these of households) are captured through "indirect" and "induced" effects[4].

While this final approach has usefulness – consistency in implementation across countries for instance, and the ability to look beyond metrics of employment, and to other variables such as Gross Value Added (GVA) – it does not seek to embed this measurement in the economic accounts for each country. In the next section, we propose how the multisectoral framework of IO tables could be used to account for the economic activity supported by renewable energy, illustrated with the specific case of offshore wind in the UK.

3. Exploring the offshore wind sector in a multisectoral framework

3.1 Input-Output and Hypothetical Extraction Methods

We employ the Hypothetical Extraction Method (HEM) to calculate the level of output and employment, plus its skill characteristics, which is supported by offshore wind activities in the UK. As described by Allan & Ross (2019,p240) in a recent application of this method: "this method uses the interconnectedness between sectors of the economy to quantify the economic importance of individual sectors to supporting activity throughout the economy – in terms of output, and employment." The required data are given in a set of inter-industry Input-Output (IO) economic accounts. These are financial accounts (given in monetary terms) which detail the nature of consumption and production in an economy for a period of time. In the square analytical IO tables,

[3] Siemens Gamesa Renewable Energy, for instance, in the UK is classified under SIC42.22 – "Construction of utility projects for electricity and telecommunications" (Companies House, 2019).

[4] Studies which use the spending-derived approach and IO multipliers to calculated the economic impact of additions to renewable energy capacity include Williams *et al* (2008); Slattery et al (2011); Markaki *et al* (2013); Ortega *et al* (2015); Sánchez-Carreira (2015); Okkonen and Lehtonen (2016); Bae and Dall'erba (2016); Lehr *et al* (2016); Mikulić et al (2018); Kečec *et al* (2019); Varela-Vázquez and Sánchez-Carreira (2015); and Ramos *et al* (2019).

termed Industry-by-Industry (IxI), each industry in the economy is identified as both a row and a column in the accounts.

We define economic activity in each sector as the sum of intermediate sales to other industries and to final demand, we can specify (for a two sector example):

$$X_1 = a_{11}X_1 + a_{12}X_2 + .. + a_{1n}X_n + f_1$$

$$X_2 = a_{21}X_1 + a_{22}X_2 + .. + a_{2n}X_n + f_2$$

where X_i is the output of sector i, a_{ij} is a coefficient which represents the output of sector i needed to produce one unit of output of sector j, and f_i is the final demand sales of sector i. In matrix notation this can be represented by:

$$\boldsymbol{x} = \boldsymbol{A}\boldsymbol{x} + \boldsymbol{f}$$

which gives the following solution for X:

$$\boldsymbol{x} = (\boldsymbol{I} - \boldsymbol{A})^{-1}\boldsymbol{f} \text{ or } \boldsymbol{x} = \boldsymbol{L}\boldsymbol{f}$$

where I is the identity matrix and L is the Leontief inverse matrix.

The extraction of individual industries using hypothetical extraction (HE) can be shown using a partitioned matrix where (again with the two sector case):

$$\boldsymbol{A} = \begin{bmatrix} a_{11} & a_{21} \\ a_{12} & a_{22} \end{bmatrix}$$

In this case, extracting the intermediate connections of sector 1 would mean replacing the elements including sector 1 in the A matrix with zero, e.g. $a_{11} = a_{21} = a_{12} = 0$. In addition, the final demand for sector 1 would also be set to zero. If f^* and $A^*$are the matrices after extraction, then the economic contribution to output of sector 1 would be found by the comparison of the pre- and post-extraction economy, i.e. $x^* - x = (I - A^*)^{-1}f^* - (I - A)^{-1}f$. Similarly, the impacts on employment, GVA or emissions could be shown with the addition of an appropriate sectoral employment-, GVA- or emissions-output coefficient respectively[5].

Dietzenbacher and Lahr (2013) discuss that while the typical HEM is the complete removal of an industry identified in the accounts, partial removal, for example of a firm(s) within an industry is also possible. This is proposed to emulate the consequences of reductions in an industry's capacity to produce. In the case of extraction of a firm emulate an industry, they propose that intermediate sales by the industry be reduced by the proportion of the industry attributed to the firm (α). The row values for industry k (where k = 1, i.e. the industry containing the firm to be extracted) – barring the diagonal elements - are reduced by the portion α so that the matrix A^α is given by:

$$A^\alpha = \begin{bmatrix} a_{11} & \alpha a_{21} \\ a_{12} & a_{22} \end{bmatrix}$$

In their partial extraction, Dietzenbacher and Lahr (2013) note that this is equivalent to assuming that the firm no longer produces the output: equivalent to either lower demand or that the supplies are met by production outside of the economy in question. In the partial extraction, it is proposed that the final demands for sector k can either be kept unchanged or reduced by the value of α. The former is

[5] For instance, with m_i as the employment output coefficient (employment divided by output for sector i) the change in employment associated with the extraction of sector 1 would be $E^* - E = m(I - A^*)^{-1}f^* - m(I - A)^{-1}f$.

equivalent to assuming that previous final demand continues to be met by the parts of the industry not extracted, while the latter assumes that demand falls. In the case of our partial extraction of the offshore wind element of the electricity sector (without disaggregation) we make the assumption that – in keeping with the extraction of industries – that both intermediate sales and final demands for the extracted element of the electricity industry are extracted.

In addition, we identify the spending within final demand that is associated with additions of new offshore wind capacity. This means that can we can partition f into renewable (R) and non-renewable (NR) demands for the outputs of each sector:

$$\boldsymbol{f} = \begin{bmatrix} f_1^{NR} & f_1^R \\ f_2^{NR} & f_2^R \end{bmatrix}$$

This allows us to capture the contribution of both the extraction of the identified sector, plus any additional final demands associated with offshore wind activity, such as new capacity[6].

3.2 Data

For our analyses, we use a set of 2010 IO tables for the UK as reported in Allan et al (2019a,b), the latest data available at the time of writing. The 2010 IO table is a symmetric Industry-by-Industry IO table with 98 industries (at SIC07), which we aggregate up to 39 sectors as given in Appendix A. These data in the IO tables also record socioeconomic characteristics by linking two indicators to sectoral output so that we can explore the activity supported by offshore wind in more than purely economic (i.e. monetary, output) terms. These are sectoral employment (in Full-time equivalent, FTEs) and CO_2, respectively, so we can construct appropriate employment- and emissions-output coefficients. Allan et al. (2018) detail the construction of the base year emissions. Sectoral employment is disaggregated in the IO table by nine occupation categories (Standard Occupational Classification). We aggregate these to three categories that we term “High”, “Medium” and “Low” skilled for presentation purposes.[7]

In addition, we extend the UK IO tables through disaggregation of the electricity sector with details of different (operational) generation technologies. Standard IO tables only report a single a single electricity sector (SIC 35). As noted earlier, this sector contains firms mapped to the activities within this SIC activities, 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 aggregated sector is very 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 considerable 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

[6] We do not separately identify exports of offshore wind technology (goods or services), however this could be added to f^R where data exist.

[7] The nine categories are 1) “Managers & Senior Officials”, 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”. More details on these skills are given in Ross (2017).

retail and trading – counted as part of the electricity sector in current UK IO accounts – comprise a major element of the employment within the sector, and so again ideally should be disaggregated.

The data given in Allan et al. (2019a,b) use information on plant-level production and market price by half-hourly time-step based on the framework developed in Connolly (2018). We can thus capture the timing and economic value of production by each generation technology in identifying the revenues for each technology. This method can take into account that some technologies produce only when demand (and therefore price) is high, while others are unable to alter their outputs in response to market signals. This disaggregation therefore splits the single electricity sector in the initial tables into 10 sectors: one comprising the non-generation activities (transmission, distribution and supply) and nine separate electricity production sectors: Coal, Gas & Oil, Nuclear, Onshore Wind, Offshore Wind, Pumped, Hydro, Biomass, Other. This approach is of considerable policy interest given the focus on radically changing the composition of the electricity sector in favour of renewables.

In addition, we extend the data from Allan et al. (2019a,b) to separately identify the portion of investment spending within final demand in 2010 which is consistent with the addition of new offshore wind capacity. This is implemented using the net additions of capacity and the associated UK spending. We use net additions to offshore wind capacity between 2010 and 2015 – given than the pre-development phase is roughly six years, projects in the UK will have spending on their construction for up to six years prior to operational. We estimate a vector of investment expenditures in the UK in 2010 using cost categories within CAPEX costs, their assumed UK content, and the timing: this totals £1,552 million in 2010 prices, with £439 million spent in the UK. This is equivalent to 0.25% of total investment spending in the UK in this year[8]. Non-offshore-related GFCF expenditure is necessarily reduced by the scale of this spending associated with offshore wind developments.

4. Results

We report our results in three main sections: Section 4.1 reports the results of the hypothetical extraction of the operational offshore wind sector in the aggregated set of accounts. Section 4.2 reports the extraction of operational offshore wind sector using our purpose-built disaggregated table which identifies renewable sub-sectors, including offshore wind. Section 4.3 presents the results of the extraction of the new additions of offshore wind capacity.

4.1 Partial extraction of the offshore wind sector in the aggregated model

We begin with the analysis predicated upon the IO table and model in which there is a single aggregated electricity sector. We hypothetically extract the portion of that sector which relates to offshore wind. We estimate that the total output of the UK offshore wind sector in 2010 is £104 million, which corresponds to 0.15% of SIC 35, covering Electricity Generation, Transmission, Distribution and Supply. Thus, we use α=0.15 to reduce the α (row) coefficients and final demand for the electricity sector.

Table 1 gives gross output (£m) and the number of employment (FTE) jobs supported by the offshore wind sector – taken as a share of the overall electricity sector. These are identified as direct', 'direct

[8] Given the increase in offshore wind capacity since 2010, we would expect that this ratio has increased significantly.

plus indirect' (Type I), and the 'direct, indirect plus induced' (Type II) effects. The `direct' figures are these of the (estimated) offshore wind sector itself. Direct employment is estimated to be 102 FTE jobs, output of £104 million and GVA of £17 million[9]. These direct jobs disaggregated by skill categories, shows that the majority of jobs are high skill (55%), while 43% and 2% are in medium and low skill categories respectively.

The offshore wind sector, however, also supports jobs throughout the economy. All products are made using intermediate inputs from other sectors of the economy. The production of intermediates requires the employment of workers. Additionally, sectors sell their outputs to households, and will therefore be impacted by changes in household incomes (through wages). The scale of these two effects is captured in the 'indirect' and 'induced' effects, respectively (see e.g. Allan & Ross (2019) for a more detailed discussion).

Turning to the indirect and induced impacts of the (estimated) offshore sector, the ratios between direct and indirect and induced effects are, of course, identical to those which would be true for the aggregate electricity sector as a whole in this method.

The 'Direct, plus indirect' (Type I) effect for output is 1.6 times the direct effect (£166m/£104m) – and that of employment is 3.9 times larger (394/102). Gross Value Added is less than the level of output as not all the spending falls on goods produced in the UK (recall, we have adjusted for local content) and only a portion of spending falls on GVA in each sector.

The Type II effects ('Direct, plus indirect, plus induced') show that these ratios increase to 2.9 and 11.5 for output and employment respectively. Emissions associated with the offshore sector total 246 MKG CO_2e emissions in the Type I case, and 365 MKG CO_2e under Type II. While these economic and emissions results are interesting in themselves, we are particularly interested in how this "naïve" extraction of offshore wind compares to that where we use the IO with disaggregation of the offshore electricity generation. Note that these emissions, of course, reflect the emissions intensity of the electricity sector as a whole: unthinking use of aggregate sectoral data can lead to particularly misleading results (as we confirm in Section 4.2).

The Type II employment and output impacts across sectors of the economy are summarised in Figure 2 as a "running total" (i.e. summing up the shares of total supported employment/output by sector in turn). Figure 2 shows that half of the total output supported by offshore wind on this approach is located directly in Sector 16, Electricity, transmission & distribution (ELE), whilst only 13% of total employment are supported within that sector. The (partially extracted) ELE sector supports employment mainly in sectors 30 and 36, Wholesale & Retail Trade (WHO) and Services (SER), with 16% and 23% of total employment respectively. Output is mainly supported in the SER sector (Sector 36), with 13% of total output, and Sector 3, Crude Petroleum + Natural Gas & Metal Ores + Coal (CRU), supporting 8% of total output. We expect these sectoral linkages to differ when using the offshore wind-specific disaggregation in the following section

[9] Note, as in this method we are using the aggregate electricity sector, the direct figures for offshore wind are simply the α values multiplied by the values for the overall sector.

4.2 Extraction of the operational offshore wind sector in disaggregated model

Table 2 gives output and employment supported by the offshore wind sector, now reflecting the actual cost structure of the operational offshore wind sector as identified in the disaggregated set of IO accounts given by Allan et al. (2019a,b).

The direct employment supported by offshore wind is 134 jobs, and £104m in output. These 134 jobs are further broken down by three skill categories, showing that the majority (59%) of the jobs are within the high skill category, 38% are medium skilled, and only a very small share of jobs (3%) are in the low skill category. This would indicate that the operational sector itself is relatively high skilled – both compared to the UK economy as a whole and the aggregate electricity sector.[10] Note that the direct effects (other than output, of course) are higher than the levels implied by applying HEM to the table with the aggregated electricity sector, and in the case of GVA much higher.

Type I effects show that output is 1.7 times greater than the direct effect (£182m/£104m) – and that of employment is 6.2 times (842/134). This suggests that the majority of jobs the offshore wind sector supports are outwith the sector itself. The Type I supported skilled jobs are a 4.6 multiple of these in the offshore wind sector itself (362/79), for medium skilled, and for low skilled this is 7.9 (402/51) and 19.8 (79/4) respectively. Although overall there is a large high skill component, there is a shift towards medium skilled labour as impacts beyond the offshore wind sector itself are considered. Now 43% of total jobs are highly skilled, 48% are medium skilled, and 9% are low skilled.

The Type II results highlight similar key findings. That is, whilst output is 2.5 times greater (£262m/£104m), jobs supported throughout the economy are a multiple of 11.5 times of these directly in the sector (1,546/134). Along with the increased number of jobs supported as compared to the Type I effects, there is a shift towards low skilled jobs (bringing the skill distribution closer to the UK average). The Type II jobs are 43% high skilled, 46% medium skilled, and 11% low skilled. The Type II skilled jobs are a 8.4 multiple of these in the offshore wind sector itself (664/79), for medium skilled, and low skilled this is 13.8 (704/51) and 44.0 (176/4) respectively.

These results show that there are significantly more jobs supported throughout the economy by the offshore wind sector than was implied by the analysis in Section 4.1. Disaggregation of the offshore wind sector reveals that the simple partial extraction of the electricity sector underestimates the scale of employment supported by offshore wind by almost 30% (373/1173).

Typically, the offshore wind sector is regarded as a *high skill sector* – a feature also reflected in our results of the direct effects. However, when considering the system-wide results, we show that the offshore wind sector supports a wider distribution of skills. Particularly, there is a shift away from high skill jobs to medium and to low skilled jobs when considering the skill component of jobs supporting activities within the offshore wind sector.

Whilst the offshore wind sector does not generate CO_2 emissions itself, it does have an impact on emissions in a system-wide context. As such, when taking into consideration the 'direct, indirect, plus induced effects', the offshore wind sector can be attributed to 22 MKG CO_2e emissions (less than 1% of total UK emissions).[11] Note that this is less than 10% of the emissions compared to the case in Section

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[10] The UK data from the IO table (Allan et al., 2019a,b) indicate that 42% of workers are high skilled, 44% medium skilled, and 14% low skilled.
[11] See Allan et al., (2018) detail the construction of the base year emissions.

4.1, reinforcing the importance of conducting the analysis with an appropriately disaggregated electricity sector.

Figure 2 shows that 40% of the total output contribution is directly in the operational offshore wind sector. As previously, this sector has strong linkages to the Wholesale and Services sectors, Sectors 30 and 36, carrying 12% and 16% of total output respectively. In contrast to the previous case (Section 4.1), however, the offshore wind sector (Sector 21, EGF) does not have strong linkages to Sector 3 (Crude Petroleum), for example, showing a very different distribution of impacts across sectors when only the aggregate Electricity sector is considered. Similar observations can be made for employment. The main linkages of the offshore wind sector are here to sectors 29, 30 and 36, Construction (CON), Wholesale, and Services, with 10%, 27%, and 18% of total employment respectively.

4.3 Extraction of the operational offshore wind sector in disaggregated model including investment spending

Table 3 shows output employment supported by the offshore wind sector, including both the operational (disaggregated) offshore wind sector and the element of GFCF expenditure associated with additions of capacity. As we are extracting elements related to final demand plus that removed in Section 4.2, we expect to see larger numbers across all categories of impact. It is therefore not surprising that here we see the largest economic contributions. The scale of the differences are perhaps surprising at first glance, but they reflect the scale of the sector's expansion and the distinctive linkages of CAPEX as against O&M expenditures.

The 'direct' figures are those of the operational wind energy sector itself, plus those activities directly involved in meeting investment demand. Direct employment is estimated to be 2,453 jobs, with £542 million of output and £327 million of GVA. By skills types, the direct jobs are disaggregated as follows: 1,046 high skill (43% of total direct employment), 1,209 medium skill (49%) and 198 low skill (8%). It is interesting to note that compared to Tables 1 and 2, this is the first instance of employment being concentrated in the medium skill category, and that the low skill share of direct employment has more than doubled as a consequence of incorporating the impacts of investment expenditures on offshore wind capacity.

From Table 3, we see that the Type I effects show that supported output is 1.8 times and GVA is 1.6 times greater than the direct effect. Employment supported by Type I is 5,319 jobs, some 2.1 times greater than direct jobs. This is a much reduced ratio compared to Section 4.2 (where total employment was 11.5 times larger than direct employment) and is explained by the larger direct figure for offshore wind activity when employment associated with investment spending is considered. Type II employment is 10,243, 4.2 times greater than the direct employment.

Looking at the distribution of employment skills categories for Type I and Type II employment, these shows that the (rounded) shares of employment are identical for Table 2 and 3, despite the difference in scale. Including investment expenditures therefore appears to increase the scale of economic activity considerably – output, GVA and employment increase by 5.8 times, 3.1 times and 6.6 times respectively between Table 2 and 3 – but the distribution of employment across high, medium and low skill activities remains the same. This is in important insight which we would not expect to be general finding – but will reflect the level of aggregation, the distribution of investment expenditure across UK economic sectors and the detail of skills disaggregation within the table.

In contrast to Section 4.1 and 4.2, Figure 2 shows a more nuanced distribution across sectors in terms of output and employment. A large proportion of output is now in Services (24%), Wholesale (10%), and Iron, steel + metal (IRO) sector (11%), whilst the (operational) offshore wind sector contributes 7% to total output. Employment impacts are ranked similarly. Almost one-quarter (24%) of total employment is carried by the Services sector, 19% by the Wholesale sector, and 12% by the Iron sector, with only around 1% of total employment contributed to the offshore wind sector. We note that there is significantly greater amount of emissions supported by the offshore wind sectors' activities in this scenario. Comparing the emissions column between Table 2 and 3, we see the additional emissions supported outside of the operational offshore wind sector, and related to the whole economy multiplier effects of spending on new capacity in the UK.

We end on a note of caution. The dominance of investment expenditure effects in this analysis reflects the significant expansion of offshore wind capacity in the relevant period. In a static steady-state investment expenditures would be expected to decline significantly, so as ultimately to equal the level of replacement investment required to maintain the capacity of the sector. In such circumstances, the relative scale of investment expenditures would be much reduced, and the economic impacts would reflect this new composition of spending. However, for the foreseeable future significant increases in offshore wind capacity continue to be anticipated, for example, in the recent Offshore Wind Sector Deal (HM Government, 2019), so that the impacts identified here are likely to maintain their policy relevance for some time.

Table 1: Direct, indirect, and induced effects of the offshore wind sector taking a portion of aggregated electricity sector, UK 2010.

	Output (£m)	Gross Value Added (£m)	Emissions (MKG CO_2e)	FTE Employment			
				High skill	Medium skill	Low skill	Total
Direct	104	17	-	56 (55%)	44 (43%)	3 (2%)	102
Direct, plus indirect (Type I)	166	47	246	184 (47%)	181 (46%)	28 (7%)	394
Direct, indirect, plus induced (Type II)	306	100	365	527 (45%)	521 (44%)	125 (11%)	1,173

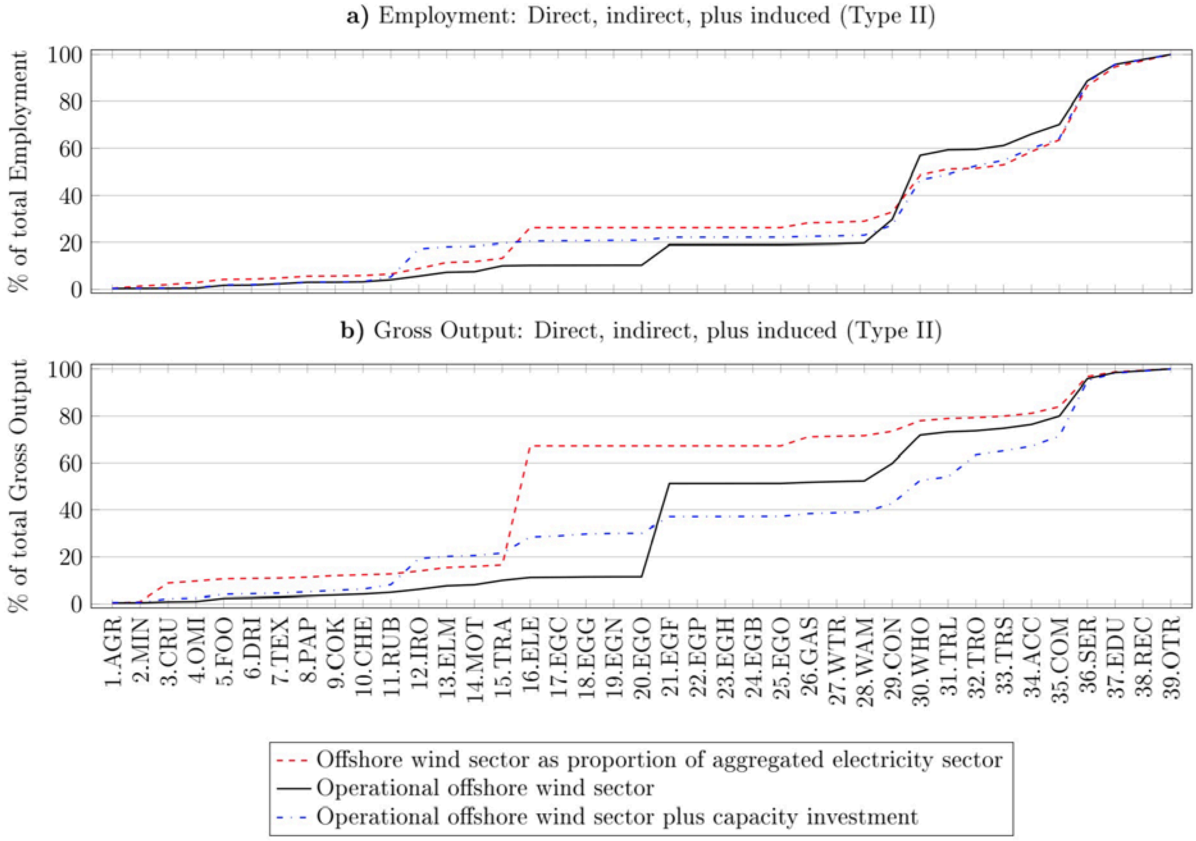
Table 2: Direct, indirect, and induced effects of the operational offshore wind sector, UK 2010.

	Output (£m)	Gross Value Added (£m)	Emissions (MKG CO_2e)	FTE Employment			
				High skill	Medium skill	Low skill	Total
Direct	104	179	-	79 (59%)	51 (38%)	4 (3%)	134
Direct, plus indirect (Type I)	182	215	8	362 (43%)	402 (48%)	79 (9%)	842
Direct, indirect, plus induced (Type II)	262	253	23	665 (43%)	704 (46%)	176 (11%)	1,546

Table 3: Direct, indirect, and induced effects of the operational offshore wind sector *plus capacity expenditures*, UK 2010.

	Output (£m)	Gross Value Added (£m)	Emissions (MKG CO_2e)	FTE Employment			
				High skill	Medium skill	Low skill	Total
Direct	542	327	331	1,046 (43%)	1,209 (49%)	198 (8%)	2,453
Direct, plus indirect (Type I)	952	509	633	2,280 (43%)	2,565 (48%)	474 (9%)	5,319
Direct, indirect, plus induced (Type II)	1,507	780	734	4,405 (43%)	4,683 (46%)	1,155 (11%)	10,243

Figure 2: Direct, indirect, and induced employment and output by individual sector as proportion of total



5. Discussion and Conclusions

Measuring the economic impact of renewable energy technologies is important to help policymakers understand the consequences of policy decisions. While a number of methods have been used – including surveys, economic accounts and simple IO modelling analysis of renewable energy expenditures – they do not embed these measures in a set of economic accounts, from which additional analysis can be undertaken. We have illustrated how offshore wind activities can be considered in IO accounts, and demonstrated the levels of activity – output, Gross Value Added, employment (disaggregated by skills) and emissions – supported by the offshore wind sector in the UK.

We show (in Section 4.1) that a “naïve” extraction of offshore wind using an IO table and model which, in accordance with current official accounts practice, treats the electricity sector as a single, aggregated sector, understates (compared to section 4.2) the scale of economic activity (i.e. GVA) that is attributable to the sector (as measured using an appropriately disaggregated IO accounts and model). This confirms the tangible benefits from systematic disaggregation of IO tables to reflect sub-sectors of interest, rather than relying on ad hoc techniques for partial extraction, particularly in the case where the aggregate sector contains very heterogeneous activities. Naïve hypothetical extraction from a standard, aggregated IO table also proves very misleading in terms of the scale of emissions attributed to the offshore wind industry. The effective monitoring of the economic and emissions impacts of offshore wind, and other renewables sectors, requires an appropriately disaggregated IO table and model.

Our results indicate that operational offshore wind activity and the spending associated with additions to capacity supported 10,243 jobs in the UK in 2010, with these jobs broadly shared between high and medium skill activities. Focusing only on the operational offshore wind sector itself – i.e. activities involved in the production of electricity from offshore technologies – would have underestimated this impact by almost 8,500 jobs. In addition, focusing on ‘direct’ jobs in generation activities, which our analysis suggests are predominantly high-skilled, would have missed the important contribution to medium and low skill jobs which are supported by the sector in the rest of the economy.

Several further points can be made. First, our analysis uses the most recent IO table for the UK, which dates from 2010. Subsequent (significant) increases in the scale the offshore wind sector mean that we would now expect the scale of the direct activity supported by the sector to have also increased. Additionally, plans to continue to develop future offshore wind capacity suggest that there will be considerable further investment activity related to offshore wind. Our framework could straightforwardly be applied to more recent IO tables as they become available, or to regions/nations where more recent tables have been published. Second, our use of estimates of local content associated with investment spending may be incorrect. We have used estimates of the extent to which expenditure on capacity by category of costs will be sourced in the UK, and have an overall UK content of 28%. This is lower than more recent estimates of UK local content (RenewableUK, 2017), which suggest that in 2017 this had increased to 48%, up from 43% in 2015. This appears to have been increasing in recent years with the development of the UK supply chain for offshore wind construction projects.

Third, we have not undertaken any regional analysis. In addition to the overall economic contribution of offshore wind, the recent Sector Deal acknowledged that there has already been – and many continue to be – a clustering of UK offshore wind activity. It is noted in the Sector Deal for instance, that such clusters “are already emerging, generally located close to windfarms or areas with a strong, pre-existing manufacturing base, oil and gas, or R&D presence” (HM Government, 2019, p. 8). Thus, there may be sensible reasons to consider the geographical distribution of the sector’s contribution through extending the hypothetical extraction to a multi-regional framework.

Appendices

Appendix A Sectors, codes, and abbreviations

1. AGR	Agriculture, forestry & fishing
2. MIN	Mining & quarrying
3. CRU	Crude Petroleum + Natural Gas & Metal Ores + coal
4. OMI	Other Mining & mining services
5. FOO	Food (+ Tobacco)
6. DRI	Drink
7. TEX	Textile, Leather & Wood
8. PAP	Paper & Printing
9. COK	Coke & refined petroleum products
10. CHE	Chemicals & Pharmaceuticals
11. RUB	Rubber, Cement, + Glass
12. IRO	Iron, steel + metal
13. ELM	Electrical Manufacturing
14. MOT	Manufacture of Motor Vehicles, Trailers & Semi-Trailers
15. TRA	Transport equipment + other Manufacturing (incl Repair)
16. ELE	Electricity, transmission & distribution
17. EGC	Electricity generation - Coal
18. EGG	Electricity generation - Gas & Oil
19. EGN	Electricity generation - Nuclear
20. EGO	Electricity generation - Onshore Wind
21. EGF	Electricity generation -Offshore Wind
22. EGP	Electricity generation - Pumped
23. EGH	Electricity generation - Hydro
24. EGB	Electricity generation - Biomass
25. EGO	Electricity generation - Other
26. GAS	Gas; distribution of gaseous fuels through mains; steam & air conditioning supply
27. WTR	Natural water treatment & supply services; sewerage services
28. WAM	Water Management & remediation
29. CON	Construction - Buildings
30. WHO	Wholesale & Retail Trade
31. TRL	Land Transport
32. TRO	Other transport
33. TRS	Transport support
34. ACC	Accommodation & Food Service Activities
35. COM	Communication
36. SER	Services
37. EDU	Education health & defence
38. REC	Recreational
39. OTR	Other private services

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