Renewable Energy 221 (2024) 119853

Contents lists available at ScienceDirect

Renewable Energy

journal homepage: www.elsevier.com/locate/renene

A systematic methodology to assess local economic impacts of ocean renewable energy projects: Application to a tidal energy farm

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ARTICLE INFO

Keywords:
Input-output analysis
Ocean renewable energy
Tidal energy
Economic assessment
Local impacts
Supply-chain analysis

ABSTRACT

Ocean renewable energy (ORE) is one of the most important clean sources of energy and a major player towards the EU ambitions of being net zero emission by 2050. However, at present, there are few examples of commercially viable ORE technologies and no large-scale projects currently under implementation. Together with social and environmental analyses, the assessment of economic impacts is one of the key elements to help policy makers build a compelling case to gain local community acceptance and implement ORE projects. This paper presents a systematic methodology to assess local economic impacts of renewable energy projects, including jobs creation and impacts on gross value added and income. By combining the use of Location Quotients – which are indexes informing on local industrial specialisation – with the Input-Output multipliers the method can be used to map the supply-chain potential of a local economy and estimate local impacts compared to global ones. The method has been applied to a tidal project carried out in Orkney, Scotland. The research demonstrates the merit of early economic assessments for understanding the economic benefit of ORE projects, particularly for the local communities in which they are located, and it provides a methodological framework to be tested in other case studies.

1. Introduction

Ocean energy has attracted growing interest in recent years as it is one of the most promising drivers towards the EU ambitions to achieve net zero emission by 2050 [1,2]. The EU offshore renewable energy strategy has set the ambitious targets of reaching 1 GW and 40 GW of installed ocean energy capacity by 2030 and 2050, respectively [2], and a number of European projects are already planned that could reach 600 MW of streaming tidal energy in the coming years [3]. Prior to the construction of any large-scale farms, alternative designs must be compared, and preferred design solutions identified [4]. In this line, and besides the pure techno-economic assessment, which is often the prime requisite from the perspective of the project funder or private investor [5,6], the issues of environmental quality, social equity and economic welfare should be duly considered for any development of renewable energy projects [7–9].

Unlike environmental and techno-economic assessments, which have been the subject of growing interest from the scientific community and, therefore, benefit from mostly established methods and indicators (e.g., the Levelized Cost of Electricity for the techno-economic assessment and the CO2 emissions or other LCA related indicators for the environmental assessment), the evaluation of economics impacts has received comparatively less attention [10]. As a result, economic assessment studies still suffer from several shortcomings that may hinder a meaningful interpretation of results, including a lack of clarity in the definition of variables and benchmarks [11], the exact definition of economic impacts metrics [4], and, most importantly, whether assessed impacts are local only or have an export contingent [4,12].

In terms of variables, economic impacts can be assessed using different indicators. Job creation, in general, is the most used [7]. In this context, as indicated in Refs. [4,7], comparability of this indicator is often limited as studies do not always consider part- and/or full-time jobs or even do not provide any information about whether part- or full-time jobs are assessed. Hence, the authors recommend that to enable comparability between different studies and projects, the number of jobs should always be assessed in full-time equivalents (FTE) or person-years. As an example [12], estimated that between 23 and 33 Full Time Equivalent (FTE) jobs would be created in the Welsh economy for every installed MW of marine energy. Higher figures were instead provided in a study on cost reduction pathway of tidal stream energy in the UK and

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https://doi.org/10.1016/j.renene.2023.119853
Received 15 March 2023; Received in revised form 7 September 2023; Accepted 16 December 2023

France, i.e., 36 and 46 FTE/MW, respectively [13]. On the other hand [14,15], specified job creation in terms of jobs/years [15]. estimated 45.5 job years/MW for a tidal park deployed in Scotland, while [14] estimated 60 and 133 job years/MW for tidal parks deployed in Scotland and Portugal, respectively. Another economic indicator often evaluated for renewable energy projects is gross value added (GVA), which can be calculated as the difference between all inputs at purchase prices and gross production. To foster comparability, the normalised GVA can be expressed in €/MW. For example [14], estimated GVA for a Scottish and Portuguese tidal park to be € 4.14 million/MW and € 5.83 million/MW, respectively.

Economic impacts can also be classified as direct, indirect, or induced effects and referred to the specific phases of the life cycle of ORE projects. According to the input-output (IO) method [16], direct impacts refer to purchases of one industry from other industries to satisfy the demand for e.g., new ORE plants. Indirect effects are the business-to-business purchases in the supply chain taking place in the region that stem from the initial industry input purchases, while the induced effects refer to the increase in household spending due to the additional income of employees in the sectors involved within the ORE project. However, as indicated by Ref. [7], the definition and differentiation between direct and indirect effects not always is clear among practitioners. On top of this, the authors also highlighted that most studies do not specify which phases of the life cycle of ORE projects are assessed in the analysis of economic impacts, nor do they specify which specific industries can benefit from the economic impacts.

An additional issue facing studies examining economic effects is the extent to which they can identify economic impacts that benefit the region in which the ORE project is implemented, including the creation of jobs and the improvement of regional economic activities related to the ORE supply chain [12,17,18]. Focusing on the effects of ORE developments at a local level is key for various reasons [7]. First, decision-making on the deployment of ORE sometimes takes place at a local or regional level instead of the national level because regions may have decision-making power to hinder or promote the project development. Therefore, evaluating local economic benefits will help decision-makers to better understand the impacts of ORE development in their regions. Second, besides the direct ORE industry-related benefits, information on the economic potentials may support other regional businesses to identify market opportunities or encourage businesses from outside to settle in a region. Third, assessing the regional economic impacts of ORE projects may be of particular importance in front-runner regions where ORE developments are observed critically. In fact, illustrating the regional benefits such as local job opportunities can aid to create a compelling case for gaining local community acceptance and support [8,19], which, in turn, it would make it easier for decision-makers and especially for elected ones to communicate positive aspects and decide in favour of ORE developments.

The aim of this paper is to presents a systematic methodology to map the supply-chain potential of a local economy and assess the local economic impacts such as employment or GVA linked to an ORE project. The methodology combines in a novel way the use of Location Quotients (LQs) – which are indexes informing on local industrial specialisation [20]– with the Input-Output (IO) multipliers generally used to estimate economic impacts [4,7,14]. The contribution of this paper is threefold: first, it provides a structured methodological framework aligned with life cycle thinking to analyse the supply chain and estimate the economic impacts of ORE projects. Second, the methodology allows to better understand the capacity of a local economy to support the supply chain of an ORE project and provides information on the expected economic impacts to benefit the local area. Third, the paper presents the analysis of a real case study focusing on a 34.5 MW tidal energy array based on the Atir full-scale prototype [21], the Magallanes' tidal device that has been operating since March 2019 at the Fall of Warness tidal test site in Orkney (UK).

The reminder of the paper is organised as follows: Section 2 illustrates the proposed methodology for the supply chain and economic impacts evaluation of ORE projects. Section 3 presents the case study of a 34.5 MW tidal energy array based on the Atir full-scale prototype. Section 4 depicts the numerical results obtained for the case study, and finally, Section 5 summarises our conclusions, including policy recommendations and limitations of the study.

2. Proposed methodology

2.1. Theoretical framework and scope of analysis

Fig. 1 introduces the elements and workflow of the economic assessment framework proposed in this study.

First, the sources of economic impacts are differentiated according to the phases of the life cycle of an ORE project, namely: manufacturing, installation, operation and maintenance, deinstallation and disposal [22]. Hence, other indirect opportunities for the local economy related to the know-how generated in ocean energy sector and the possibility to export this expertise to wider energy markets, have been considered outside the scope of this assessment framework.

Second, the type of economic impacts includes both *direct* and *indirect* impacts. Direct Impacts capture the economic activities that are conducted along the life cycle of the ORE project. These cover, for example, the staff directly employed in development and operation and all first-tier supply chain expenses related to device manufacturing and installation. Indirect impacts **r**efer to the additional output generated by companies in the supply chain supporting the first-tier suppliers. The additional economic activity in these companies is passed down through their supply chains and generates additional, indirect benefits for many other companies. Besides direct and indirect impacts, IO multipliers also allow for the possibility to estimate induced impacts, who may capture the knock-on benefits that the new employment and salaries can have in the economy, e.g., the salaries earned by those employed in additional jobs spent on goods and service elsewhere in the economy. However, since this type of impacts are much less reliable (and also more challenging to calculate), most IO tables do not provide multipliers for induced effects. Therefore, these are excluded from this framework.

Third, we define quantitative indicators to inform on selected economic impacts. These are.

- Gross economic output: it refers to the overall impact in monetary terms upon an industry or the overall economy linked to the deployment of the ORE project. This can be differentiated between direct output (the expenditures required to build and deploy the ORE project) and indirect output (the further spending affecting industry's suppliers).
- Employment**:** it refers to the number of jobs that are created by the deployment of the ORE project. This is expressed as Full Time Equivalents (FTE), a measure that converts full- and part-time (PT) jobs into a common currency (where one PT job is equivalent to half a FT job).
- Gross value added (GVA): GVA is the commonly accepted measure of wealth creation for an economy. It is what is left of gross output after the purchased goods and services have been paid for. This residual output is then available for distribution as profits, wages and salaries and capital investment costs.
- Income: it refers to the compensation of employees and it indicates the change in compensation due to the deployment of the ORE project.

The last aspect of interest is the scenario definition. This generally relies on the available technical and economic specifications of the ORE project, such as geographical location, installed capacity, CAPEX and OPEX and useful life of the ORE farm. Knowing the geographical location is key to 1) address and analyse the local supply chain (step 2) and 2) identify and apply respective IO multipliers (step 3). Likewise,

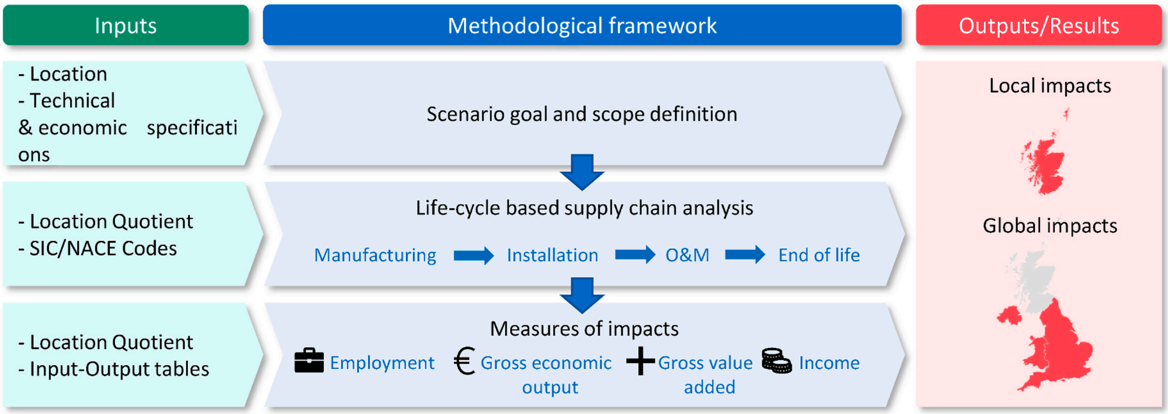

Fig. 1. Economic assessment framework.

installed capacity and useful life are key inputs to normalize the results and allow for comparison with other ORE studies. Finally, the use and granularity of technical-economic information is generally linked to the degree of confidentiality of this type of reports [5]. In general, within a project, it should be possible to share this information between partners as confidentiality agreements are in place. In other cases, the only possibility will be to rely on more aggregated published values or approximations based on technical experience.

2.2. *Supply-chain analysis*

After defining the scope of the analysis, the second step consists in mapping and analysing the ORE project supply-chain. In this context, knowledge of the various activities that take place during the life cycle of the ORE project, from the production, installation, operation and maintenance of the tidal device, and finally the decommissioning phase, is crucial. In general, regardless of the specifics of any ORE project, the type of activities performed will reflect the type of technology used, such as tidal or wave devices. Hence detailed description of economic activities involved can be easily retrieved from existing studies and/or reports. As an example, for the tidal energy, Segura et al. [23] provide a life cycle cost methodology in which a detailed description of activities is provided for each life cycle stage. Other examples can be found in e.g., Refs. [24–27]. Similarly [28,29], provide a description of economic activities for wave energy arrays deployment.

Once identified all the economic activities occurring along the life cycle of the ORE projects, these need to be linked to available regional statistics. In essence, this step aims to link each activity of the ORE project to a specific type of standard economic activity. In the case of UK, the classification of reference will be the Standard Industrial Classifications (SIC[1]), while for the rest of Europe the Statistical Classification of Economic Activities (NACE[2]) can be used. These are the industry standard classification systems used in the UK and the EU, respectively, and provide data at the regional level and by type of industry on employment and GVA, among other economic indicators. The use of standardised classification is required for two reasons: first it permits a consistent comparison between different geographies and, hence, the calculation of the LQs. Second, it allows for connecting IO tables, which are generally based on this type of structured data (SIC/NACE), and, hence, the use of IO multipliers for impacts assessment (section 2.3).

Based on the regional employment or GVA statistics, the LQs can be estimated for each economic activity of interest. LQs are computed as a ratio that compares a region to a larger reference region according to some characteristic or asset (e.g., employment shares or GVA shares based on industrial activities). Hence, if for example, x is the GVA generated by sector k in a region l, y is the GVA generated by the whole economy in a region l, and X and Y are similar data points representative of a larger geography average (e.g., country level or Europe), then the LQ or relative concentration of asset k in the region l compared to the larger geography is:

$$LQ_{l,k} = \frac{x_{l,k}/y_l}{X_{EU,k}/Y_{EU}}$$

Differently from employment or GVA shares, the LQs reveals which industries make the regional economy unique, or in other words, what is the sectoral specialisation of a region in comparison to a national or international benchmark. A LQ of 1.0 in any industrial activity means that the region and the nation are equally specialised in that activity, while a LQ higher than 1.0 means that the region has a higher concentration than the nation. Industries with a high LQ (>1.2) are important because imply that a region is very specialised in an industry, and, hence, is more likely to bring money into the region. The estimation of the LQs makes it easy to understand which of the activities related to the ORE will most likely be absorbed by the local supply chain, and therefore will contribute to the local economy development. The information provided by the LQs can also be complemented by employment data. In fact, when considering an industry's LQ, it is also important to consider the underlying number of jobs as the final economic impacts will also be proportional to the magnitude of the sectoral or economic activity. In this line, a high LQ coupled with a high number of jobs will produce the biggest economic impacts in an economy. By contrary, an economic activity with a high LQ will have a limited effect on the economy – in absolute terms - if the number of jobs is low.

2.3. *Impact assessment approach*

The final step of the methodology concerns the assessment of economic impacts through the use of first the multipliers obtained from Input-Output (IO) tables and second the LQs previously estimated. IO modelling is a quantitative method of macro-economic analysis that permits to consider interdependencies between different branches of the economy. This modelling approach enables the economic benefit of a region to be assessed, based on the knowledge of direct sectoral spending and indirect spending due to the interrelationships between economic sectors. By using the relationship between changes in demand and the resulting economic activity, IO tables can provide estimates on how new expenditures will impact economic development aspects such

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[1] SIC classification can be found at https://www.ons.gov.uk/methodology/classificationsandstandards/ukstandardindustrialclassificationofeconomicactivities/uksic2007.

[2] NACE classification can be found at https://ec.europa.eu/eurostat/ramon/nomenclatures/index.cfm?TargetUrl=LST_NOM_DTL&StrNom=NACE_REV2&StrLanguageCode=EN.

as employment, GVA or income [4,7].

As anticipated before, and in line with the procedure proposed by Draycott et al. [14], all ORE project expenditures should be allocated to the most appropriate industrial standard classes (i.e., SIC or NACE). This allocation should be done by identifying the industry most influenced by the cost entry. In some cases, this means attributing costs between multiple industries by the expected relative influence. Summing total expenditure in each class provides indication as to the key sectors being shocked, and hence which ones should be kept as separate classes, and which can be aggregated to simplify the analysis and presentation of results.

At this point, unlike the empirical practice, which directly applies the IO multipliers to the respective expenditure of an industry category to estimate economic impacts, we differentiate between local impacts and those having an export contingent. Distinguishing local from *global* impacts allows, on the one hand, to understand the degree to which large projects such as ORE farms benefits the local area or, conversely, has a limited impact on local development [7]. On the other hand, it also allows for relaxation of the IO modelling assumption of “no supply constraints”. This condition assumes that there is always significant excess capacity in the economy such that the supply side passively adjusts to demand. However, within a regional application assuming passive supply-side is particularly limiting since labour and capital can typically be considered scarce resources in the short term.

In order to differentiate between local and global impacts, we took advantage of the LQs, which, as said above, are indicators measuring the sectoral specialisation of a local area (e.g., a region) compared to a larger geography (e.g., a country). If a region is highly specialised in a sector, then it is likely to be able to satisfy an additional demand for services in that sector. If, on the other hand, a region does not specialize in one sector, then it is more likely that these services will be outsourced, i.e., supplied from other regions. As a rule of thumb, based on the review of previous studies, see e.g. Ref. [12], which provides procurement assumptions based on the level of regional specialisation for Wales, and a consultation with device/project developers,[3] the following allocation criteria are suggested to impute direct expenditures of industrial categories between a local and global economy.

- $LQ_{l,k} > 1.20$: the local economy, *l*, benefits 75 % of the direct expenditure in sector *k*.
- $0.80 < LQ_{l,k} < 1.20$: the local economy, *l*, benefits 50 % of the direct expenditure in sector *k*.
- $LQ_{l,k} < 0.80$: the local economy, *l*, benefits 25 % of the direct expenditure in sector *k*.

Whilst these criteria may serve as general guidance, the exact allocation share should always be validated by sectoral experts from the local supply chain or alternatively corroborated with existing documentation such as sectoral studies or industrial roadmaps.

Finally, once direct spending has been split between local and global economies according to LQs, respective multipliers can be applied to calculate economic impacts. Mathematically it can be expressed as:

$$EI_{n(l,g)k} = EXP_k * PER_{n(l,g)} * IO_{n(l,g)k}$$

Where $EI_{n(l,g)k}$ is the economy impact of an *n* economy, – i.e., a local (l) or global (g) economy, in industrial sector (k). EXP_k is the direct expenditure in industrial sector k. $PER_{n(l,g)}$ is the percentage share of direct expenditure to allocate to the *n* economy and $IO_{n(l,g)k}$ is the multiplier of the *n* economy in industrial sector k.

3. Case study

This section outlines the project “Next Evolution in Materials and Models for Ocean Energy” (NEMMO), an ORE project funded by the HORIZON 2020 program, within which the proposed methodology was developed and tested. NEMMO aimed to advance the state-of-the-art of tidal turbine technology by improving the yield and reliability of tidal turbines. As part of the project, a techno-economic analysis and a socio-economic analysis were carried out to analyse the expected financial viability and economic impacts of a 34.5 MW tidal energy array based on the Atir full-scale prototype [21]. The Atir device consists of a 45-m steel platform connected to a submerged part where the hydrogenators are fitted. Two 21-m-high counter-rotating three-bladed rotors are situated below the hull, which combined achieve 1.5 MW rated power (Fig. 2). Fig. 3 shows the site location of Fall of Warness, Orkney (UK), the offshore tidal test area of the European Marine Energy Centre (EMEC), where the Atir device has been operating since March 2019.

To perform the economic assessment, this paper takes as a starting point the results of the techno-economic analysis carried out in NEMMO project. A summary of cost components is provided in Table 1. Due to confidentiality reasons, the monetary amounts linked to each economic activity have been grouped into “cost” categories and expressed in percentage terms. From a life cycle point of view, the manufacturing phase is the main driver of costs as it covers 80.6 % of total capital expenditures (CAPEX). The remaining 19.4 % concerns installation (11 %), management fees (7.3 %) and decommissioning (1.1 %). Within the manufacturing phase, the most expensive element is the platform, which accounts for more than 33 % of CAPEX. It follows the rotor, which includes the blades (24.5 %), and the mooring system (11.3 %). On the other hand, the cost of preventive maintenance is the highest Operating expenditure (OPEX) component, and it represents the 57 % of total OPEX. It is followed by insurance and fixed expenses (31 %) and corrective maintenance (12 %). To note that, while CAPEX amounts are by definition “one-time” expenditures, OPEX is provided as annual expenditure. As it will be shown in the results section, this consideration is key for a correct interpretation of economic impacts. Further details on technical specificities of the Atir device, as well as the description of techno-economic assessment approach can be found in deliverables D6.3 at the NEMMO website https://nemmo.eu/.

4. Results

4.1. Supply-chain

Fig. 4 shows the results of the supply chain analysis applied to the NEMMO case study. In this case, as the tidal test site is located in Orkney, Scotland region was considered as “the local economy”, while Britain as the “global economy”. The economic activities were grouped by the nature of the components of the tidal park (i.e., vessel, power take off (PTO), rotor, mooring system etc) and organised by life cycle stage.[4] It should be noted that the economic activities carried out in the installation and decommissioning phase are the same, so these are provided only once in Fig. 4. Economic activities whose bars are below 1 are those most likely to be outsourced in the global economy, while the reverse is true for those economic activities with bars greater than 1.

According to Scottish sectoral specialisations, different patterns can be observed across the several economic activities. First, Scotland seems very well positioned to lead the industrial activities linked to the manufacturing of the floating platform (SIC 30110: *Building of ships and floating structures*). Indeed, the LQ for this activity indicates that Scotland

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[3] This research took advantage from the technical and sectoral knowledge of the participants of the EU project “Next Evolution in Materials and Models for Ocean Energy” (NEMMO).

[4] The exact definition of the economic activities as defined in the SIC classification is shown in italics. Full description of SIC activities is provided in Annex 1 Table A1. Organisation of SIC activities by life cycle stage and nature of ORE components is provided in Annex 1 Table A2.

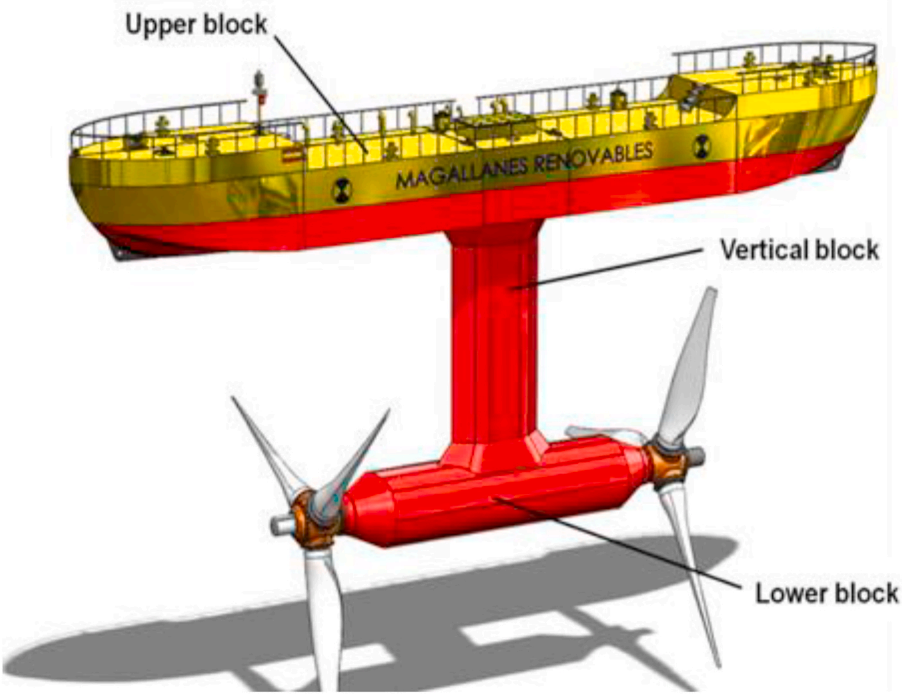

Fig. 2. Schematic view of Atir tidal device.

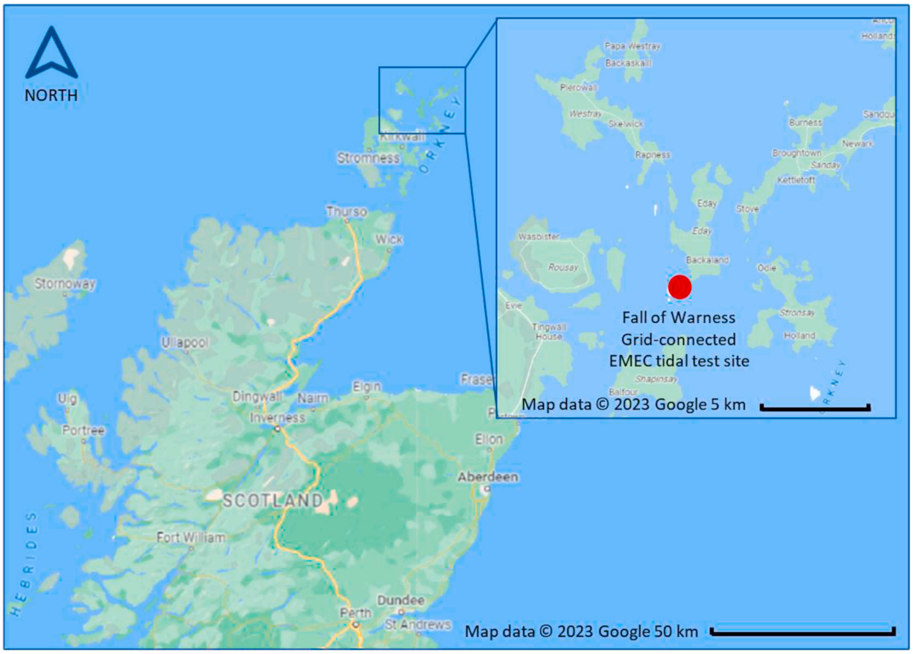

Fig. 3. Location map of the offshore tidal device test area.

is specialised in this sector three times more than the national average (LQ = 3.3). This indicates that the Scottish region would be able to cater for most of these activities, thus generating a significant local impact. In addition, this economic activity also has an important portion of local employment, thus maximizing local impacts. Similar findings can be observed for activities related to *test drilling, test boring and core sampling for construction* (SIC 43130) within the installation phase (LQ = 4), and activities related to *renting and leasing of freight water transport equipment* (SIC 77342), within the operation phase (LQ = 5.5). However, in these latter cases, the expected local impacts could be somewhat limited by the small size of the sectors within the economy, as suggested by the number of employees that are among the lowest on record.

By order of magnitude, remaining economic activities where Scotland may expect significant local impacts are *engineering related scientific and technical consulting activities (SIC 71122), renting and leasing of other machinery, equipment and tangible goods (SIC 77390)* within the operation phase*, manufacture of electronic components (SIC 26110)* and *manufacture of other electronic and electric wires and cables,* which relates to the manufacturing phase of the PTO and electric system, including cables.

On the other hand, Scotland economy is less specialised in those activities relating to metal/metal structure production, which are the backbone of the rotor and mooring system manufacturing. In this line,

Table 1

Summary of CAPEX, OPEX in percentage (%) terms.

CAPEX Component	% contribution to CAPEX	OPEX component (annual cost)	% contribution to OPEX
Platform	33.2 %	Preventive maintenance	56.9 %
Power Take-off system	9.3 %	Corrective maintenance	11.8 %
Rotor	24.5 %	Fixed exp. & Insurance	31.3 %
Auxiliary system	1.0 %		
Mooring system	11.3 %		
Electric system	1.3 %		
Installation	11.0 %		
Management fees	7.3 %		
Decommissioning	1.1 %		
CAPEX TOTAL	**100 %**	**OPEX TOTAL**	**100 %**

activities like *casting of steel* (SIC 24520), or *forging, pressing, stamping and roll-forming of metal (SIC 25500)* are underrepresented activities in Scotland and therefore most likely supplied by the British economy – or others. The same reasoning applies to certain activities within the operation phase. These are: *storage facilities for water transport activities (SIC 52101), non-life insurance (65120) or public relations and communication activities (70210).* For other economic activities, whose LQs remain closer to 1, there are no clear significant benefits to the Scottish economy. Consequently, we can expect a balanced impact between the two scales, i.e., 50 % captured by the local economy and 50 % captured by global economy.

It is also interesting to note that this approach, if conducted over the years, allows to see how an economy specialises over time and to evaluate whether industrial strategies achieved the desired effects. As an example, Scotland's clear commitment to ocean renewable energy has led the region to become an international benchmark in recent decades [30,31]. This is reflected in the increase over time of Scotland LQs related to ocean economic activities, such as the *renting and leasing of freight water transport equipment* which went from 1.2 in 2013 [26] to 5.5 in 2018.

4.2. Economic impacts

Fig. 5 shows the economic impacts expected by the development of the NEMMO tidal energy project. Similarly to the supply-chain overview, the results are aggregated by type of the tidal park components (i.e., structure (vessel), power take off (PTO), rotor, mooring system etc) and ordered by life cycle stage. Local impacts are distinguished from global impacts, based on the Scottish supply chain specialisation and the IO multipliers of the local and global economy, i.e., Scotland and Great Britain, respectively.

In terms of gross economic output, the total expected impact is 158 M€ split roughly equally between the Scottish (52 %) and UK economies (48 %). In terms of employment, the project seems to favour above all Scotland, where the majority of new jobs are expected (55 %), while the impacts on income and GVA seem very balanced between the two geographical areas. The economic activities that would benefit Scotland most are certainly those linked to the construction of ships and floating structures. These would have a local impact in Scotland more than double the UK impact on gross economic output (38 vs 15 M€) and employment (188 vs 63 FTE). The better performance of Scotland in this sector is due, as seen before, to its high specialisation in this sector (LQ 3.3). The same is true for income and GVA indicators, albeit with a narrower gap between the two economies. In this case, the higher UK multipliers for income and GVA offset the specialisation effect of Scotland. Similar interpretations can be done for the group of economic activities relating to the rotor manufacturing and the installation and decommissioning phases in which Scotland is very specialised.

On the other hand, economic activities relating to rotor manufacturing would create larger impacts in the UK economy than the Scottish economy. This is because of the relative lower specialisation that Scotland has in activities related to concrete products for construction purpose and metal/metal structure production. Similar findings apply to the mooring system. Also in this case, Scotland does not seem very specialised in the underlying economic activities, consequently fewer local impacts are expected linked to this industrial category.

In terms of FTE jobs, which is one of the most important indicators for building societal support, 531 FTE jobs are expected to be created in Scotland, while 434 FTE jobs at UK-wide level. Again, the main driver of

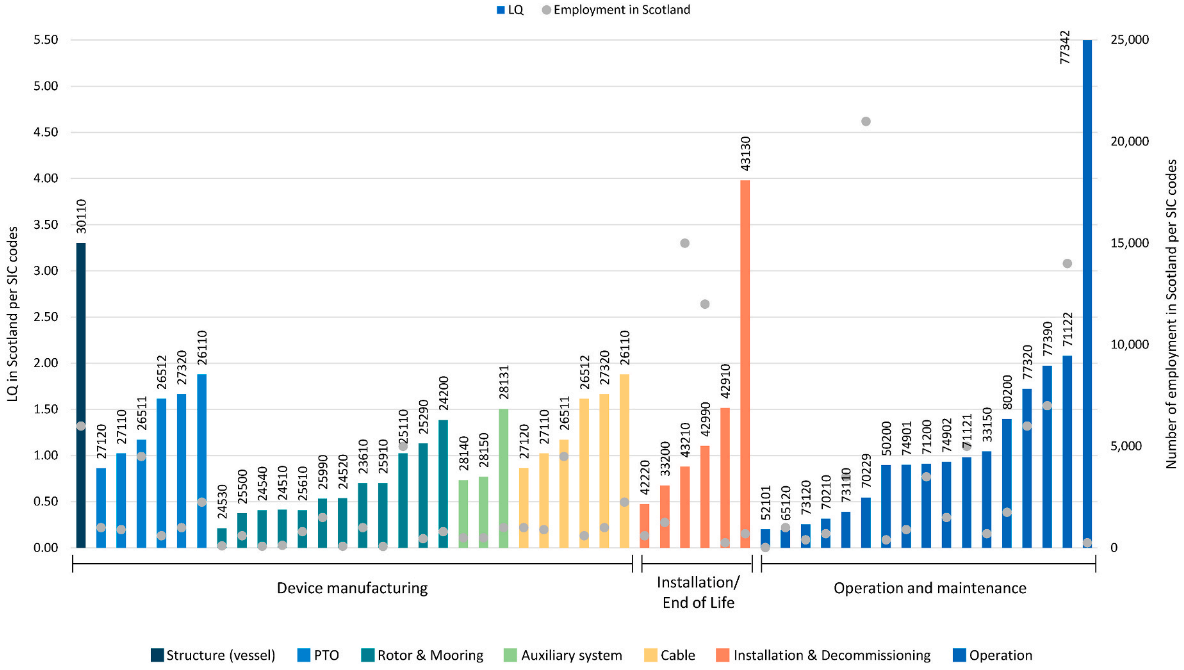

Fig. 4. Mapping the Scotland supply chain for the NEMMO case study.

Fig. 5. Economic impacts.

job creation in Scotland would be the ships and floating structures construction sector, which would generate 188 FTE jobs, followed by the activities related to the installation of tidal farm with 100 FTE jobs, and the activities related to power-take-off systems manufacturing, 69 FTE jobs. It should be noted that, despite Scotland's low specialisation in rotors manufacturing activities, the large size of this sector makes it an important factor for Scotland too, as it would create 56 FTE jobs. In addition to local jobs, the economic impact of rotor manufacturing is expected to create as much as 170 FTE jobs at UK level. This is the most important driver of economic impacts at UK level, followed by the activities linked to the manufacturing of mooring system (78 FTE jobs) and building of ships and floating structures (62 FTE jobs).

It is important to keep in mind that economic impacts are estimated based on direct expenditure in one or the other industrial category. Some capital expenditures such as those concerning the manufacturing of tidal farm elements are one-time expense distributed along few years. As an example, expenditure for installing the tidal farm might take few years to be completed. In this case, as an example, the expected FTE jobs will be relative to this time horizon. On the other hand, operational expenditures, such as maintenance, are recurring expenses that are projected on an annual basis and extend to the end of the project's useful life, which in this case study is set to 25 years. These considerations have direct implications on the interpretation of economic impacts as those related to operation and maintenance (O&M) should be considered as annual impacts.

5. Conclusions

The aim of this paper is to provide a systematic methodology for estimating economic impacts like employment, GVA or income, distinguishing those impacts that are most likely to bring benefits to the local economy, i.e., the area in which the ORE project is located. The main motivation for this new approach is the lack of research addressing the local economic effects associated with ORE projects. Understanding the local economic impacts of ORE projects is a critical prerequisite to securing government support and community approval. Furthermore, regional assessments are a fundamental complement to macro analyses as they are more sensitive to local realities and provide more appropriate guidance for future planning and roadmaps. In addition, this paper also responds to the need for a structured methodological framework to guide and encourage practitioners in assessing the economic benefits that ORE projects can provide to society [32]. In particular, it promotes the use of transparent accounting methods, highlighting the connection between the life cycle phases of ORE projects and their economic impacts, and enables comparison between case studies or regions.

The methodology combines in an innovative way the use of IO multipliers, generally used in this type of assessments, with the LQs, indices informing on the specialisation of an economy. This approach permitted first to gain a quick view on the strengths and weakness of the Scottish supply-chain. In this context, we found that Scotland mainly specialises in industrial activities related to the manufacturing of the floating platform and in preparatory activities related to the installation of the tidal power plant. Therefore, greater economic impacts for the Scottish economy can be expected from these sectors. In contrast, the Scottish economy is less specialised in those activities related to the production of metal/metallic structures, which are strongly linked with the manufacturing of rotors and mooring systems. Therefore, in this case, the economic impacts will be mainly externalised, i.e. they will not stimulate the local economy. The paper also reveals that in terms of gross economic output the tidal farm could generate 2.4 million/MW in the Scottish region and 2.2 million/MW in the rest of the UK, while in terms of employment it would provide 15.40 FTE jobs per MW for the Scottish region compared to 12.60 FTE jobs per MW for the rest of the UK. Finally, regarding the GVA and income, the study estimated 0.86 million/MW and 0.61 million/MW for Scotland and 0.98 million/MW and 0.62 million/MW for the rest of UK, respectively [26,30,31].

A number of relevant policy recommendations emerge from these findings. First, this type of ex ante research on regional potential is important for exploring the scope of economic opportunities and the constraints on realizing those opportunities. Along these lines, this ex-ante research identifies the strategic sectors of the supply chain that policy should involve enhancing the local economy. Therefore, a key issue for policy makers is to ensure that ORE developers are aware of opportunities to purchase goods and services locally and, where possible, alert local suppliers to these same opportunities. Second, it is also important to reflect on the structural changes that an ORE project can trigger and, therefore, how responsive the regional supply chain may be to the needs of developers. In this context, early knowledge of the skills and technological capabilities required by an ORE project can help local businesses identify market opportunities or encourage external businesses to establish themselves in the local area. Third, it is important to highlight the importance of monitoring actual economic impacts. Ex-post analysis appears to be a weak area in the renewable energy sector as most of the studies examined during this research focused on ex-ante analysis. Lack of effective monitoring can mask differences between predicted and actual impacts. Monitoring economic impacts in the construction and O&M phases is important to verify both forecasts and implementation of conditions. Therefore, governments and regulators should be equally demanding in terms of certificates and impact analyses, both in the procurement and operational phases [32].

To conclude, the proposed methodology also comes with some limitations that should be recognised. First, the methodology makes use of multipliers that derive from IO tables. Typically, these tables are available at national or European level, and in exceptional cases at regional level (see e.g., Scotland). Hence, it may happen that in other case studies practitioner do not have multipliers to apply to the local economy. In this case, while developing an IO table would be the recommended approach –but certainly beyond scope in most cases, we suggest using the same multipliers across the two economies as, in general, the difference is small (see multipliers for Scotland and UK in Annex 1, Table A2). Second, regarding the LQs, the analysis is based on historical data, which may not reflect current situation or future trends. In the future, there may be new inward or domestic investment to meet the needs of the sectors that are poorly represented in terms of LQs. In addition, while the LQs indicate regional specialisation in specific sectors and a presence of skills relevant to the ORE industry, it does not imply that these sectors have the capacity or willingness to grow or diversify into this type of business. Finally, it should be recalled that while this methodological framework lays the foundations for a transparent and systematic assessment of economic impacts, it still relies on "expert judgment" for the expenditure share allocation between the local and global economy. Therefore, future studies could address this shortcoming by proposing innovative data-driven approaches that remove this qualitative element.

CRediT authorship contribution statement

Marco Bianchi: Conceptualization, Methodology, Investigation, Supervision, Writing – original draft, Writing – review & editing, Funding acquisition, Project administration. **Iratxe Fernandez Fernandez:** Methodology, Investigation, Data curation, Formal analysis, Writing – review & editing.

Acknowledgments

This research is funded by the NEMMO European Horizon 2020 Framework programme with the grant reference number 815278.

The authors are grateful to two anonymous referees for their constructive comments and suggestions. Any remaining errors are solely the authors' responsibility.

Annex 1.

Table A1
Names of Standard Industrial Classification

SIC CODE	Industry name
30110	Building of ships and floating structures
26110	Manufacture of electronic components
26511	Manufacture of electronic instruments and appliances for measuring, testing, and navigation, except industrial process control equipment
26512	Manufacture of electronic industrial process control equipment
27110	Manufacture of electric motors, generators and transformers
27120	Manufacture of electricity distribution and control apparatus
27320	Manufacture of other electronic and electric wires and cables
23610	Manufacture of concrete products for construction purposes
24200	Manufacture of tubes, pipes, hollow profiles and related fittings, of steel
24510	Casting of iron
24520	Casting of steel
24530	Casting of light metals
24540	Casting of other non-ferrous metals
25110	Manufacture of metal structures and parts of structures
25290	Manufacture of other tanks, reservoirs and containers of metal
25500	Forging, pressing, stamping and roll-forming of metal; powder metallurgy
25610	Treatment and coating of metals
25910	Manufacture of steel drums and similar containers
25990	Manufacture of other fabricated metal products
28131	Manufacture of pumps
28140	Manufacture of other taps and valves
28150	Manufacture of bearings, gears, gearing and driving elements
24200	Manufacture of tubes, pipes, hollow profiles and related fittings, of steel
24510	Casting of iron
24520	Casting of steel
24530	Casting of light metals
24540	Casting of other non-ferrous metals
25110	Manufacture of metal structures and parts of structures
25290	Manufacture of other tanks, reservoirs and containers of metal
25500	Forging, pressing, stamping and roll-forming of metal; powder metallurgy
25610	Treatment and coating of metals
25910	Manufacture of steel drums and similar containers
25990	Manufacture of other fabricated metal products
33200	Installation of industrial machinery and equipment
42220	Construction of utility projects for electricity and telecommunications
42910	Construction of water projects
42990	Construction of other civil engineering projects
43130	Test drilling and boring
43210	Electrical installation
70210	Public relations and communication activities
70229	Management consultancy activities (other than financial management)
73110	Advertising agencies
73120	Media representation
71121	Engineering design activities for industrial process and production
71122	Engineering related scientific and technical consulting activities
71200	Technical testing and analysis
74901	Environmental consulting activities
74902	Quantity surveying activities
80200	Security systems service activities
33150	Repair and maintenance of ships and boats
50200	Sea and coastal freight water transport
52101	Operation of warehousing and storage facilities for water transport activities of division 50
65120	Non-life insurance
71122	Engineering related scientific and technical consulting activities
71200	Technical testing and analysis
77342	Renting and leasing of freight water transport equipment
77390	Renting and leasing of other machinery, equipment and tangible goods
77320	Renting and leasing of construction and civil engineering machinery and equipment

Table A2
Multipliers and Location Quotients (LQs) applied to the SIC

Life cycle phases	Components	SIC CODE	Multipliers[1,2]							LQ[3]
			OUTPUT		Employment (effect)	Income (effects)		GVA (effects)		
			Scotland	UK	Scotland & UK[4]	Scotland	UK	Scotland	UK	
Device manufacturing	Structure (vessel)	30110	1.50	1.82	7.40	0.30	0.59	0.40	0.87	3.30
	Power Take Off (PTO)	27120	1.30	1.68	1.20	0.50	0.48	0.60	0.70	0.86

(*continued on next page*)

Table A2 (*continued*)

Life cycle phases	Components	SIC CODE	Multipliers[1,2]							LQ[3]
			OUTPUT		Employment (effect)	Income (effects)		GVA (effects)		
			Scotland	UK	Scotland & UK[4]	Scotland	UK	Scotland	UK	
		27110	1.30	1.68	1.20	0.50	0.48	0.60	0.70	1.02
		26511	1.30	1.51	6.20	0.40	0.58	0.60	0.82	1.17
		26512	1.30	1.51	6.20	0.40	0.58	0.60	0.82	1.61
		27320	1.30	1.68	13.20	0.50	0.48	0.60	0.70	1.66
		26110	1.30	1.51	6.20	0.40	0.58	0.60	0.82	1.88
	Rotor	24530	1.30	1.50	6.80	0.30	0.33	0.20	0.57	0.21
		25500	1.30	1.47	10.80	0.50	0.46	0.60	0.70	0.37
		24540	1.30	1.50	6.80	0.30	0.33	0.20	0.57	0.40
		24510	1.30	1.50	6.80	0.30	0.33	0.20	0.57	0.41
		25610	1.30	1.47	10.80	0.50	0.46	0.60	0.70	0.41
		25990	1.30	1.47	10.80	0.50	0.46	0.60	0.70	0.53
		24520	1.30	1.50	6.80	0.30	0.33	0.20	0.57	0.54
		23610	1.50	1.72	9.10	0.30	0.43	0.60	0.70	0.70
		25910	1.30	1.47	10.80	0.50	0.46	0.60	0.70	0.70
		25110	1.30	1.47	10.80	0.50	0.46	0.60	0.70	1.02
		25290	1.30	1.47	10.80	0.50	0.46	0.60	0.70	1.13
		24200	1.40	1.80	7.40	0.30	0.42	0.40	0.62	1.38
	Auxiliary system	28140	1.30	1.64	7.60	0.40	0.44	0.60	0.72	0.73
		28150	1.30	1.64	7.60	0.40	0.44	0.60	0.72	0.77
		28131	1.30	1.64	7.60	0.40	0.44	0.60	0.72	1.50
	Mooring	24530	1.30	1.50	6.80	0.30	0.33	0.20	0.57	0.21
		25500	1.30	1.47	10.80	0.50	0.46	0.60	0.70	0.37
		24540	1.30	1.50	6.80	0.30	0.33	0.20	0.57	0.40
		24510	1.30	1.50	6.80	0.30	0.33	0.20	0.57	0.41
		25610	1.30	1.47	10.80	0.50	0.46	0.60	0.70	0.41
		25990	1.30	1.47	10.80	0.50	0.46	0.60	0.70	0.53
		24520	1.30	1.50	6.80	0.30	0.33	0.20	0.57	0.54
		23610	1.50	1.72	9.10	0.30	0.43	0.60	0.70	0.70
		25910	1.30	1.47	10.80	0.50	0.46	0.60	0.70	0.70
		25110	1.30	1.47	10.80	0.50	0.46	0.60	0.70	1.02
		25290	1.30	1.47	10.80	0.50	0.46	0.60	0.70	1.13
		24200	1.40	1.80	7.40	0.30	0.42	0.40	0.62	1.38
	Cable	27120	1.30	1.68	13.20	0.50	0.48	0.60	0.70	0.86
		27110	1.30	1.68	13.20	0.50	0.48	0.60	0.70	1.02
		26511	1.30	1.51	6.20	0.40	0.58	0.60	0.82	1.17
		26512	1.30	1.51	6.20	0.40	0.58	0.60	0.82	1.61
		27320	1.30	1.68	13.20	0.50	0.48	0.60	0.70	1.66
		26110	1.30	1.51	6.20	0.40	0.58	0.60	0.82	1.88
Installation	Installation	42220	1.50	2.07	13.00	0.40	0.42	0.70	0.84	0.47
		33200	1.30	1.63	6.90	0.40	0.49	0.70	0.75	0.67
		43210	1.50	2.07	13.00	0.40	0.42	0.70	0.84	0.88
		42990	1.50	2.07	13.00	0.40	0.42	0.70	0.84	1.10
		42910	1.50	2.07	13.00	0.40	0.42	0.70	0.84	1.52
		43130	1.50	2.07	13.00	0.40	0.42	0.70	0.84	3.98
Operation and maintenance	O&M	52101	1.40	1.87	12.20	0.50	0.60	0.70	0.86	0.20
		65120	1.30	1.80	4.80	0.20	0.30	0.50	0.77	0.20
		73120	1.20	1.58	12.20	0.30	0.45	0.80	0.85	0.26
		70210	1.20	1.63	12.00	0.60	0.58	0.80	0.85	0.31
		73110	1.20	1.58	12.20	0.30	0.45	0.80	0.85	0.39
		70229	1.20	1.63	12.00	0.60	0.58	0.80	0.85	0.54
		50200	1.30	1.49	6.90	0.40	0.37	0.60	0.65	0.89
		74901	1.30	1.87	15.30	0.50	0.57	0.80	0.86	0.90
		71200	1.30	1.84	14.00	0.50	0.61	0.80	0.85	0.91
		74902	1.30	1.87	15.30	0.50	0.57	0.80	0.86	0.93
		71121	1.30	1.84	14.00	0.50	0.61	0.80	0.85	0.98
		33150	1.30	1.49	6.90	0.40	0.54	0.70	0.91	1.04
		80200	1.10	1.61	39.60	0.70	0.54	0.90	0.93	1.40
		77320	1.20	1.51	13.20	0.40	0.46	0.80	0.91	1.72
		77390	1.20	1.51	13.20	0.40	0.46	0.80	0.91	1.97
		71122	1.30	1.84	14.00	0.50	0.61	0.80	0.85	2.08
		77342	1.20	1.51	13.20	0.40	0.46	0.80	0.91	5.50
End-of-Life	Decommissioning	42220	1.50	2.07	13.00	0.40	0.42	0.70	0.84	0.47
		33200	1.30	1.63	6.90	0.40	0.49	0.70	0.75	0.67
		43210	1.50	2.07	13.00	0.40	0.42	0.70	0.84	0.88
		42990	1.50	2.07	13.00	0.40	0.42	0.70	0.84	1.10
		42910	1.50	2.07	13.00	0.40	0.42	0.70	0.84	1.52
		43130	1.50	2.07	13.00	0.40	0.42	0.70	0.84	3.98

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