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Can Offshore Wind Energy Be a Lever for Job Creation in France? Some Insights from a Local Case Study

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Abstract The French government has launched three separate calls for tender in July 2011, March 2013, and December 2016 to install 3.5 GW of offshore wind. In addition to contributing to the fulfillment of environmental commitments, the deployment of offshore wind energy is expected to be a lever for economic development. To assess gross economic impacts, mainly in terms of job creation, we built a regional input-output model of the wind farm off Saint-Brieuc located in the region of Brittany, north-western France. Our model indicates that the project will have positive effects on Brittany's economy. In particular, during the investment phase, the wind farm is expected to lead to €0.38 M/year/MW of added value and 6.03 full-time equivalent (FTE) jobs/year/MW. During the operation and maintenance (O&M) phase, the model predicts the generation of €0.15 M/year/MW of added value and 1.02 FTE jobs/year/MW. These results imply that the project will increase Brittany's GDP slightly by 0.22 and 0.09% during the investment and O&M phases, respectively. Results also show that out of total wealth created in France, 38 and 66% will be created in Brittany as well as 32 and 51% of employment during respectively investment and O&M phases. A comparative analysis highlights in particular that economic impacts are generally stronger during the investment phase. It also demonstrates that the magnitude of economic impacts depends on the proportion of local industries in the supply chain. Policy implications of our model stress the need to revise the economic, technological, regulatory, and social frameworks within which the offshore wind industry currently operates in France to establish the conditions necessary for its development.

Keywords Offshore wind · Economic impacts · Input-output model · France

JEL Classification Q_{42} · Q_{43} · D_{57} · R_{15}

1 Introduction

In 2008, the European Union (EU) adopted the so-called climate and energy package, targeting a 20% reduction in its greenhouse gas emissions by 2020 (with respect to 1990 levels) as well as a 20% increase in its energy efficiency and a 20% share of renewable energy in total energy consumption. Along the same lines, in early 2014, it proposed a new policy framework for 2030, supporting and extending the 2020 climate and energy package. In particular, by 2030, the EU aims to reduce domestic greenhouse gas emissions by 40% below 1990 levels, improve energy efficiency by 30%, and reach a share of renewable energy of at least 27% in total energy consumption.

To increase the share of renewable energy in the total energy consumption as defined by the EU, the French government decided in 2008 as part of the Grenelle Forum on the Environment (*Grenelle de l'environnement*) to increase the share of renewable energy in total energy consumption to 23% by 2020 [69]. In particular, since France possesses 3500 km of coastline, four maritime seaboards, and the second highest wind energy potential in Europe, it was decided within the framework of the Grenelle Forum on Maritime Policy (*Grenelle de la mer*) to target the development of 6 GW of marine renewable energy by 2020, based mainly on offshore wind.

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In July 2011, the French government launched the first call for tender for 3 GW of offshore wind in five areas located off Dieppe-Le Tréport (Seine-Maritime *département*, 750 MW), Fécamp (Seine-Maritime, 500 MW), Courseulles-sur-mer (Calvados *département*, 500 MW), Saint-Nazaire (Loire-Atlantique *département*, 750 MW), and Saint-Brieuc (Côtes d'Armor *département*, 500 MW). The project off Dieppe-Le Tréport (Seine-Maritime, 750 MW) was the only unsuccessful tender. In March 2013, a second call for tender was announced for an additional 1 GW of offshore wind off Dieppe-Le Tréport (Seine-Maritime, 500 MW) and Noirmoutier (Vendée *département*, 500 MW). More recently in December 2016, the third call for tender for 500 MW of offshore wind in Dunkerque (Nord *département*) was launched (cf. Fig. 1).

In addition to contributing to the fulfillment of environmental commitments, the deployment of offshore wind energy is also expected to be a new lever for local and national economic development in France. Here, we build a regional input-output (I-O) model to assess the gross economic impacts of the project of Saint-Brieuc, a small town in the region of Brittany. This project is expected to enhance regional power production from renewable sources and create new employment opportunities [52].

Brittany is characterized by an electricity supply-demand deficit with possible supply interruption in periods of peak demand during the winter. For the period from 2000 to 2012, consumption increased by 22.21% in Brittany compared with only 11.9% on the national level [37]. During the same time period, although regional electricity production coming mainly from renewable sources has increased by 134%, it covered no more than 11.8% of Brittany's electricity needs[1] (see Fig. 2). This situation highlights the importance of the Saint-Brieuc offshore wind project because, with an installed capacity of 500 MW, it is expected to satisfy about 7% of the total electricity consumption of Brittany.

Although the project clearly plays a role in supporting local energy production, in this paper, we will focus on analyzing its expected economic impacts mainly in terms of job creation. The literature contains a number of papers studying the employment impacts of renewable energies [11, 46, 50, 58, 77, 97]. However, to our knowledge, this article is the first study to focus on the case of offshore wind farms in France.

We examine economic production, gross added value, and full-time equivalent (FTE) jobs to measure the magnitude of expected regional economic impacts. We distinguish between direct, indirect, and induced impacts. Direct impacts take place within the industries immediately involved in the project during the development, construction, installation, and operation and maintenance (O&M) phases. Indirect impacts cover the changes in inter-industry trade as businesses respond to the new demand brought on by upstream offshore wind activities. Induced impacts measure the growth in economic activity due to increases in income, and therefore consumer spending, of employees/households. We calculate expected economic impacts for the two [most important] phases of the project namely the investment (i.e. construction and installation) and the O&M phases.

The paper is structured as follows. In Section 2, we present the Saint-Brieuc offshore wind project and its expected regional economic impacts. In Section 3, we present the methodology and data. In Section 4, we discuss our results based on a thorough comparative analysis. Finally, in Section 5, we conclude and detail some policy implications.

2 Presentation of the Project and Its Expected Economic Impacts

The Saint-Brieuc offshore wind project is conducted jointly by Iberdrola and Eole-Res SA, which respectively hold a 70% and 30% stake in the project (together, Iberdrola and Eole-Res SA represent the Ailes Marines SAS consortium). This collaboration includes the development, construction, and operation of the farm. In the Saint-Brieuc project, 62 turbines rated at 8 MW and reaching 215 m in height for a total of 496 MW will be installed. The project is financed by the private sector. Its total investment cost is estimated at €2 B[2] divided into two parts: capital expenditures (CAPEX) and operation expenditures (OPEX). CAPEX represent 70 to 75% of the total cost and OPEX 25 to 30%. This investment cost is broken down into several items of expenditures as shown in Table 1 [4, 52]. Ailes Marines SAS estimates that the project will satisfy the annual electricity consumption of 840,000 habitants [79].

According to Ailes Marines SAS [3, 5], the project will require 7 years, from 2013 to 2020, to be completed, with the development phase ending in 2016. The development phase focused on analyzing the technical and environmental characteristics of the project as well as on performing impact studies. From 2017 to 2020, construction and installation will be carried out. It is expected that the farm will be operational by late 2020. It will be operated for 20 years from 2020 to 2040 before being dismantled.[3]

The project is expected to enhance the development of the French offshore wind industry. Although there currently is no well-established offshore wind industry in France, some components will be locally manufactured and several companies located mainly in north-western France[4] will participate in the

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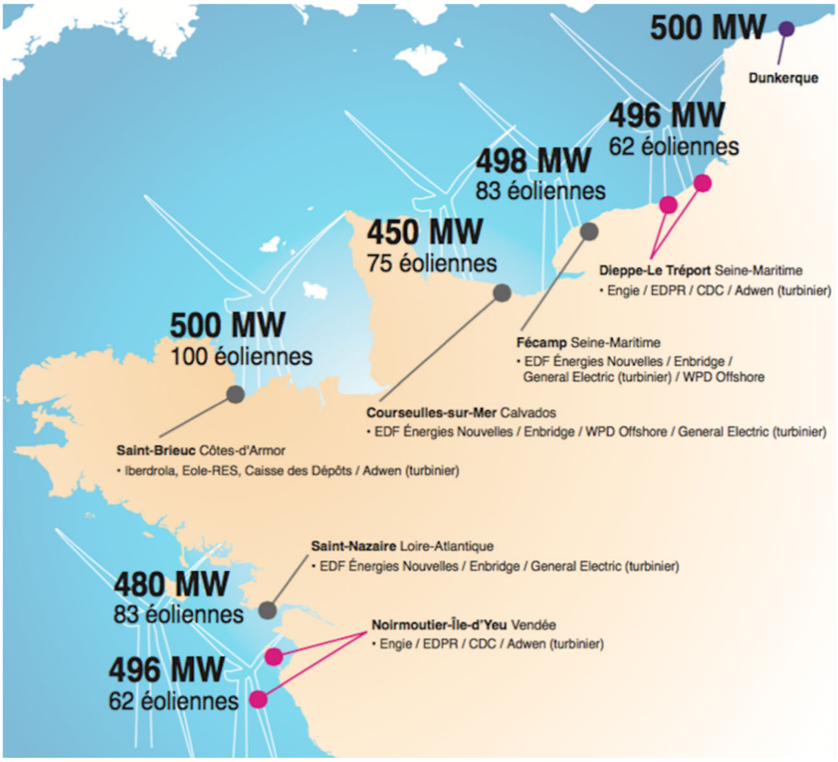
[1] For example, in 2012, Brittany imported 29.9% of its electricity needs from the Cordemais thermal power station (Loire-Atlantique region) and about 70% from the Flamanville (Normandy region) and Chinon (Centre region) nuclear power plants.

[2] This estimate does not include the cost of connecting the farm to the mainland grid.

[3] For details on the schedule of the project, interested readers can consult Ailes Marines SAS [5]. In addition, some technical characteristics of the project are presented in Appendix 2.

[4] Also called the *Grand-Ouest français*, this area is not clearly defined and does not correspond to any administrative division but covers the Brittany, Normandy, and Pays-de-la-Loire regions and sometimes also includes the northern part of the Nouvelle-Aquitaine region as well as the Indre-et-Loire and Loir-et-Cher *départements* (both part of the Centre region).

Fig. 1 Offshore wind zones involved in French public calls for tender (the first round in gray, the second in pink, and the third in purple). Source: Observe-ER 2017



manufacture of 3600 turbine components [7]. In this context, a directory of companies that may potentially participate in the Saint-Brieuc project was prepared by the Bretagne Pôle Naval cluster, through which 71 companies were identified BPN [16, 17].

Moreover, it is expected that two ports will be fitted out in Brittany. For manufacturing the electric substation and jacket foundations, Ailes Marines SAS decided to install factories in the port of Brest in the Finistere *département* because it is the only port in Brittany suitable for such operations. In fact, in addition to being easily accessible from the sea, by land and by rail, it has a high available storage capacity [23]. For maintenance activities, the port of Saint-Quay-Portrieux in Côtes d'Armor near the Saint-Brieuc offshore farm has been selected and will be set up to reduce transportation costs and any delays.

Furthermore, it is also expected that the development of the Saint-Brieuc project will engender positive impacts on some economic activities that are not directly related to the offshore wind sector. For instance, during the construction phase, the project may enhance hotel and restaurant activities, particularly if an onshore base is considered for the construction stage [67]. Similarly, during the O&M phase, tourism may be stimulated, because the region already has many attractive features [23].

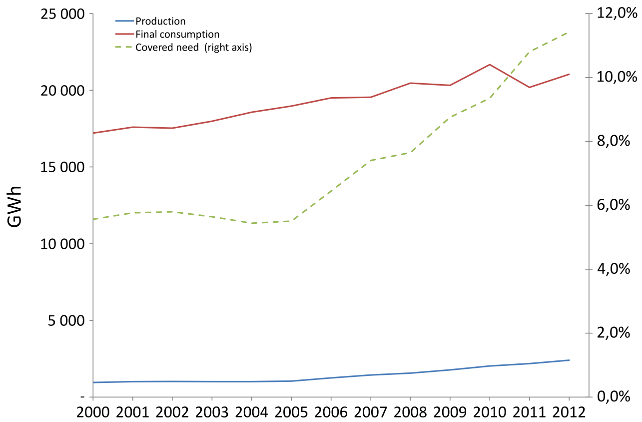


Fig. 2 Production of electricity (GWh), consumption of electricity (GWh), and covered needs, i.e., the share of local electricity production in total electricity consumption (%)

Table 1 Cost breakdown of the Saint-Brieuc offshore wind project (%) [4]

Task	Proportion of total cost (%)
Turbine system	47
Foundations	37
Inter-turbine cable	5
Offshore electric substation	4
Studies and consulting	5
Other	2
Total	100

3 Methodology and Data

This section aims to present the methodology that we used to estimate the economic impacts of the Saint-Brieuc offshore wind project. In particular, in Subsection 3.1, we provide arguments supporting the relevance of using an I-O model. In Subsection 3.2, we present the main methodological aspects dealing with the calculation of regional economic impacts using an I-O model. Finally, in Subsection 3.3, we detail the data and assumptions that we made to model offshore wind impacts during the investment and O&M phases.

3.1 The Relevance of the I-O Model for Our Impact Studies

Table 12 in Appendix 3 provides a literature review dealing with the methodologies most widely used to assess the economic impacts of renewable energy technologies. It revealed two frequently used methodologies. The first is based on macro-economic modeling exercises using I-O tables, calculable general equilibrium (CGE), and macro-econometric (M-E) models. In some cases, econometric regressions are also used. The second methodology, referred to as analytical methodology, is based on surveys and other written information, i.e., data collection based on interviews, company annual reports, official tax-related business registers, and government statistics [39, 58, 86].[5]

After considering the advantages and drawbacks of the methodologies, we chose the I-O model to assess the economic impacts of the Saint-Brieuc offshore wind project. Although it has limitations, we believe that it provides the best trade-off between the aim of our study, the robustness of expected results, and the specific constraints inherent to the regional scale of the study as well as the specificities of the framework within which the offshore wind industry is currently emerging in France.

More precisely, we used an I-O model for five main reasons:

- We do not aim to focus only on impacts on the industrial component of the offshore wind sector, i.e., a bottom-up approach, but we also strive to analyze the impacts of the expansion of this sector on the economy, i.e., a top-down approach.
- CGE and M-E models require more detailed information than I-O models and are generally applied at higher aggregated levels, i.e., European or national. Their application to regional studies is still very limited.
- I-O models are more accessible than CGE and M-E models which generally require a large and sometimes multidisciplinary research team. National I-O models constructed by the National Institute for Statistics and Economic Studies[6] are publicly available. Employing regionalization techniques, we were able to conduct a regional study.[7]
- We aim to assess direct, indirect, and induced impacts, particularly employment impacts. The I-O model is more suitable than analytical methods, which generally only quantify direct impacts.
- Given the emergent nature of the offshore wind industry in France and its fragmented supply chain, we could not use analytical methods, in particular surveys.

Surveys require clear identification of appropriate participants who will be contacted to complete questionnaires. Moreover, observing the controversial framework within which the offshore wind industry is currently emerging in France, we doubt that the response rate would be sufficient for drawing a reliable conclusion.

For these reasons, we used an I-O model for our regional impact analysis of the Saint-Brieuc offshore wind project.

As discussed in Miller and Blair [71], two types of I-O models can be constructed for regional studies: a single-region model and multi-region model, based either on an interregional approach or on a multiregional approach. From a theoretical point of view, the multi-region model allows for a more detailed analysis because it identifies the geographical origin of impacts by incorporating interregional feedback. However, because this type of model is based on an established regional accounting system which does not exist in France, we can only use a single-region model.

3.2 Methodological Aspects of the Calculation of Economic Impacts

Based on Appendix 4, we explain below the calculations of direct, indirect, and induced impacts (Subsection 3.2.1) at a regional scale (Subsection 3.2.2). The magnitude of these impacts is determined by four key factors:

- The size (or the cost) of the project: The bigger the project, the higher the value of the final induced demand is, and the higher the impacts of the project are.
- The share of industry production devoted to buying intermediate products: An increase in the value of technical coefficients leads to an increase in indirect impacts.

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[5] Comparisons of different macro-economic models are well-documented in the literature [18, 58, 65, 71, 91, 104]. Likewise, analytical modeling methodologies have been amply described [11, 39, 86, 87, 101]. Therefore, we summarize only the most important studies focusing on energy impact assessments using these methodologies in Appendix 3.

[6] *Institut National de la Statistiques et des Études Économiques* (INSEE).

[7] Brown et al. [18] analyzed the robustness of I-O model results by comparing their results with those drawn from an ex post econometric analysis of economic impacts of wind power development in US counties. They showed that I-O models provide a good assessment of economic impacts despite its limitations.

- The regional import rate indicating the proportion of imports of intermediate and final products: The regional import rate of a region is inversely proportional to regional technical coefficients and to indirect and induced impacts.
- The share of employee wages in the production value of industries affected by the project. The share of employee wages in the production value is directly proportional to the induced impacts.

3.2.1 Brief Background on How to Calculate Economic Impacts Using I-O Models

Direct impacts take place inside the industries directly involved in the project during the investment and O&M phases.[8]

We assume that X^{di}, V^{di}, and L^{di} respectively represent the *n*-vectors of economic production, added value, and labor in the industries directly involved in the project. Direct impact on economic production corresponds to the production value of the industries directly affected by the change in the final demand induced by the project. According to the supply-demand equilibrium, the value of this economic production X should be equal to the value of the change in final demand, Y^*. Thus,

$$X^{di} = Y^*. \tag{1}$$

By knowing respectively the *n*-vector of added value per unit of economic production and the *n*-vector of labor intensity corresponding to the quantity of labor required to produce one monetary unit of production l, we can calculate the direct impacts of the project in terms of added value and quantity of labor as follows:

$$V^{di} = \hat{\upsilon} X^{di}; \tag{2}$$

$$L^{di} = \hat{l} X^{di}, \tag{3}$$

where the caret indicates that the matrix is diagonal.

Indirect impacts represent changes in inter-industry purchases as they respond to the new demand induced by upstream offshore wind activities. In other words, indirect impacts are the changes affecting the various industries of the economy directly and indirectly providing goods and services to industries directly involved in the project.

We assume that X^{indi}, V^{indi}, and L^{indi} respectively represent the *n*-vectors of production, added value, and labor of industries indirectly involved in the project. By knowing the production process of all industries, new industries included, and the final demand inherent to the project, Y^*, we can calculate the sum of direct and indirect impacts on the economic production as follows:

$$X^{dir+indi} = (I - A)^{-1}\, Y^* = BY^*, \tag{4}$$

where I is the identity matrix, A the matrix of technical coefficients, and $B = (I - A)^{-1}$ the inverse Leontief matrix.

Likewise, the direct and indirect impacts on added value and labor, respectively, are calculated as follows:

$$V^{dir+indi} = \hat{\upsilon}(I - A)^{-1} Y^* = \hat{\upsilon} BY^*; \tag{5}$$

$$L^{dir+indi} = \hat{l}(I - A)^{-1} Y^* = \hat{l} BY^*. \tag{6}$$

Therefore, indirect impacts are calculated as the difference between the sum of direct and indirect impacts and the direct impacts:

$$X^{indi} = X^{dir+indi} - X^{dir}; \tag{7}$$

$$V^{indi} = V^{dir\ \ +indi} - V^{dir}; \tag{8}$$

$$L^{indi} = L^{dir+indi} - L^{dir}. \tag{9}$$

Induced impacts typically measure the growth in economic activity due to the increase in incomes and therefore consumer spending of employees/households. The increase affecting household incomes is engendered by the increase in economic production induced by the project.

We assume that X^{indu}, V^{indu}, and L^{indu} respectively represent the *n*-vectors of production, added value, and labor within industries due to induced impacts. These impacts are calculated by extending the matrix of technical coefficients to household sector $\overline{A}$. When applying the closed Leontief model [63] as detailed in Appendix 4, the sum of direct, indirect, and induced impacts for production is equal to

$$X^{dir+indi+indu} = \left(I - \overline{A}\right)^{-1} Y^* = \overline{B} Y^*. \tag{10}$$

Similarly, the sum of direct, indirect, and induced impacts respectively on added value and labor is calculated as follows:

$$V^{dir+indi+indu} = \hat{\upsilon}\left(I - \overline{A}\right)^{-1} Y^* = \hat{\upsilon}\overline{B} Y^*; \tag{11}$$

$$L^{dir+indi+indu} = \hat{l}\left(I - \overline{A}\right)^{-1} Y^* = \hat{l}\overline{B} Y^*. \tag{12}$$

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[8] Several industries are directly involved in the project, depending on the phase (see Subsection 3.3.2. Nonetheless, the main difficulties in calculating direct impacts are the attribution of costs/expenditures to the industries involved according to the activity nomenclature adopted by the French National Institute for Statistics and Economic Studies (INSEE).

We therefore deduce induced impacts as the difference between the sum of all impacts, i.e., direct, indirect, and induced, and the sum of direct and indirect impacts:

$$X^{indu} = X^{dir+indi+indu} - X^{dir+indi}; \tag{13}$$

$$V^{indu} = V^{dir+indi+indu} - V^{dir+indi}; \tag{14}$$

$$L^{indu} = L^{dir+indi+indu} - L^{dir+indi}. \tag{15}$$

We calculated direct, indirect, and induced gross impacts for the investment and O&M phases.

3.2.2 Adaptation of the I-O Model to the Regional Scale

France has not developed a regional accounting system; we therefore regionalized the French national I-O table as detailed below to analyze regional impacts.

We calculated regional technical coefficients by subtracting imports from the technical coefficients [85]:

$$a_{ij}^{R} = \left(1 - m_{ij}\right) a_{ij}, \tag{16}$$

where a_{ij}^{R} represents regional technical coefficients of industry *j* for input *i*, a_{ij} technical coefficients of industry *j* for input *i*, and m_{ij} the import rate indicating the proportion of input *i* consumed by industry *j* established outside of Brittany.

The import rate incorporates national import rates m_{ij}^{N} representing inputs produced outside of France and regional import rates m_{ij}^{R} indicating inputs produced in France but outside of Brittany:

$$m_{ij} = m_{ij}^{N} + m_{ij}^{R}. \tag{17}$$

National import rates m_{ij}^{N} are assumed to be stable within France regardless of the region. They were calculated directly from the national I-O table as follows:

$$a_{ij}^{N} = \left(1 - m_{ij}^{N}\right) a_{ij}, \tag{18}$$

where a_{ij}^{N} represent national technical coefficients of industry *j* for input *i*.

Several studies have focused on the estimation of regional import rates m_{ij}^{R} to compensate for the lack of data on interregional trade. For instance, Leontief and Strout [62] developed the gravity model to estimate the trade of products between different regions. Although this method is more satisfactory from a theoretical point of view, it is difficult to implement. An alternative method calls for the use of location quotients to estimate regional technical coefficients [71]. The most frequently used location quotient in the literature is the simple location quotient (*SLQ*). Nevertheless, one of its shortcomings is that the import rate is only determined by the relative sizes of selling sector *i* and the study region. In this context, several studies dealing with the construction of regional I-O tables have developed *SLQ*s by calculating weighted location quotients (*WLQ*) leading to more reliable estimations of import rates. For instance, based on Round [85], Flegg et al. [43] and Flegg and Webber [42] worked out a location quotient commonly noted as *FLQ*, which takes into account the relative size of selling sectors *i*, the relative size of buying sectors *j*, and the size of the region. Several empirical studies have shown that *FLQ* provides a more accurate estimation of the import rate.[9]

Flegg and Webber [42] start with cross-industry location quotient ($CILQ_{ij}$), taking into account both the size of selling sectors *i* relative to the size of buying sectors *j* and the size of the region relative to the size of the nation λ. Therefore, they calculate the location quotient as:

$$FLQ_{ij} = CILQ_{ij}\lambda \text{ with } \lambda = \left(log_2\left[1 + \frac{V^R}{V^N}\right]\right)^{\delta}, \tag{19}$$

where V^R and V^N respectively represent the total added value of the region and the nation.

Flegg and Webber [42] suggest estimating δ by using an econometric tool. In case of inadequate regional data, as in our case, they recommend setting δ to 0.3. Regional technical coefficients were therefore calculated by using the following equation:

$$a_{ij}^{R} = \begin{cases} a_{ij}^{N} \text{ if } FLQ_{ij} \geq 1 \\ a_{ij}^{N}\left(FLQ_{ij}\right) \text{if } FLQ_{ij} < 1. \end{cases}$$

3.3 Data and Assumptions

In Subsection 3.3.1, we give a general description of the required database and the I-O method that we used. In Subsections 3.3.2 and 3.3.3, we detail the data and assumptions regarding, respectively, the investment and O&M phases for the simulation of the impacts of the project.

3.3.1 Preliminary Methodological Presentation

The database of the I-O model is the I-O table, which describes the origin and destination of products *i* (with *i* = 1. .. *n*) and the production process in industry *j* (with *j* = 1...*n*). We consider a symmetrical I-O table in which each industry is assumed to produce only one product. Therefore, the number of products is equal to the number of industries, that is *n*, and the production of product *i* is equal to the production of industry *j* when *i* = *j*. The I-O table is used to calculate the matrix of technical coefficients A indicatinsg the goods and services needed to

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[9] It primarily reduces estimation errors [15, 41, 96].

produce one monetary unit per industry. In addition, the I-O table estimates the vector of the final demand Y for a given year.

We use the French I-O table for the year 2010 [38] which is symmetrical[10] and broke down into 64 industries and products according to the statistical Classification of Products of Activity (CPA) 2008. The values of domestic and imported commodities consumed by institutional agents within an economy are indicated in this I-O table.

A number of articles have used I-O models to assess the economic impacts of renewable energies [27, 58, 61, 66, 78, 83]. Two I-O approaches are generally used, either the "final demand approach" or the "complete inclusion in the technical coefficients matrix" [71]. The first approach considers the intermediate inputs consumed by the new industry as an exogenous change. They are recorded in the model as the final demand. In contrast, the second approach seeks to integrate the new industry in the technical coefficient matrix. Within the framework of the deployment of renewable energies, the second approach requires estimating the share of new renewable energy electricity consumed by regional industries and assessing how it affects the share of electricity coming from conventional energy sources consumed by the same regional industries.

The first approach has been widely used to estimate the economic impacts of renewable energy where their development is assumed to have no effect on the pattern of inputs used by other sectors and do not involve an offsetting constraint on the output of any sector [18, 21, 65]. The second approach has also been used in the literature to study the consequences of renewable energy deployment. For instance, Garrett-Peltier [46] use it to compare the employment effects of renewable energy and fossil fuels. In general, the second approach is more suitable when the production of the new industry aims to substitute for the production of other industries.

Here, we use the "final demand approach." We assume that the construction of an offshore wind farm will not affect the pattern of inputs used by other sectors in the Brittany region. Moreover, we know that the development of offshore wind energy in Brittany does not aim to replace the production of electricity coming from conventional fuels but to supplement it. We calculated the technical coefficients a_{ij} and the national technical coefficients a_{ij}^{N}. By using Eq. (19), we also estimated the interregional trade to obtain the regional technical coefficients a_{ij}^{R} to calculate regional indirect and induced impacts. However, the implementation of this equation requires knowing the regional added value of industries. Because France has a poor regional accounting system, this regional added value was calculated as the pro-rata number of employees in the region relative to the country for each industry by assuming that labor productivity is relatively similar between Brittany and France.[11]

Calculating induced impacts requires knowing the share that employee wages account for in the production for each industry and the share of household consumption in total employee wages for each product. These data are not available at a regional scale, but we assume that the proportion of wages in production as well as the consumption pattern of households are similar for Brittany and France.

3.3.2 The Investment Phase: Creating the Vector of Demand to Model the Impacts of Offshore Wind[12]

To calculate direct, indirect, and induced economic impacts during the investment phase, we started by creating the vectors of final demand Y^* which represent the direct impact of the project in terms of economic production. These calculations were performed by assuming that the investment phase will take 4 years (from 2016 to 2020) and that the total investment cost for this period amounts to €1860 M, i.e., €465 M per annum (excluding the development phase). Based on Table 1 from Section 2 and on Junginger et al. [57], IHS EER [53], RIH [84], GL BPN [48], FEM [40], Scottish Entreprise [88], Sun et al. [94], and Johnstone et al. [56], we split the investment cost into different items of expenditure as shown in the first column of Table 2. Then, keeping in mind that the main construction activities will be conducted in the Brittany and Normandy regions, we determined which industries would be affected (according to the CPA (2008) nomenclature) as well as their relative contributions to the total investment cost (in % and in M€) which is allocated to each item of expenditure with respect to the industries involved as presented in the last four columns of Table 2.

To convert these expenditures into a vector of final demand, we should first estimate what proportion of them will be allocated to Brittany. As indicated in ESA [33], all transactions of single-region institutional units are allocated to the region in which such units have their predominant economic interest. The production activity usually takes place where the units are located. However, in some cases, the place of production activity can be different from the place where the unit is located, e.g., construction sector. The production value is therefore recorded in the region where the production activity takes place (and not in the place where the institutional unit is

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[10] Eurostat [38] provides a symmetrical I-O table because it publishes both the use and the make matrices. For more information with regard to the construction of this symmetrical I-O table, interested readers can consult Eurostat [36].

[11] The number of employees by region and industry is given in the 2011 population census [54].

[12] During a discussion about our paper on 4 May 2016, Raphaël Dufeu from Ailes Marines SAS, the company that won the call for tender for the Saint-Brieuc project, explained that some uncertainties remain with regard to the construction process and the associated choice of suppliers due to the fragmented supply chain and the embryonic nature of the offshore wind industry in France. Therefore, assumptions that we consider in Subsection 3.3.2 with regard to cost allocation during the investment phase are reasonable.

Table 2 Assumptions on investment cost allocation to items and industries according to the French aggregated nomenclature (NA-64) during the investment phase (2016–2020)

Item of expenditure	Affected industries	Share in total cost (%)	Share in total cost (M€)	
			Total (M€)	Annual (M€)
Wind turbine: construction, assembly, and installation	F: construction and construction works	47	940[a]	235[a]
Foundation: construction and installation	F: construction and construction works	23	460[b]	115[b]
Marine network: construction and installation	F: construction and construction works C27: electrical equipment	10	200[c]	50[c]
Connection: cable and shore-based facilities	F: construction and construction works	13	260[d]	65[d]
Farm development	–	7	140[e]	47[e]
Total	–	100	2000	512

[a] €940 M = €2 B × 47%, where €2 B represents total CAPEX of the project and 47% the share of expenditures devoted to wind turbine construction in the total cost. $€235\ \mathrm{M}=\frac{€940M}{4}$.

[b] €460 M = €2 B × 23%. $€115\ \mathrm{M}=\frac{€460M}{4}$.

[c] €200 M = €2 B × 10%. $€50\ \mathrm{M}=\frac{€200M}{4}$.

[d] €260 M = €2 B × 13%. $€65\ \mathrm{M}=\frac{€260M}{4}$.

[e] €140 M = €2 B × 7%. $€47\ \mathrm{M}=\frac{€47M}{4}$.

located) if the activity requires significant labor input for at least 1 year. Given this rule, we explain below the conversion of the cost/investment expenditures into a vector of final demand.

The first item of investment expenditures, i.e., wind turbine construction, assembly, and installation, includes several different stages of production. Mainly, two stages should be distinguished: construction and assembly and installation. Because we have no information on the breakdown of the cost between these two stages, we assumed that 50% goes to the construction stage, i.e., €118 M, and 50% to assembly and installation, i.e., €118 M. The construction stage includes the production of the different wind turbine components, e.g., the blade, mast, and generator. According to AREVA [8], this production is carried out by companies that are mainly located outside of Brittany, in particular in the city of Le Havre which is located in Normandy. Therefore, no expenditures can be associated with Brittany for this stage. For the assembly and installation stages, assembly will also be carried out outside of Brittany in the port of Le Havre close to where the wind turbine components will be constructed. However, for supervising the installation, we assumed that a local office will be set up in Brittany to supervise the works. We therefore considered that half the expenditures assumed to be equally divided between assembly and installation will go to the Brittany region, i.e., €59 M. In sum, we estimated that of the €235 M invested each year for wind turbine construction, assembly, and installation (the first item of expenditures in Table 2), nearly €60 M will go to Brittany.

With regard to the second item of investment expenditures, i.e., foundation construction and installation, we assumed that a local office will be set up in Brittany to supervise the works. Therefore, all the expenditures induced by these activities, belonging to the construction industry classification, will be assigned to the Brittany region.

The third item of investment expenditures, i.e., marine network construction and installation, includes two stages: the construction and the installation of the marine network. We assumed that each one will involve 50% of investment expenditures, i.e., €25 M. Because BPN [16, 17] argue that numerous local companies in Brittany have the skills to produce electrical cable, we assumed that 50% of investment expenditures devoted to the construction stage of the marine network will benefit Brittany, in particular the electrical equipment industry, i.e., €12.5 M. As for the installation phase, we assumed that some local office will be set up in Brittany to supervise the works. Thus, all investment expenditures devoted to the installation will benefit the region.

Finally, we assumed that all investment expenditures under the fourth item, i.e., connection: cable and shore-based position, will benefit Brittany. In fact, we can safely assume that at least one local site office will be set up in Brittany to coordinate the operations inherent to cable and shore-based facilities.

Table 3 summarizes our assumptions and input data. It gives the annual investment expenditures assigned to Brittany and provides the various items of the final demand vector that will be used to determine the economic impacts of

Table 3 Assumptions on investment costs allocated to Brittany with regard to items of expenditure and affected industries during the investment phase (2016–2020)

Item of expenditure	Affected industries		Total cost (M€)	Share of investment cost going to Brittany
	Construction industry	Electrical equipment industry		
Wind turbine: construction, assembly, and installation	60	0	60	
Foundation: construction and installation	115	0	115	
Marine network: construction and installation	25	13	38	
Connection: cable and onshore substation	65	0	65	
Total (M€)	253	25	278	
Share of investment cost going to Brittany				$60\%=\frac{\text{€}278M}{\text{€}465M}$

the investment phase of the Saint-Brieuc offshore wind project for the region of Brittany.

3.3.3 Impact Calculation During the O&M Phase

Economic impacts during the O&M phase arise from the production and maintenance activities of the Saint-Brieuc offshore wind farm.

We used the output approach to estimate the direct impact of the project in terms of economic production (European Commission et al. [34]). We multiplied the expected physical production by the expected unitary price. According to Iberdrola and Eole-Res [51, 52], AREVA [8], and CRE [29], the expected production is 1750 GWh per annum and the unitary net price €66,500 per GWh [29]. The value of economic production is therefore estimated at €116 M per annum. According to Lehr et al. [60], the rate of added value is equal to 50%; thus, the added value is about €58 M. With regard to employment, based on Oxford Economics [80], Colbert-Busch et al. [26], Zammit and Miles [103], and Sercy et al. [89], we used a weighted average value of estimations of the expected number of jobs calculated for offshore wind farms during the O&M phase[13] equal to 0.4 FTE jobs per MW.[14] Applying this value implies that the Saint-Brieuc offshore wind farm totaling 500 MW will have a staff of 200 employees.

To estimate the indirect and induced impacts, we assumed that the production process—different inputs representing intermediate consumption as well as primary inputs such as labor and capital—of offshore wind is quite similar to the production process of onshore wind because current offshore wind technologies are based on onshore wind technology [94]. Therefore, we referred to the Lehr et al. [60] study, which estimated the different inputs/intermediate consumption required to produce one monetary unit of the electricity produced by wind energy farms (see Table 4) to estimate the indirect and the induced impacts inherent to the O&M phase. More specifically, we calculated indirect and induced impacts using the matrix of regional technical coefficients from respectively the open and the closed Leontief models [63] (see Appendix 4). We used Eqs. 4 to 9 and Eqs. 10 to 15 to respectively calculate indirect and induced impacts.

4 Results and Some Policy Implications

In Subsection 4.1, we summarize results and carry out a comparative analysis. We note that according to the available information, we successfully carried out a comparative analysis on employment impacts only. In Subsection 4.2, we give some policy implications.

4.1 Presentation of Results and Comparative Analysis

Table 5 summarizes results. It details annual direct, indirect, and induced impacts in million euros and per megawatt for each phase of the project. Our results show that the highest relative impacts occur during the investment phase. In particular, during this phase (from 2016 to 2020), economic production is expected to total €442 M and gross added value €191 M or on a per annum basis €0.88 M/year/MW and €0.38 M/year/MW. They also show that the investment phase creates 3016 FTE jobs which is the equivalent of 6.03 FTE jobs/year/MW. During the O&M phase lasting from 2020 to 2040, annual economic production and gross added value are expected to respectively reach €163 M or €0.32 M/year/MW and €79 M or €0.15 M/year/MW. For employment, 511 FTE jobs, thus, 1.02 FTE jobs year/MW, are expected annually. These results indicate that the project will

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[13] After eliminating the highest value calculated by Zammit and Miles [103].

[14] Details about estimations of Oxford Economics [80], Colbert-Busch et al. [26], Zammit and Miles [103], and Sercy et al. [89] are presented in Tables 6 and 14 (Appendix 5).

Table 4 Values of inputs required for the production of one monetary unit of power from the Saint-Brieuc offshore wind farm [31, 60]

Nomenclature (CPA 2008)	Title	Value (€)
C22–C23	Rubber and plastic products and other products made of non-metallic elements	0.015
C25	Manufactured metal products, except machinery and equipment	0.095
C27	Electrical equipment	0.125
C28	Machinery and equipment n.e.c.	0.090
C29–C30	Transportation equipment	0.050
F	Construction and construction works	0.030
G	Wholesale and retail trade services	0.055
H	Transportation and storage services	0.010
K	Financial and insurance services	0.015
LZ	Real estate services	0.015
	Total intermediate consumption	0.500
	Employee compensation	0.120
	Other net taxes on production	0.025
	Operating surplus, net	0.355
	Added value	0.500
	Production	1

increase the GDP of Brittany by 0.22 and 0.09% during the investment and O&M phases, respectively.[15]

Based on two literature reviews respectively dealing with the quantification of the economic impacts of the Saint-Brieuc offshore wind project (Table 13 from Appendix 5[16]) and overseas offshore wind projects (Table 14 from Appendix 5), Table 8 presents a comparative analysis on the employment generated by the Saint-Brieuc offshore wind farm.[17] Part I of this table which gives the results of studies assessing the economic impacts of the Saint-Brieuc offshore wind farm shows that our expected levels of employment in Brittany during the investment and O&M phases, considered separately, are relatively optimistic. In particular, our results foresee 1919 direct FTE jobs in Brittany during the investment phase. Similarly, Nass&Wind [76] states that between 1500 and 2000 direct FTE jobs will be generated whatever the region. During the O&M phase, Nass&Wind [76] and Oxford Economics [80] respectively estimated the total expected number of direct FTE jobs for all regions/geographical areas at 60 and 110.[18] However, our results suggest that 200 FTE jobs will be created in Brittany.

Considering the aggregated impact of the investment and O&M phases on employment, the comparative analysis shows that the number of expected jobs in Brittany estimated by Ailes Marines SAS [6] is lower than our estimates. In contrast to their assertion that 1000 direct FTE jobs will be created, our results suggest that there will be 2119 direct FTE jobs. Similarly, when compared to estimations of BPN [16], quoted in CCICA [23], our results show that a large part of employment generated will occur in Brittany: more precisely, of the 2500 direct FTE jobs, 2119 will be located in Brittany. Conversely, compared with results of EWEA [39] showing that 5500 direct and indirect jobs can be expected of the Saint-Brieuc project, our results indicate that only 2732 direct and indirect jobs can be expected.

When comparing our results with those of overseas offshore wind farms having an equivalent size to the Saint-Brieuc farm, i.e., 500 MW, as reported in part II of Table 8,[19] we found high variability. For example, US DE [98] corroborate our results. They state that for a farm of 500 MW, 4.99 FTE jobs per MW and 1.66 FTE jobs per MW (per annum) are expected during the investment and O&M phases, respectively, which is comparable to our results, i.e., 6.03 FTE jobs per MW and 1.02 FTE jobs per MW (per annum) during the same respective phases. Nevertheless, Oxford Economics [80] and Colbert-Busch et al. [26] indicate that our results overestimate employment impacts during the investment and the O&M phases. For example, according to Colbert-Busch et al. [26], 500 MW of installed offshore wind capacity can engender 3.62 FTE jobs/year/MW during the investment phase and 0.67 during the O&M phase. Conversely, estimations from Sercy et al. [89] and Zammit and Miles [103] reveal that our results comparatively underestimate impacts during the investment. For instance, although our results predict 6.03 FTE jobs per MW, Zammit and Miles [103] states that 19 FTE jobs per MW can be created. As for total employment impact, results of Flynn and Carey [44] appear to suggest that we overestimate the expected total number of jobs, i.e., 7.05 per MW (per annum) compared with 3.92 jobs per MW.

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[15] Calculations were done with respect to the 2013 GDP level which is equal to €86,934 M.

[16] None of estimations quoted in Table 13 from Appendix 5 and part I of Table 8 have been published in the academic literature. They were collected from various internet sources, i.e., reports, press conference documents, and the local press, which usually provide no details on the methodology used.

[17] Although it is widely accepted that results from different assessment exercises can vary and sometimes conflict, we wish to emphasize that our comparative analysis should be considered with caution in particular, due to discrepancies with regard to how jobs are defined. For example, Simas and Pacca [90] argue that "manufacturing of key components, power plant construction and O&M are considered direct jobs. However, some studies include planning and project management, research and development, energy companies, utilities, banks, and other services". They add that "the definition of indirect jobs is even vaguer. While some authors estimate the indirect effects of materials and services consumed on the upstream supply chain, other studies consider consultancies and several minor components not directly related to the sector. There are also studies which include induced jobs in the final quantification. Usually, job losses in other energy industries due to high investments costs of renewable energy technologies are not accounted for. The treatment of the differences between temporary and permanent jobs is also an issue that is often not addressed."

[18] Average value.

[19] As shown in Table 14 from Appendix 5, estimations quoted in part II of Table 8 were generated from modeling exercises based on well-founded theoretical approaches contrary to estimations presented in part I of the same table (see also footnote 16).

Table 5 Summary of annual economic impacts for Brittany

Type of impact	Economic production (M€)	Added value (M€)	Jobs (FTE)
	The investment phase (2016–2020)		
Direct impacts	278	111	1919
Indirect impacts	68	30	460
Induced impacts	96	50	637
Total	442	191	3016
Total per MW	0.88[a]	0.38[a]	6.03[a]
	The O&M phase (2020–2040)		
Direct impacts	116	58	200
Indirect impacts	26	10	153
Induced impacts	21	11	158
Total	163	79	511
Total per MW	0.32 [b]	0.15 [b]	1.02 [b]

[a] $0.88 = \frac{462}{500}, 0.38 = \frac{462}{500}, 6.03 = \frac{462}{500}$

[b] $0.32 = \frac{163}{500}, 0.15 = \frac{163}{500}, 1.02 = \frac{163}{500}$

Since at this stage of the analysis we only assessed regional impacts of the project, we extended our study by evaluating national impacts (see below) to quantify the share of wealth and employment captured by the Brittany region. Therefore, we performed the same I-O analysis on the French national I-O table. Similar to the regional assessment, the two phases of the project were treated separately, i.e., investment and O&M. Again, for the investment phase, in analogy to the regional impacts assessment (see Table 3), we assumed that 60% of cost expenditures will be located in France (nationwide). The results of this exercise are given in Tables 6, 7, and 8.

They show that at the national level, during the investment phase, the Saint-Brieuc project will generate an added value amounting to €1.01 M/year/MW (compared with €0.38 M in Brittany) and 19.04 FTE jobs/year/MW (compared with 6.03 FTE jobs in Brittany). Using these results to calculate the share that Brittany carries in terms of total impacts (see Table 3) shows that the Brittany region captures 38% of wealth and 32% of jobs created by the Saint-Brieuc project. These low values can be explained, firstly, by relatively small low investment expenditures allocated to the Brittany region, i.e., 60% according to our assumption[20] and, secondly (to a lesser extent), the loss of wealth induced by interregional imports.

For the O&M phase, the Saint-Brieuc project is expected generate an added value equal to €0.23 M/year/MW (compared with €0.15 M in Brittany). Moreover, it will sustain 2.01 FTE jobs/year/MW (compared with 1.02 FTE jobs in Brittany). Therefore, the Brittany region is predicted to capture 66% of the wealth and 51% of the jobs created by the project. Thus, contrary to the investment phase, Brittany can benefit quite well from the economic impacts induced by the O&M phase.[21]

In sum, depending on the proportion of regional investment that will be decided by stakeholders and on which we have made assumptions to feed our I-O model, i.e., 60%, Brittany can benefit from positive wealth and employment impacts. The magnitude of these impacts is nevertheless small. In particular, the project is expected to increase the regional GDP by 0.22 and 0.09% during the investment and O&M phases, respectively, which corresponds to 38 and 66% of national economic impacts. As for employment impacts, 32 and 51% part will be captured by Brittany during the same phases.

4.2 Policy Implications

As shown by our results, although the local project off Saint-Brieuc is expected to induce positive employment impacts, these impacts are nevertheless small. However, with the recent ambition of France to establish a strong national offshore wind industry, more significant impacts may ensue. In France, one criterion for the evaluation of

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[20] We note that according to our I-O model, the economic multipliers are strong. For instance, an expense of €1 generates a production value of €2.90. This means that the investment expenditures have strong ripple effects. Similarly, for the employment multiplier, an expense of €1 generates 20.48 FTE jobs. Therefore, the main reason for the weak economic impacts of the project in Brittany compared with the national level is the low relative proportion of regional investment expenditures.

[21] The loss of wealth for Brittany during the O&M phase is solely attributed to inter-regional imports. In fact, during this phase, multiplier effects are low. For instance, an expense of €1 generates a production value of €2.06. This means that the O&M expenditures have relatively weak ripple effects. Similarly, for the employment multiplier, an expense of €1 generates only 8.67 FTE jobs.

Table 6 Summary of annual economic impacts for France

Type of impacts	Economic production (M€)	Added value (M€)	Jobs (FTE)
	The investment phase (2016–2020)		
Direct impacts	465	189	3277
Indirect impacts	399	181	2874
Induced impacts	487	135	3373
Total	1351	505	9524
Total per MW	2.70[a]	1.01[a]	19.04[a]
	The O&M phase (2020–2040)		
Direct impacts	116	58	200
Indirect impacts	67	27	357
Induced impacts	57	34	449
Total	239	119	1006
Total per MW	0.47[b]	0.23[b]	2.01[b]

[a] $2.70 = \frac{1351}{500}, 1.01 = \frac{1351}{500}, 19.04 = \frac{1351}{500}$

[b] $0.47 = \frac{239}{500}, 0.23 = \frac{239}{500}, 2.01 = \frac{239}{500}$

applications in response to calls for tender for offshore wind is the "industrial and social quality of the project," which accounts for 40% of the total score and aims to foster the industrial development of offshore wind in France by encouraging nationwide organization of the value chain, nationwide creation of economic activity, and nationwide development of experience curve effects [28]. In this context, to construct turbines, Alstom[22] for instance is expected to set up two factories in Saint Nazaire (Pays-de-la-Loire region) for the construction of generators and nacelles, two factories in Cherbourg (Normandy) for the construction of blades and masts, and an engineering center in the Pays-de-la-Loire region devoted to support the creation of an independent offshore wind industry. Also, areas in the ports of Le Havre (Normandy), Cherbourg, Brest (Brittany), and Saint-Nazaire are dedicated to the pre-assembly and installation phases [2]. Similarly, Ailes Marines SAS[23] has defined a development program that aims at establishing a sustainable and independent French offshore wind industry with both local and export development opportunities. Under this program, human resources and local companies (mainly in Brittany) have been identified to be involved in different roles along the supply chain [3, 17, 24, 70].

When focusing on human resources and employment impacts, a crucial step is to start setting up measures to develop a skilled workforce. Given the embryonic nature of the offshore wind industry in France, its fragmented supply chain and the uncertainty with regard to its future development prospects, a shortage of skilled workers in some roles, e.g., offshore security and maintenance technicians, can be expected [47]. In the short term, the supply of skilled workers is likely to come from other sectors including the onshore wind, offshore oil and gas, automotive, and aerospace sectors, although there are challenges in attracting experienced workers. Alternatively, the workforce can be sourced internationally within the framework of overseas collaborations that may promote knowledge transfers. In the long term, after identifying needs when possible, it is important to define a long-term strategy for workforce training and planning. The offer of training courses should operate on both levels of education and training, both initial and continuing. It is also important to ensure that instructors are certified through professional training courses (*formation professionnelle*) because this consolidates the promotion of jobs specific to

Table 7 Contribution of Brittany to total economic impacts

Type of impacts	Economic production	Added value	Jobs
	The investment phase (2016–2020)		
Direct impacts	60%	59%	59%
Indirect impacts	17%	17%	16%
Induced impacts	20%	37%	19%
Total	33%	38%	32%
	The O&M phase (2020–2040)		
Direct impacts	100%	100%	100%
Indirect impacts	39%	37%	43%
Induced impacts	37%	32%	35%
Total	68%	66%	51%

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[22] Alstom is a member of Éolien Maritime France, the consortium that bid on and won the tender for the Fécamp (Seine-Maritime, 500 MW), Courseulles-sur-mer (Calvados, 500 MW), and Saint-Nazaire (Loire-Atlantique, 750 MW) offshore wind farms.

[23] Ailes Marines SAS won the tender for the Saint-Brieuc offshore wind farm (Côtes d'Armor, 500 MW).

Table 8 Comparative analysis on the employment impact of the Saint-Brieuc offshore wind farm (based on Tables 13 and 14)

Reference	Phase	Results		Comments on the jobs considered in the reference
		Reference	Our model	
Part I				
Comparison of our results (see Table 5) with those from other studies on the employment impact of the Saint-Brieuc offshore wind farm (see Table 13)				
Ailes Marines SAS [6]	Manufacturing, installation, and O&M	1000 jobs	2119 jobs	2119 = 1919 + 200. Only direct jobs were considered
Nass&Wind [76][a]	Manufacturing and installation	[1500–2000] jobs[b]	1919 jobs	Indirect and induced jobs do not appear to be considered
	O&M	60 jobs[b]	200 jobs	Only direct jobs were considered
Oxford Economics [80][a]	O&M	[95–125] jobs[b]	200 jobs	Only direct jobs appear to be considered
EWEA [39][a]	Global impacts	5500 jobs[b]	2732 jobs	2732 = 1919 + 460 + 200 + 153. Induced jobs were not considered
	O&M	150 jobs[b]	353 jobs	353 = 200 + 153. Induced jobs were not considered
CCICA [23]	Conception, development, manufacturing, installation, and O&M	[2010–2250] jobs[b]	1919 jobs	Only direct jobs appear to be considered
	O&M	30 jobs[b]	200 jobs	Only direct jobs appear to be considered
BPN[a]	Global impacts	2500 jobs[b]	1919 jobs	Only direct jobs appear to be considered
	O&M	[60–80] jobs[b]	200 jobs	Only direct jobs appear to be considered
Part II				
Comparison of our results (see Table 5) with those of studies assessing economic impacts of overseas offshore wind farms (see Table 14)				
Sercy et al. [89]	Construction and component manufacturing	23.97 jobs per MW	6.03 jobs per MW	$€47\ \mathrm{M} = \frac{€47M}{4}$
	O&M	0.25 jobs per MW (per annum)	1.02 jobs per MW (per annum)	$60\% = \frac{€278M}{€465M}$
US DE [98]	Construction	4.99 jobs per MW	6.03 jobs per MW	$4.99 = \frac{20100}{4027}$
	O&M	1.66 jobs per MW (per annum)	1.02 jobs per MW (per annum)	$1.66 = \frac{6700}{4027}$
Zammit and Miles [103]	Construction	[19–39] jobs per MW	6.03 jobs per MW	–
	O&M	[1.64–1.67] per MW	1.02 jobs per MW (per annum)	–
Colbert-Busch et al. [26]	Component manufacturing and installation	3.62 jobs per MW (per annum)	6.03 jobs per MW (per annum)	$3.62 = \frac{293+3329}{1000}$
	O&M	0.67 jobs per MW (per annum)	1.02 jobs per MW (per annum)	$0.67 = \frac{678}{1000}$
Oxford Economics [80]	O&M	[0.35[c]–0.45[d]] jobs per MW	1.02 per MW (per annum)	$0.35 = \frac{7230}{25000}$ and $0.45 = \frac{450}{1000}$
EWEA [39]	Farm development, turbine and component manufacturing, and installation	15.1 jobs/year/MW[e]	n.a.	Number of jobs includes both offshore and onshore wind. Induced jobs were not considered

Table 8 (continued)

Reference	Phase	Results		Comments on the jobs considered in the reference
		Reference	Our model	
	O&M	0.33 jobs per (cumulative) MW	1.02 jobs per MW (per annum)	
Boettcher et al. [13]	O&M	0.34 jobs per MW (annual)	1.02 jobs per MW	$0.34 = \frac{6734}{20000}$
Carbon Trust [22]	R&D, engineering and design, turbine and component manufacturing and services	[1.10–1.41] jobs per MW	6.03 jobs per MW	$1.10 = \frac{32000}{29000}$ and $1.41 = \frac{41000}{29000}$
	Installation and O&M	[0.27–1] per MW	1.05 per MW (per annum)	$0.27 = \frac{8000}{29000}$ and $1 = \frac{29000}{29000}$
GWEC [49]	Farm development, turbine and component manufacturing, and installation	15.1 jobs/year/ MW[e]	n.a.	Estimation in GWEC [49] is extracted from EWEA [39]. Includes both offshore and onshore wind. Induced jobs were not considered
	O&M	0.33 jobs per (cumulative) MW	1.02 jobs per MW (per annum)	
Flynn and Carey [44]	Manufacturing, installation, and O&M	3.92 jobs per MW	7.05 per MW	(per annum)[f]

[a] Quoted in CCICA [23]

[b] This estimation is relative not only to Brittany but also to all geographical areas that can be affected by the project

[c] This estimation is associated with an expected installed capacity of 20.5 GW by 2020

[d] This estimation is associated with an installed capacity of 1 GW by 2010

[e] This means 15.1 jobs per additional installed MW in 1 year

[f] 7.05 = 6.03 + 1.02 where 6.03 represents the number of jobs per MW (per annum) during the investment phase and 1.02 the number of jobs per MW (per annum) during O&M

offshore wind.[24] Interestingly, by developing a skilled workforce, France could export its know-how and thereby enhance local employment impacts. For example, the five Haliade 150–6-MW offshore wind turbines of the American Block Island Wind farm, currently in operation, were manufactured by the French Alstom Group at its factory in Saint-Nazaire.

Obviously, measures aiming at developing a skilled workforce should be associated with other measures focusing on ensuring electricity price accessibility for consumers, stabilizing the regulatory and legal frameworks for wind power, and enhancing the social acceptability of wind turbines. In the preliminary stage of offshore wind development, reducing investment costs and thus electricity prices is a key lever to ensuring the large-scale deployment of offshore wind. In the long run, cost reduction can be expected due to the accumulation of experience and economies of scale. IRENA [55] argues that costs have fallen more than 30% in the 15 years since the first wind farm opened. Wiser et al. [102] also expects, although uncertainties persist, cost reductions of 24–30% by 2030 and 35–41% by 2050. Nevertheless, as stated by Blanco [10], Snyder and Kaiser [92], and Musial and Ram [75], in the short and medium terms, public financial support mechanisms are crucial to cope with high costs. In this context, IRENA [55] argues that cost reductions have been aided by government financial support to address the security of electricity supply and the decarbonization of electricity production.

Currently in France, investment costs are borne by the private sector [3]. Government financial support to offshore wind is indirect and goes through feed-in tariffs. For an operation period of 20 years, it was set at €130/MWh for the first 10 years and between €30 and 130/MWh for the last 10 years depending on the geographical location of the farm. The *Contribution au Service Public de l'Électricité* (CSPE) finances feed-in tariffs because it aims to have local and regional governments bear the additional financial burden engendered by the production of electricity from renewable sources in general and offshore wind in particular. According to CRE [29], the additional financial costs that will be generated by the four scheduled offshore wind farms from the first French call for tender amount to €1.1 B per year starting from 2020.[25]

5 Conclusion

While opponents to the large-scale deployment of offshore wind usually point out its high cost and lack of competitiveness, its advocates argue that expected economic benefits can be high. This paper presents a case study to assess local economic impacts of the 500-MW offshore wind farm off Saint-Brieuc in Brittany, in particular employment impacts. We used a regional I-O model that we implemented with the few available data on the project in an informative way to paint a robust picture of deployment prospects of offshore wind in France and its expected impacts.

Results show that depending on the rate of regional investment with respect to the supply chain roles, the project weakly, but nevertheless positively, impacts Brittany's economy. It is expected to increase the GDP of Brittany by 0.22 and 0.09% during the investment and O&M phases, respectively. More specifically, during the investment phase, €0.88 M/year/MW of economic production, €0.38 M/year/MW of gross added value, and 6.03 FTE jobs/year/MW are expected. During the O&M phase, €0.32 M/year/MW of economic production, €0.15 M/year/MW of gross added value, and 1.02 FTE jobs/year/MW are also expected. Compared to the national impacts of the project, these results imply that 38 and 66% of wealth creation will be captured by the Brittany region during the investment and O&M phases, respectively. They also imply that 32 and 51% of employment impacts will be benefit Brittany during the same phases.

These results shed light on the potential role that offshore wind investments can play in the long run in stimulating economic development mainly at the local scale. In particular, through the development of new economic sectors, job creation, and consumer spending, such investments are expected to enhance regional economies. Therefore, in a context of economic deceleration in France associated with recurrent and alarming debates over resource depletion and climate change issues, accelerating the development of offshore wind represents an opportunity. Nevertheless, in France, there is currently a profound need to revise the economic, technological, legal, regulatory, and social frameworks within which the offshore wind industry is currently emerging to establish the conditions for its sustainable development. Despite the scheduled farm construction after the three calls for tender in July 2011, March 2013, and December 2016, the offshore wind industry is still in its early stages because the cost of offshore electricity is currently very high, the supply chain is fragmented, the regulatory context is uncertain, the legal framework is undefined, and the social acceptability is shaky. Short-run and long-run measures targeting to support both the demand and the supply sides are necessary. We particularly advocate technology incentives, e.g., government R&D, subsidies, and tax credit, which all promote early knowledge transfer and overcome barriers to market entry, and market pull, i.e., feed-in tariffs, Renewables Obligations (RO), taxes, measures devoted to enhancing the deployment of wind technology by creating demand and developing markets. Successful experiences in the UK or Denmark show the effectiveness of the combination of both of these two types of measures. Conversely, they also highlight that France is lagging behind in mobilizing its human, technological, and geographical resources to develop its offshore wind industry. Regional collaborations and international cooperation can surely accelerate the process and offer wider benefits.

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[24] The main institutions delivering training courses related to offshore wind in particular and to marine renewable energies in general in France are L'École Centrale of Nantes (http://www.ec-nantes.fr/), L'ENSTA Bretagne of Brest (http://www.ensta-bretagne.fr/), L'École Navale (http://www.ecole-navale.fr/), maritime secondary schools, and maritime vocational schools [47].

[25] This corresponds to an additional annual cost of €160/MWh.

Appendix 1. Overview of the global offshore wind capacity[26]

Table 9 Global cumulative offshore wind capacity in 2015 and 2016

Country	Installed capacity (MW)	
	2015	2016
UK	5100	5156
Germany	3295	4108
People's Republic of China	1035	1627
Denmark	1271	1271
Netherlands	427	1118
Belgium	712	712
Sweden	202	202
Japan	53	60
South Korea	5	35
Finland	32	32
USA	0.02	30
Ireland	25	25
Spain	5	5
Norway	2	2
Portugal	2	0
Total	12,167	14,384

Table 10 The 25 largest operational offshore wind farms in the world in 2016

Farm	Capacity (MW)	Country	Number of turbines	Commissioning date
London Array	630	UK	175	2012
Gwynt y Môr	576	UK	160	2015
Greater Gabbard	504	UK	140	2012
Anholt	400	Denmark	111	2013
BARD Offshore 1	400	Germany	80	2013
Global Tech I	400	Germany	80	2015
West of Duddon Sands	389	UK	108	2014
Walney (phases 1 and 2)	367.2	UK	102	2011 (phase 1) 2012 (phase 2)
Thorntonbank (phases 1–3)	325	Belgium	54	2009 (phase 1) 2012 (phase 2) 2013 (phase 3)
Sheringham Shoal	315	UK	88	2012
Borkum Riffgrund 1	312	Germany	78	2015
Thanet	300	UK	100	2010
Nordsee Ost	295	Germany	48	2015
Amrumbank West	288	Germany	80	2015
Butendiek	288	Germany	80	2015
DanTysk	288	Germany	80	2015
EnBW Baltic 2	288	Germany	80	2015
Meerwind Süd/Ost	288	Germany	80	2015
Lincs	270	UK	75	2013
Humber Gateway	219	UK	73	2015
Northwind	216	Belgium	72	2014
Westermost Rough	210	UK	35	2015
Homs Rev II	209.3	Denmark	91	2009
RØdsand II	207	Denmark	91	2010

Appendix 2. Supplementary information on offshore wind in France

General

In July 2011, the first call for tender was launched by the French government for installing 3 GW of offshore wind power in five areas in north-western France: Dieppe-Le Tréport (Seine-Maritime *département*, 750 MW), Fécamp (Seine-Maritime *département*, 500 MW), Courseulles-sur-mer (Calvados *département*, 500 MW), Saint-Nazaire (Loire-Atlantique *département*, 750 MW) and Saint-Brieuc (Côtes d'Armor département, 500 MW). Only the Dieppe-Le Tréport project failed to meet selection criteria. Winners of the call for tender are Éolien Maritime France (EMF) for the Fécamp (498 MW), Courseulles-sur-mer (450 MW) and Saint-Nazaire (480 MW) projects and Ailes Marines S.A.S for the Saint-Brieuc project (500 MW). EMF, whose main shareholders are EDF Energies Nouvelles and Dong Energy Power (a Danish energy company), uses wind turbines supplied by Alstom. Ailes Marines SAS, whose main shareholders are Iberdrola and Eole-Res SA, works with wind turbines supplied by Areva. It has also set up a partnership with Technip and STX [68]. In March 2013, the second call for tender for an additional 1 GW of offshore wind in Dieppe-Le Tréport (500 MW) and Noirmoutier (Vendée département, 500 MW) was annouced. GDF Suez in collaboration with Areva, Neoen Marine, and EDP Renouvelable won this second call for tender.

The Saint-Brieuc offshore wind project

According to Iberdrola and Eole-Res [51] and Arfi et al. [9], the project will be performed in partnership with Neoen Marine for the development stage, Areva for turbine construction and

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[26] Information contained in Tables 9 and 10 was extracted from www.gwec.com [Accessed 31 March 2017].

procurement, Technip for engineering and offshore installation, RTE for network connection, and Nass&Wind for the identification and the development of manufacturing sites. In Table 11, we give some characteristics of the project.

Table 11 Some characteristics of the Saint-Brieuc offshore wind project

Site characteristics	Number value	Comment
Average wind speed	8.5 m/s	–
Annual production	1750 GWh/year	7% of annual electricity consumption in Brittany
Equivalent power	3500 h	–
Loading factor	40%	–
Availability	93%	7% of waste. Wind turbines rotate 90% of the time
Distance from the coast	17 km[a]	80% more than 20 km
Average depth	34 m	–
Minimum distance between rows	1 km	Fishing possible between wind turbines
Commissioning date	2020	–
Date of dockyard completion	2020	–
Lifetime: O&M	20 years: from 2020 to 2040	–
Avoided *CO*2 emissions	488,800 t p.a.	–
Cost of installing 1 MW	€4 M	–

Source: [51, 52]) and AREVA [8]

[a] For the first offshore turbine

Appendix 3. Literature review of the methodologies used for assessing economic impacts of renewable energy technologies

Table 12 Methodologies used for assessing economic impacts of renewable energy technologies—non-technical

Reference	Methodologies					
	Macro-economic modeling methodologies				Analytical methodologies	
	I-O model	CGE model	M-E model	Econometric regression	Surveys	Other recorded data
Blazejczak et al. [12]			x			
Coffman and Bernstein [25]		x				
Simas and Pacca [90]	x					x[a]
Markaki et al. [66]	x					
Wang et al. [99]	x[b]					x[b]
Böhringer et al. [14]		x				
Llera et al. [64]						x[c]
Oliveira et al. [78]	x					
Brown et al. [18]				x		
Lehr et al. [61]			x			
Collins et al. [27]	x					
Lambert and Silva [58]	x				x	
Slattery et al. [91]	x					
Tourkolias and Mirasgedis [97]	x					
Mukhopadhyay and Thomassin [74]	x					
Cai et al. [20]	x[b]					x[b]
Sastresa et al. [86]						x[c]
Wei et al. [100]						x[d]
Solar Foundation [93]					x	
Caldés et al. [21]	x					
Blanco and Rodrigues [11]					x	
EWEA [39]					x	
DG ET [30]	x					
Lehr et al. [60]	x				x	

Table 12 (continued)

Reference	Methodologies					
	Macro-economic modeling methodologies				Analytical methodologies	
	I-O model	CGE model	M-E model	Econometric regression	Surveys	Other recorded data
Pollin et al. [83]	x					
Neuwahl et al. [77]	x					
Moisan and Chêne [72]						x[e]
AEE [1]	x[f]				x[f]	x[g]
Thornleya et al. [95]						x[h]
DWEA [32]					x	
Moreno and Lopez [73]			x			x[i]
European Parliament [35]						x[j]
Madlener and Koller [65]	x					
Hillebrand et al. [50]			x			
FMENCNS-BMU [45]	x				x	
Pfaffenberger et al. [82]						x[j]
Pedden [81]						x[j]

[a] Bibliographical review, expert opinions, data collection from reviews, and interviews conducted for wind power plant managers, O&M technicians, representatives of six wind turbine component manufacturers, project managers, and environmental agencies

[b] An I-O model is used to calculate indirect jobs and analytical methodology to determine direct jobs

[c] The method employed relies on the collection and critical analysis of the results obtained based on primary information sources. The model design includes contributions taken from a prior analysis of the existing assessment methods

[d] The methodology is based on an analytical job creation model applied for the US power sector and covering the period going from 2009 to 2030. The model compiles data from 15 job studies dealing with renewable energy, energy efficiency, carbon capture and storage, and nuclear power

[e] Net production and employment ratios (imports were ignored)

[f] Indirect employment was calculated on the basis of questionnaires and the subsequent modification of the I-O table

[g] Analysis of annual reports and information from the government tax office

[h] First, authors developed a staffing pattern for each plant based on a technical appraisal of its operational requirements. Then, they quantified jobs related to the development and construction of the plant (which are available only for a fixed period) based on experience and consultation

[i] Regional information was provided by the Regional Energy Foundation and the Spanish Renewable Energy Development Plan 2000–2010

[j] Non-econometric meta-analysis

Appendix 4. Brief technical presentation of the Leontief model [63]

We differentiate between the open and the closed Leontief models [63]:

The open Leontief model [63]

The starting point of the closed Leontief model [63] is the supply-demand equilibrium relationship described as follows:

$$X = Zi + Y, \tag{20}$$

where X is the n-vector[27] of production, Z the $(n \times n)$ matrix of intermediate consumption, i the n-vector composed only of the number 1, and Y the n-vector of final demand which integrates final consumption,[28] the gross capital formation, inventory change, and exports.

The model defines an $(n \times n)$ matrix of technical coefficients A indicating the monetary amount of inputs required to produce one monetary unit. It is calculated as follows:

$$A = ZX^{-1}. \tag{21}$$

Leontief's model [63] assumes that the technical coefficients are stable. Therefore, inputs are assumed to be complementary and the model does not allow for the integration of innovation effects in the production processes. Moreover, the stability of technical coefficients implies that scale effects are constant.

Incorporating Eq. (21) into Eq. (20) gives:

$$X = AX + Y. \tag{22}$$

After re-arrangement and factorization, we obtain

$$X = (I - A)^{-1} Y = BY, \tag{23}$$

where $B = (I - A)^{-1}$ is the $(n \times n)$ inverse Leontief matrix and I the identity matrix.

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[27] n represents the number of products within an economy.

[28] The demand for final consumption comes from households, public administrations, and non-profit institutions serving households.

The inverse Leontief matrix is the core element of the Leontief model [63]. It links the production vector X to the final demand vector Y by indicating the total (direct and indirect) production required to satisfy one monetary unit of the final demand. The different elements of the inverse matrix of Leontief b_{ij} indicate the required value of production of different industries i to satisfy one monetary unit of demand for the product j. By summing the rows i for a column j in matrix B, we obtain the production multipliers for product j:

$$O_j^X = \sum_{i=1}^{n} b_{ij} \tag{24}$$

The production multipliers O^X are used to estimate the indirect impacts.

Equation (23) can be extended to incorporate added value and employment. Leontief's model [63] assumes that the added value per unit of production is stable as indicated in the following equation:

$$V = \hat{\upsilon}X, \tag{25}$$

where V is n-vector of the added value for industry j and v the n-vector of the added value per unit of production for each industry j. The caret indicates that the matrix is diagonal.

By integrating Eq. (25) into Eq. (23), we obtain

$$V = \hat{\upsilon}(I-A)^{-1}Y = \hat{\upsilon}BY. \tag{26}$$

The elements of matrix $\hat{\upsilon}B$ ($\upsilon_i b_{ij}$) indicate the total (direct and indirect) value added of industry j stemming from the demand of product i. By summing rows i in column j in matrix $\hat{\upsilon}B$, we find the added value multipliers for product j:

$$O_j^V = \sum_{i=1}^{n} \upsilon_i b_{ij} \tag{27}$$

The same reasoning is adopted for employment. Leontief's model [63] assumes that the employment per unit of production is stable as indicated in the following equation:

$$L = \hat{l}X, \tag{28}$$

where L is n-vector of employment in industry j and l the n-vector of the employment per monetary unit of production for each industry j. By integrating Eq. (28) into (23), we obtain:

$$L = \hat{l}(I-A)^{-1}Y = \hat{l}BY. \tag{29}$$

Elements of the matrix $\hat{l}B$, noted ($l_i b_{ij}$), indicate the total (direct and indirect) employment in industry j stemming from the demand of product i. By summing in the matrix $\hat{l}B$ the different rows i for the column j, we obtain the employment multipliers for product j:

$$O_j^L = \sum_{i=1}^{n} l_i b_{ij}. \tag{30}$$

The closed Leontief model [63]

The closed Leontief model [63] is an extension of the open model. It assumes that the household sector is endogenous.[29] Subsequently, to integrate the household sector, the vectors and matrix in Eq. (20) should be extended. The ($n \times n$) matrix $\overline{Z}$ becomes the $(n+1)\,(n+1)$ matrix Z. It henceforth integrates an additional row corresponding to the household labor payment input Z_R and an additional column corresponding to the final consumption of households Z_C:

$$\overline{Z} = \begin{pmatrix} Z & Z_C \\ Z_R & 0 \end{pmatrix}.$$

Moreover, the n-vector X becomes the $(n+1)$-vector $\overline{X}$ by integrating an additional row X_{n+1} corresponding to household production that is equal to the total input from labor payment:

$$\overline{X} = \begin{pmatrix} X \\ X_{n+1.} \end{pmatrix}.$$

The new n-vector of final demand $\overline{Y}$ excludes the vector of household final consumption from the vector of final demand in the open model, because it is integrated in matrix $\overline{Z}$.

The supply-demand equilibrium is therefore written as follows:

$$\overline{X} = \overline{Z}_i + \overline{Y}. \tag{31}$$

The $(n+1)\,(n+1)$ matrix of technical coefficients is calculated as in the open model:

$$\overline{A} = \overline{ZX}^{-1}. \tag{32}$$

By integrating Eq. (32) into Eq. (31), and after rearrangement and factorization, we obtain:

$$\overline{X} = \left(I-\overline{A}\right)^{-1}\overline{Y} = \overline{BY}, \tag{33}$$

where $B = \left(I-\overline{A}\right)^{-1}$ is the ($n \times n$) inverse Leontief matrix. Its elements $\overline{b}_{ij}$ indicate the value of production

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[29] This assumption means that a household earns income in payment for its labor input. It spends this income for the consumption of goods and services.

(direct, indirect and induced) of industry j required to satisfy one monetary unit of demand for product i. By summing rows i in column j in the matrix $\overline{B}$, we find the production multipliers for product j:

$$O_j^{\overline{X}} = \sum_{i=1}^{n} \overline{b}_{ij}. \tag{34}$$

By adopting the same reasoning as in the open model, it is possible to calculate the added value and employment multipliers:

$$O_j^V = \sum_{i=1}^{n} \upsilon_i \overline{b}_{ij} \tag{35}$$

$$O_j^L = \sum_{i=1}^{n} l_i \overline{b}_{ij}. \tag{36}$$

Appendix 5. Literature reviews on estimations of employment impacts of offshore wind farms

Table 13 Overview of estimations of employment impact of the Saint-Brieuc offshore wind farm

References	Topic	Methodology	Expected employment impact
Ailes Marines SAS [6][a]	Assessing employment impact of the Saint-Brieuc offshore wind farm	n.a.[b]	- 2000 direct FTE jobs are expected in western France (1860 specific to manufacturing and installation and 140 to O&M) among which 1000 are expected in Brittany
CCICA [23][c]	Assessing the employment impact of the Saint-Brieuc offshore wind farm	n.a.	- Oxford Economics [80]: 95 to 125 FTE jobs are expected during the O&M phase - EWEA [39]: 5500 FTE jobs are expected among which 150 are specific to O&M - European Commission (2001): 2010 to 2250 FTE jobs are expected, among which 30 are specific to O&M - Bretagne Pôle Naval (BPN): 2500 FTE jobs are expected, among which between 60 to 80 are specific to O&M
Nass and Wind [76][d]	Assessing the employment impact of the Saint-Brieuc offshore wind farm	n.a.	- 2000 direct FTE jobs are expected during manufacturing and installation and 60 during O&M.

[a] Estimations quoted in this reference have been also cited in the local press (see Ouest France [79])

[b] Not available

[c] CCICA [23] presents a compilation of estimations of employment impacts of the Saint-Brieuc offshore wind project based on Oxford Economics [80], EWEA [39], European Commission (2001), and Bretagne Pôle Naval (BPN). We note that bibliographic details of the European Commission (2001) and Bretagne Pôle Naval are not available in CCICA [23]. Therefore, the methodologies used to estimate the number of jobs are unknown. The methodologies used in Oxford Economics [80] and EWEA [39] are presented in Table 14

[d] Quoted in CCICA [23]

Table 14 Overview of studies assessing the economic impacts of overseas offshore wind farms

References	Topic	Country	Methodology	Results
Sercy et al. [89]	Assessing economic and fiscal impacts of a 40-MW offshore wind farm off the coast of South Carolina from 2016 to 2036	USA	Policy Insight PI+ economic modeling engine (Regional Economic Models, Inc. (REMI)). It is an input-output and computable general equilibrium-based model as well as a new economic geography model. Economic impacts are estimated using employment, total compensation, output, net state or local government revenue, and direct, indirect, and induced impacts[a]	- In 2016, during the construction and the manufacture of components, creation of 959 direct, indirect and induced jobs, \$46.3 M in wages, and \$148.4 M in output is expected - During the O&M phase (2017–2037), annual creation of 10 direct, indirect, and induced jobs, \$934,000 in wages, and \$2.8 M in output is expected
US DE [98]	Assessing economic impacts of offshore wind developments in Georgia, South Carolina, North Carolina, and Virginia	USA	Jobs and Economic Development Impact (JEDI) model based on an input-output methodology[b].	- In 2020, during which 25% of the supply chain investment will be carried out locally, 252 MW are expected to induce

Table 14 (continued)

References	Topic	Country	Methodology	Results
			Economic impacts are estimated using employment, earning, and output as metrics. The model estimates gross impacts which are distributed across three categories namely project development and on-site labor impacts, local revenue and supply chain impacts, and induced impacts	4220 FTE jobs during the construction phase and 410 annual FTE jobs during the O&M phase - In 2030, when 62% of the supply chain investment will be carried out locally, 4027 MW is expected to induce 20,100 FTE jobs during the construction phase and 6700 annual FTE jobs during O&M phase[c]
Zammit and Miles [103].	Assessing economic impacts of offshore wind development in Georgia, South Carolina, North Carolina, and Virginia	USA	Jobs and economic development impact (JEDI) model based on input-output methodology[b]. The model was built around three variables: market and deployment, regional investment, and cost. For each variable, three development paths were considered. Three scenarios running from 2020 to 2030 were generated: the first assumes a small offshore industry with limited regional investment, the second supposes moderate growth of the offshore wind industry, and the third considers fast development of the industry	- During the construction phase, 19 to 39 FTE jobs per MW would be created depending on the rate of the regional development of the supply chain[d] - During the O&M phase, 1.64 to 1.67 FTE jobs per MW would be created - As the industry grows, projected earnings and outputs are higher
Colbert-Busch et al. [26]	Assessing economic impacts of 1000 MW of offshore wind industry in South Carolina. Assessing fiscal impacts of existing wind energy supply chain in South Carolina	USA	The regional dynamics (REDYN) economic modeling engine based on a social accounting matrix (SAM) and input-output functions derived from sector relationships revealed in the SAM. Those relationships provide a framework for defining equilibrium processes in the model's computable general equilibrium functions[e]	- Between 2016 and 2025, the manufacture of wind turbine components will annually generate 293 direct, indirect, and induced jobs, \$18.3 M in wages, \$54.9 M in output, and \$5.7 M in combined state and local government revenue. Installation would annually generate an annual average of 3329 direct, indirect, and induced jobs, \$163.1 M in wages, \$270.7 M in output, and \$51.2 M in combined state and local government revenue - Between 2026 and 2030, the O&M are expected to generate annually 678 direct, indirect, and induced jobs, \$41.8 M in wages, \$115.2 M in output, and \$13.4 M in combined state and local government revenue
Oxford Economics [80]	Assessing employment impacts of the O&M phase of offshore wind projects in the UK in 2010 and 2020	UK	Input-output methodology	- In 2010, a total installed capacity of 1-GW engenders about 450 jobs among which 290 are direct and 160 indirect and induced - An expected installed capacity equal to 20.5 GW by 2020 would induce about 7230 jobs among which 4000 are direct, 1660 indirect, and 1570 induced
EWEA [39]	Assessing employment impacts wind energy in the EU[f]	EU	Data collection based on surveys. Modeling exercise using scenario projection	- During development, manufacturing, and installation: 15.1 direct and indirect jobs per new MW are expected - During O&M, 0.33 direct and indirect jobs per (cumulative) MW are expected
Boettcher et al. [13]	Assessing the employment impacts of wind 51, wave and tidal industries in the UK by 2020[f]	UK	Employment model based on five input variables namely capacity, labor intensity, cost reduction, local content, and export market share. The model calculates employment split into technologies, regions, and export and domestic markets along the value chain. The evolution of employment is captured by a scenario engine	- An installed onshore and offshore wind capacity of 27 GW would generate 30,000 jobs[g] - An installed offshore capacity of 20 GW would induce 6734 jobs during the O&M[h]
Carbon Trust [22]	Assessing how much offshore wind power capacity could reasonably be required to help the UK reach the 2020 renewable energy target and what would be required to deliver needed wind capacity cost-effectively	UK	n.a.	- The UK will need to install 29 GW of offshore wind to reach the 2020 renewable energy target. Between 40,000 and 70,000 jobs and £6 M and £8 M in annual revenues are consequently expected[i]. Jobs will be distributed as follows: - 3000 to 4000 in R&D, engineering, and design

Table 14 (continued)

References	Topic	Country	Methodology	Results
GWEC [49][k]	Global wind energy outlook for 2008[f]	Global	n.a.	- 7000 to 15,000 in turbine and component manufacturing - 22,000 in services - 8000 to 29,000 in installation[j] and O&M - During development, manufacturing, and installation: 11 to 15.1 direct and indirect jobs per additional MW are expected - During O&M: 0.33 direct and indirect jobs per (cumulative) MW are expected[l]
Flynn and Carey [44]	Assessing economic and fiscal impacts for South Carolina from 480 MW of installed capacity of offshore wind	USA	An economic impact model with scenarios projection depending on the level of regional involvement of South Carolina in the manufacture and assembly of turbine generators	- 1881 direct, indirect, and induced FTE jobs are expected - An increase of annual output by $287 M and of annual disposable income by up to $93 M are expected - An increase in income tax revenues of up to $2.8 M and in corporate income tax revenues of up to $190,000 over the 2-year period of manufacturing and installation are expected

[a] More details on the model are available on www.remi.com

[b] More details on the JEDI model are available on www.nrel.gov/analysis/jedi/ and in Lantz et al. [59]

[c] These results are relative to a scenario which considers a moderate deployment of offshore wind

[d] Regional development of the supply chain supports more jobs per MW

[e] More details on the REDYN model are available on http://www.redyn.com/

[f] This reference deals with both onshore and offshore wind energy

[g] More details about the distribution of this number are not available

[h] Quoted in BWEA [19] and Oxford Economics [80]

[i] Depending on the level of government involvement to support offshore wind industry

[j] Includes indirect jobs related to the installation and construction of turbines, foundations, substations, and grid connections

[k] Quoted in [39]

[l] Cited numbers represent assumptions used in GWEC [49] for scenario construction for Germany, Denmark, Spain, and the Netherlands

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