Marine Policy 116 (2020) 103905

Contents lists available at ScienceDirect

Marine Policy

journal homepage: http://www.elsevier.com/locate/marpol

The marine economy of the United Kingdom

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ARTICLE INFO

Keywords:
Input-output
Marine economy
Marine planning
Blue growth

ABSTRACT

The marine and coastal environment is an important economic asset in the UK, and there is a need for greater information about marine economic activities for the purposes of marine management and policy. However, due to the difficulties of quantifying some marine sectors and separating them from terrestrial activities, the current size and structure of the marine economy is unknown. This paper defines a systematic approach to quantifying the UK marine economy, aiming to capture all activities in the market economy that occur within and depend upon UK marine and coastal environments, and estimates its contribution to the UK economy as a whole. The approach draws on previous research in this area and links sectors used in marine planning with the methodologies used in national accounts. The results suggest that the marine economy contributes double the amount of previous estimates to the UK economy. Changes in the structure of the marine economy, partly due to the expansion of offshore wind energy, may affect its economic contribution. The results also show that marine and coastal leisure and recreation sectors, which were previously thought to have a small economic contribution, are the second largest sector in the UK marine economy and account for the largest number of jobs. By disaggregating the economic sectors, the approach used here can underpin a marine natural capital approach, enabling economic activities to be linked with aspects of marine natural capital.

1. Introduction

The marine and coastal environment supports a number of economic activities in the United Kingdom (UK). In managing access to the marine area, policy-makers balance environmental objectives [1,2], with the government's strategy for a lower carbon energy future [3] and industrial strategy [4,5]. Economic use of the marine environment is therefore an important consideration in marine policy and marine planning in the UK [6,7]. However, there is still need for greater understanding of the contribution of marine economic sectors for the purposes of marine management [1,8,9]. Meanwhile, use of the marine environment is changing to include not only established industries such as fisheries and shipping, but also new activities such as marine energy, seabed mining and carbon storage. Marine economic activities are interconnected, occupying the same space and competing for the same resources, so the definition and measurement of these activities as one marine economy could therefore lead to improved marine management [8,10–12].

Research on the value of marine sectors in the UK market economy has been limited; several reports cover industries or regions [13–18], but many differ in approach, and there is only one estimate of the marine sector for the UK as a whole [19] using data for 2005. Since this time, the offshore wind sector has particularly grown, now supplying 9.5% of total UK electricity production [20], with licencing areas covering large areas of the marine environment. Although the economics of offshore wind energy differs significantly from other forms of electricity generation [14,21,22], the economic contribution of offshore wind to the UK economy as a whole is unknown. The contribution of marine leisure and recreational activities are also thought to be important for employment in coastal regions [6,8]. Despite this, leisure and recreation sectors have not been a focus of previous research, with coastal restaurants, historical sites, accommodation and sports omitted from previous estimates. Indeed, tourism activities rely on the aesthetic qualities of the environment [23], but the reliance of marine industry on marine aesthetic resources has not been recognised in previous research on the marine economy. Therefore, the full extent to which coastal recreation contributes to UK output and employment are currently unknown.

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https://doi.org/10.1016/j.marpol.2020.103905
Received 27 September 2019; Received in revised form 19 December 2019; Accepted 24 February 2020
Available online 6 March 2020

Input-output (IO) analysis is the foundation of economic policy-making in the UK, forming the basis of the Blue Book of UK national accounts [24]. It is an established approach for valuing the contribution of marine activities individually [14,25–29], and was used to estimate the size and structure of marine economies in Ireland, China and South Korea [30–33]. IO analyses are directly comparable to national accounts, and can show the effect of activities upon employment and demand in other economic sectors. Previous research in the UK has used IO-based approaches [19], but no studies have attempted to systematically measure the value of all economic activities in the marine area, disaggregate marine activities from published economic data, quantify the uncertainty in the estimate, or define a corresponding IO table.

This study therefore aims to systematically define activities within the UK marine economy and quantify its contribution to the whole of the UK market economy. The approach uses IO analysis to estimate the size and structure of the marine economy, making extensive use of grey literature to disaggregate marine and non-marine activities. This work particularly focusses on the contribution of offshore wind and marine recreation to economic output and employment, building on previous research by not only including activities that rely on material or spatial use of the marine environment, but also on its aesthetic qualities. A full IO table then is defined for the marine economy and used to analyse its links with other non-marine sectors. The uncertainty in the estimate is also quantified. The paper continues as follows; Section 2 provides an overview of methods and data used in this analysis. Section 3 presents the results of the IO analysis and the estimated value of sectors in the marine economy. Section 4 discusses the results. Section 5 draws conclusions and discusses the implications of this research for policy-making in the UK.

2. Methods and data

The main steps to defining a marine economy follow an approach developed by Kildow & McIlgorm [34], having been previously applied to define the marine economies of Ireland [35] and China [36]. However, these steps do not state how to decide the sectors that should be included, nor how marine sectors can be disaggregated in economic data when marine activities are combined with non-marine activities in the national accounts. Kildow & McIlgorm's approach is therefore adapted to include three additional stages needed for application in the UK; firstly, a literature review of marine sectors in the UK economy is carried out to generate a list of likely activities to be included and a decision rule is introduced to identify which economic activities are occurring in the marine area [23,37]. For the purposes of this research, the marine area is defined to include the seabed, water column, water surface and coastline immediately adjacent to the ocean (from marine plan inshore boundaries up to 1 km inland [38–40]), extending out to the limit of the UK's Exclusive Economic Zone. This definition includes all estuaries and intertidal zones as defined by UK marine plans, with the addition of a coastal 'strip', so that marine economic activity on the coast are included, particularly recreation, shipping and port activities. Secondly, economic results are disaggregated into marine and non-marine components, so that marine economic activities can be designated as separate economic sectors. For example, production of offshore wind energy is aggregated with those of other electricity technologies in the national accounts [41], but offshore wind can be disaggregated into its own economic sector, allowing for further analysis. Thirdly, the uncertainty in the estimate must be quantified from the underlying data and grey literature. The full set of steps used to define the UK marine economy are given in Fig. 1 below.

A literature review is carried out, and existing reports on the marine economy in the UK are compared, which are used to identify the broad economic sectors to be included. The way in which economic sectors interact with the marine and coastal environment is also mapped, following the method used by Klinger and colleagues [23]. For example, water transport relies on the marine surface and the coast, whereas

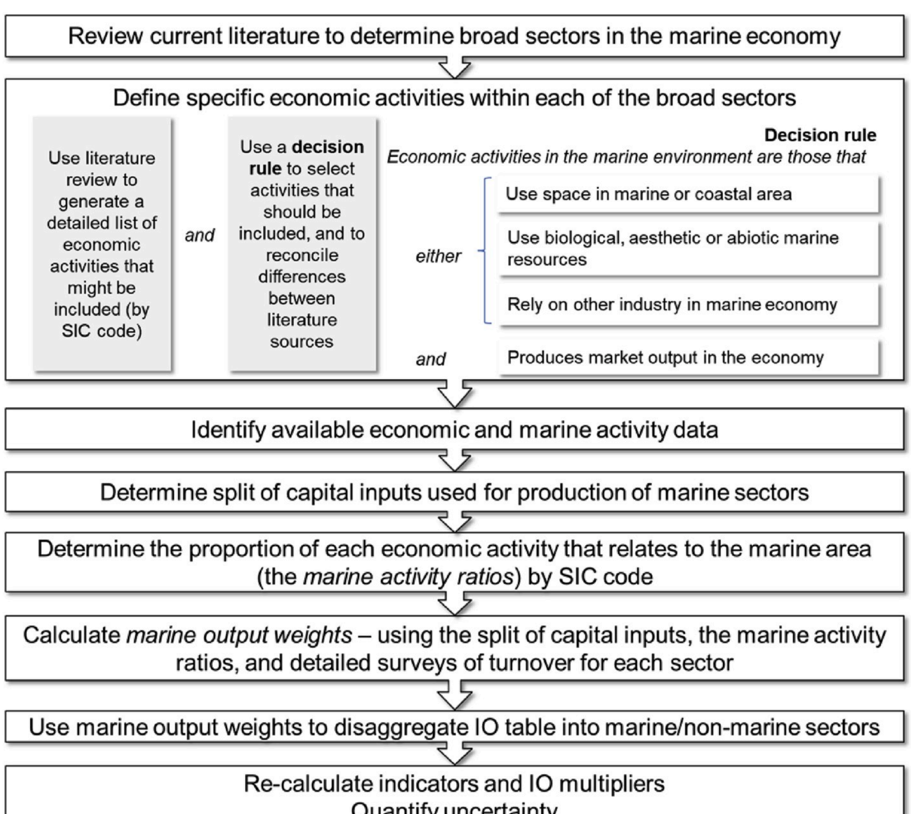

Fig. 1. Systematic approach to defining the UK marine economy and marine IO Table.

fisheries also rely in the biotic resources of the ocean. A decision rule is then designed based on this mapping; an activity is part of the marine economy if it takes place within the marine area, requires a marine resource (biotic, abiotic or aesthetic) to produce goods and services, or relies on another marine sector to produce its goods and services.

Economic activity is measured in total output and total gross value added (GVA); output of a sector is the total value of goods or services demanded from final and intermediate sectors in the economy, while total (direct and indirect) GVA is the sum of output minus intermediate consumption. This estimate uses IO tables for 2014, the most recent available from the Office for National Statistics (ONS) [41]. All other data sources and indicators used in the estimate are also for 2014, and a full list of the resources used to determine this estimate are given in the Supplementary Material. This study primarily uses the Annual Business Survey (ABS) standard abstract [42] and the Financial Analysis Made Easy (FAME) database [43], containing financial results of individual companies, to supplement the economic data provided by IO tables. The sectors of the UK IO table are based on four-digit Standard Industrial Classification (SIC) codes, a system used to classify business activities in the UK. The particular SIC codes to be included for each economic activity in the marine area is analysed through review of the relevant literature and applying the decision rule noted in Fig. 1. The different stages of production for some economic sectors are then separated out so that each stage of production can be disaggregated in the IO table. For example, the fisheries sector might include the harvesting of the resource (fishing) as well as fish processing and fish sales, but these stages of production are separate economic sectors and are recorded as such in the IO table.

The number of people directly employed in each marine sector is calculated. The number in employment is used, rather than other measures such as jobs or fulltime equivalents (FTE) so that results are comparable to EU employment. Employment is defined following that used in the UK Labour Force Survey (LFS); anyone aged 16 or older who carries out at least an hour of paid work in the week prior to the survey, or has a job from which they are temporarily absent [44]. This measurement is comparable with that of Eurostat, the only difference being that the EU commonly report employment figures for those aged between 15 and 64. Employment figures for the UK marine economy are estimated from the LFS [45], with employment detail by sector estimated using the Business Register and Employment Survey (BRES) [46] and the ABS (which contains the BRES data disaggregated by SIC code). Several sources are required because although the LFS provides the closest estimate of employment in the UK economy, the BRES and ABS provide more detail on employment by industry [44]. These data sources differ in methodology. Firstly, unlike BRES, the LFS includes public sector workers and the self-employed. Secondly, BRES data gives a point-in-time estimate of employment whereas the LFS estimates a 3 month average. Lastly, since the LFS is a household survey and BRES is a business survey, there may be differences between how people describe the industry in which they work and how that business is formally classified [44]. These methodological differences are considered when estimating the employment for each marine sector; public sector employment is excluded from the marine sectors, self-employed people are included, and variance per sector according to the different survey sources are included as part of the uncertainty analysis.

IO tables are published at a highly aggregated level. For example, marine aggregates are part of SIC code 0812 only, but in the IO table it is aggregated with 0811, 0891, 0892, 0893 and 0899 to form high level SIC 08 [41,42]. These unrelated activities must therefore be separated from the aggregated data since they contain no significant marine component, and the Annual Business Survey (ABS) is used to do so. Although the ABS is less aggregated, it provides economic data in terms of turnover and approximate GVA (aGVA) rather than total output [42]. The SIC codes for each economic activity in the marine area must therefore also be linked to the higher level of aggregation in the IO table and the approach to this is outlined in the Supplementary Material. The proportion of economic output in each SIC code that relate to activity in the marine area, which we will call *marine activity ratios*, are then estimated using a mixed set of indicators. For example, the marine activity ratio for crude petroleum can be based on the volume of it extracted from marine sources in the UK [47]. Similarly, the marine activity ratio for coastal accommodation can be based on the number of overnight stays reportedly taking place at coastal hotels [48,49]. One significant factor in the definition of the marine economy is important to mention here – the landside border of marine economic activity must be carefully considered when distinguishing the contribution of the marine economy from the non-marine sectors. In marine planning for the UK, parts of inland or non-marine economic sectors are included where they fall within the marine plan area, i.e. on the coastal margins [50]. We have followed this approach and include the SIC codes of coastal activities on the marine landside border within the estimate of the marine economy.

The inputs to production of sectors in an economy are fundamental to IO analysis. Inputs to production take the form of imports, taxes, compensation to employees, financial capital, and inter-industry inputs from other sectors in the economy [51], and the proportionate value of inputs varies for different economic activities. It is important to consider the ratio of inputs required for marine activities specifically, where they differ from their economic sector within the IO table, so that this can be used to define the marine IO table. Many marine activities are aggregated with non-marine activities of a similar nature. For example, the accommodation sector on the coast is included within the accommodation sector for the whole of the UK, and a hotel on the coast has a similar business model to that of one inland; the marine and non-marine parts of the sector are technologically similar (though some small differences may exist). Therefore, the inputs for sectors in the marine economy may remain proportional to those in the aggregated sector. One notable exception is that offshore wind energy is aggregated with all other forms of electricity generation, which are technologically dissimilar in that they require different proportions of inputs. For example, electricity generated from gas turbines requires a proportionally higher value of imports than electricity generated by offshore wind [52], and uses natural gas produced by intermediate industries [41], whereas wind energy does not. The proportion of inputs to production are analysed, in particular the supply of products from intermediate industries, compensation to employees [53] and imports [54] for offshore wind and natural gas. Intermediate industry use, compensation to employees and imports are updated for electricity products, and further details are given in Supplementary Material.

IO sectors are disaggregated using proportional weights, and in this research, we will call them the *marine output weights*, which are calculated using the total output per IO sector, ratio of inputs, marine activity ratios and ABS data. For example, 8% of UK non-metallic minerals extracted in 2014 (SIC 08) were from marine sources [47,55,56], so the marine activity ratio for marine aggregates is 8%. Once the marine output weights of each sector are known, relevant sectors in the IO table can be disaggregated into marine and non-marine components. The scaling factor approach is used to disaggregate the marine economy as described by Lui, Lenzen & Murray [57] and Wiedmann et al. [58] and the disaggregation algorithm is implemented using Python 3. The marine output weights are given in Table 2 (Section 3.2) and full details of this calculation are given in the Supplementary Material.

Multiplier analysis is used to analyse the effects of a sector across the wider economy. IO output multipliers show the amount of direct and indirect output for each sector that would be necessary to satisfy one additional unit of final demand [51]. GVA multipliers similarly show the value added by a sector from one additional unit of final demand. Multipliers are published alongside IO tables [41], but are recalculated for sectors where the proportion of inputs were estimated. The equations for these multipliers are given in the Supplementary Material, and are consistent with those given by the ONS [41].

Finally, uncertainty in the economic data is calculated using the approach by Lenzen, Wiedmann and colleagues [59,60], using the standard error or the coefficient of variation[1] of each underlying data source, with further details given in the Supplementary Material. Uncertainty in the estimation of each marine sector can come from three main sources; the underlying data used to produce the published UK IO tables, the turnover and employment figures given by the Annual Business Survey (ABS) and the data sources used to determine the weight of output for marine activity in each SIC code. The standard error for each SIC code is determined from the underlying data, where it is available, and used to calculate a standard error for the marine economy. Where the uncertainty of the underlying data could not be quantified, an estimated standard error is included to represent the low confidence in this data source. The number of supressed values in the underlying data is also measured.

3. Results

3.1. Sectors in the marine economy

Existing literature on the marine economy in the UK are compared [13,15–19,50,61], and used to identify the broad economic sectors in the UK marine economy. A summary of these sources, and comparison to the sectors used in this study, are given in Table 1. The way in which marine economy sectors interact with areas of the marine and coastal environment in the UK was also reviewed, in terms of space and resource use, which corresponds with part of the decision rule shown in Fig. 1. The detail of both these reviews are provided in the Supplementary Material.

Two sectors from the literature review are omitted from this study by applying the decision rule noted in Fig. 1; licencing activities generate government revenue so is a public (non-market) sector, and the marine environment is a marine plan sector but has no corresponding economic activity so is excluded. There are no economic results for the emerging deep-sea mining and carbon storage sectors, so these activities are omitted from further analysis. Wave and tidal energy are found to have a negligible economic contribution in the UK and so are omitted from further analysis. Marine manufacturing and equipment, including equipment produced for use in other industries and its installation, is not defined as a distinct economic sector in this analysis because these activities are captured as intermediate industries in the IO table. The number of different recreation and leisure activities that are included within the marine economy was broadened from the approach by Pugh [19] to include accommodation, sport, museums, historical sites, food and drink, in line with the approach recommended for marine planning [50].

3.2. Output and employment in the marine economy

The UK marine economy is estimated to have an output of £192 billion in 2014, representing 6.1% of total output in the UK economy [41]. The standard error for this estimate is ± £13 billion, with a coefficient of variation of 6.7%. Though some sectors have higher levels of uncertainty, these sectors are relatively small, and so there is reasonable confidence in the overall estimate in output of the marine economy. The outputs of marine economy sectors are shown in Fig. 2, where the error bars indicate 95% confidence interval, or 2 standard deviations. Sectors of the marine economy also supported 823,500 direct employees in 2014, representing 2.7% of UK employment [46,62]. However, this estimate has a high level of uncertainty; the standard error for this estimate is ±206,030, with a 95% confidence that the number of people employed in the marine economy represent between 2.0% and 3.3% of total UK employment. The output and number of people employed in each sector is given in Table 2.

Economic activities related to oil and gas in the marine area, including extraction, refining, distribution and electricity generation by natural gas turbines, represent the largest sector in the marine economy. A significant finding of these results are that marine leisure and recreation sectors are the second largest contributor to marine output in the UK, and is the largest sector in terms of employment. Shipping operations are the third largest sector. The estimated output of non-public marine defence spending (i.e. private contractors to the Ministry of Defence) is small, but also highly uncertain. The uncertainty arises because data on private sector defence spending is suppressed in the ABS and the estimates are based on turnover of defence businesses in the FAME database, which is difficult to reconcile with IO output. Public sector spending on defence is not included in this estimate of the marine economy, but it would be similarly difficult to estimate because defence spending is suppressed in governmental reporting.

3.3. Value adding effects of the marine economy

The UK marine economy has an estimated GVA of £132 billion, which represents 8.1% of total UK GVA in 2014 [63]. The GVA contributed by each sector are given in Table 2. This is higher than the proportion of marine economy output to total UK output, and can be explained by the higher value-adding effects of marine economic activities compared to the rest of the economy. The productivity of the UK marine economy (total GVA per persons employed) is estimated to be £160,437 per person, while the direct productivity (direct GVA per persons employed) is £85,400. After combining the uncertainty for employment and GVA, the standard error for total productivity is ± £45,500 per person, and ± £24,200 per person for direct productivity. Further detail of direct and indirect GVA is given by sector in Table S10 (Supplementary Material).

Disaggregating the electricity sector reveals that electricity generated from marine fossil fuels has the highest output multiplier in the UK marine economy, while offshore wind energy has the second highest multiplier. However, offshore wind energy has a lower output multiplier than other forms of electricity, meaning that it causes lower demand for output in other industries. This is because it does not use as many intermediate industry inputs such as coal, gas or oil. Offshore wind also has a lower GVA multiplier, meaning that for each unit of demand, fewer value-adding inputs are used to produce it. However, examining the detail of this result shows that offshore wind has a higher estimated effect on employee wages than other forms of electricity, with compensation of employees comprising 11% of offshore wind inputs, compared to 4% for electricity for marine fossil fuels. The output and GVA multipliers for marine energy are given in Table 3 below.

3.4. Comparison to previous estimates

The results show that the GVA of the marine economy as a proportion of total UK GVA (i.e., 8.1%) is double that of previous estimates (4.1% in 2005 [19]). The number of jobs provided by the marine economy is estimated to be much higher than the figure of 113,000 estimated in 2012 [61] and lower than that of 890,000 in 2008 [19]. However, as noted earlier, the systematic approach used in this research includes a broader set of SIC codes than were used to those produced previous estimates. To reconcile the differences in output and compare these new results against the previous estimate of marine sectors, a set of comparable figures is calculated which uses the same SIC codes as Pugh [19]. The total contribution of each marine sector to total UK GVA in 2014, the comparable figures for 2014, and the results produced by Pugh for 2005 [19] are given in Fig. 3 below.

On a comparable basis, the marine sectors in 2014 contribute 4.2% to total UK GVA, and this is in line with the 4.1% estimated by Pugh for 2005. Marine oil and gas are the largest sector in all estimates of the marine economy, but the estimate is larger in this research because economic activities such as distribution, refining and electricity

[1] Coefficient of variation is the standard error of a variable divided by the corresponding survey result [42].

Table 1
Sectors included in the marine economy.

Broad economic category	Pugh [19]	ONS & MMO [50]	Morrissey[h] [13]	Maritime UK[i] [15–17]	Seabed Users Group & APBMer [18]	Included in this study
Aggregates	✓	✓			✓	✓
Fishing and aquaculture	✓	✓[a]	✓[a]			✓
Oil and gas	✓	✓			✓	✓
Ship or boat building and repairs	✓		✓	✓		✓
Shipping operations	✓	✓	✓	✓		✓
Ports	✓	✓[b]		✓		✓
Navigation and safety	✓			✓		✓
Renewables	✓	✓		✓	✓	✓
Submarine cables	✓	✓			✓	✓
Construction	✓		✓			✓
Leisure and recreation	✓[j]	✓[c]			✓[g]	✓
Business services	✓			✓		✓
Research and development	✓					✓
Education and training	✓					✓
Defence	✓	✓				✓
Marine manufacturing and equipment	✓		✓			
Public sector licence and rental	✓[d]					
Marine environment	✓[e]	✓[f]				
Deep sea mining					✓	
Carbon capture and storage					✓	

[a] Fishing and aquaculture presented as separate sectors..
[b] Ports combined with shipping.
[c] Marine recreation and coastal tourism are separate categories, but it would be difficult to separate these categories in economic data (MMO, 2014).
[d] Turnover is government spending rather than market output.
[e] Includes environmental consulting, which is more fitting as a business service category.
[f] ONS note that no economic data fits in this category, but conservation areas and sites of scientific interest are designated in marine plans.
[g] Recreational boating only.
[h] Includes sectors for England only rather the entire UK.
[i] Prepared for Maritime UK by Oxford Economics (2013, 2015) and CEBR (2017).
[j] Water transport, tours and sport included. Accommodation, food, drink and other recreation omitted.

generation are included. The inclusion of a more comprehensive selection of marine leisure and recreation sectors make it the second largest marine economy sector, contributing 1.2% to GVA in 2014. Downstream marine fishing sectors, such as wholesale and retail sales, are similarly included bringing the total contribution of marine fishing and aquaculture to 0.3% of GVA.

4. Discussion

This comprehensive analysis shows that the marine economy accounts for a much larger proportion of the UK economy than previously thought, comprising an estimated 8.1% of GVA and 6.1% of output. The total GVA productivity of the UK is £53,287 per person employed, or £55,943 in non-public sectors [41,45], which suggests this estimated productivity of the marine economy is three times that of the UK average. This high productivity is related to the low share of employment in the marine economy (2.7%) when compared to its share of GVA (8.1%). The productivity of the marine economy is higher than the UK average because approximately 60% of the marine economy GVA is provided by industries that have a high UK productivity, such as marine oil and gas, shipping or business services [64]. Moreover, productivity estimates for the UK marine economy can be benchmarked against those of the EU's Blue Economy report; direct productivity of the UK marine economy by this estimate is £85,400, which is modestly higher than that calculated for the UK Blue Economy of £71,130 [65]. However, the EU estimate exclude the higher productivity industries of finance, chartering, shipping insurance, research and electricity generation, which are included as part of this estimate.

The analysis shows how the structure of the marine economy has changed since 2005; although oil and gas is still the largest sector, its output has declined while the offshore wind sector has grown. This changing structure of the marine economy continues to the present day and offshore wind energy generation doubled between 2014 and 2018 [20]. These changes characterise the large-scale installation of offshore wind farms and a low carbon energy strategy in the UK. The results also show how overall an increased demand for offshore wind currently has a lower output effect on the wider economy than electricity generated from natural gas. A possible reason for this is that the majority of the offshore wind turbines are currently designed and manufactured in other countries such as Germany and Denmark [66]. The implications are that with the offshore wind sector continuing to expand, the UK economy will see a slightly lower value-adding effect from these technologies in the short term. However, the construction phases of offshore wind farms have very different economic effects from their operation phases [67], and the economic contribution of offshore wind might continue to change during the next decade as wind farms are built [68]. On the other hand, as the UK has the best offshore wind resources in Europe and strong support for offshore wind, many of the turbine manufacturers are planning or projected to start or expand their manufacturing in the UK and new innovative technologies are expected to emerge [66]. This could potentially increase the value-adding and job creation effects from offshore wind. The static IO analysis used here may overstate the value-adding effects of temporary expenditures during the construction phase of offshore wind farms [14] currently and understate those of increasing domestic manufacturing in the future. Further development of this approach using a semi-dynamic IO table could mitigate these effects and be used to analyse the ongoing changes in the structure of the marine economy.

Recreation and leisure activities are a significant sector in the marine economy, the importance of which has been overlooked in previous research on the market economy. Leisure sectors represent a significant portion of marine output, and provide 26% of the jobs in the marine economy, more than double that of the largest sector (oil and gas). However, the provision of recreational activities is partially dependent on environmental factors, such as scenic merit [69,70], water quality or safety [71,72], and minimal user congestion [73]. The extent of

Table 2
Marine economy of the UK in 2014.

Broad sector	Marine sector	Marine output weight	Output, £m	GVA, £m	People Employed, 000s
Marine oil & gas	Distribution of marine gas	99%	36,359	22,182	50.0
	Electricity from marine oil and gas	44%	28,335	16,313	31.9
	Marine extraction of oil and natural gas	97%	28,196	25,018	15.6
	Refining of marine crude oil	67%	17,292	3819	8.0
	Support activities to marine petroleum	97%	4389	3715	25.3
	Total marine oil & gas		*114,571*	*71,048*	*130.8*
Marine leisure & recreation	Coastal restaurants, food and drink	21%	17,501	13,737	304.1
	Coastal accommodation	21%	5690	4392	78.4
	Sport on water	15%	1047	820	74.6
	Marine water transport rental	1%	376	328	2.9
	Tours and tour operators on water	2%	263	240	1.4
	Marine and maritime museums	3%	159	139	1.1
	Total marine leisure & recreation		*25,037*	*19,655*	*462.5*
Marine shipping	Marine water transport	98%	17,610	13,754	17.7
Marine business services	Maritime insurance and chartering	6%	5092	4111	6.5
	Marine legal services	6%	2023	1884	3.5
	Accounting for marine industries	7%	1214	1125	0.4
	Total marine business services		*8330*	*7121*	*10.4*
Marine fishing & aquaculture	Marine and coastal fishing and aquaculture	95%	1829	1206	11.8
	Fish processing	31%	2857	2153	16.0
	Wholesale of fish	1%	919	747	14.2
	Retail of fish	<1%	87	76	3.3
	Total marine fishing & aquaculture		*5693*	*4182*	*45.4*
Marine ship or boat building & repairs	Marine ship and boat building	94%	4133	3016	37.1
	Marine repair of boats or ships	94%	818	649	13.1
	Total marine ship building & repairs		*4953*	*3665*	*50.2*
Submarine cables	Submarine cables	10%	4787	3628	18.5
Marine construction	Marine civil engineering	1%	3236	2588	39.4
Offshore wind	Offshore wind	3%	2627	1950	8.7
Marine R&D	Research in the ocean	6%	2272	1852	7.1
	Environmental consulting	1%	233	196	0.3
Ports	Marine cargo handling	7%	2444	2081	22.6
Marine aggregates	Marine aggregates	8%	366	281	0.9
Marine defence	Defence activities on coast and sea	9%	123	100	8.0
Marine education	Marine education and training	<1%	22	21	0.9
Total marine economy			192,303	132,165	823.5

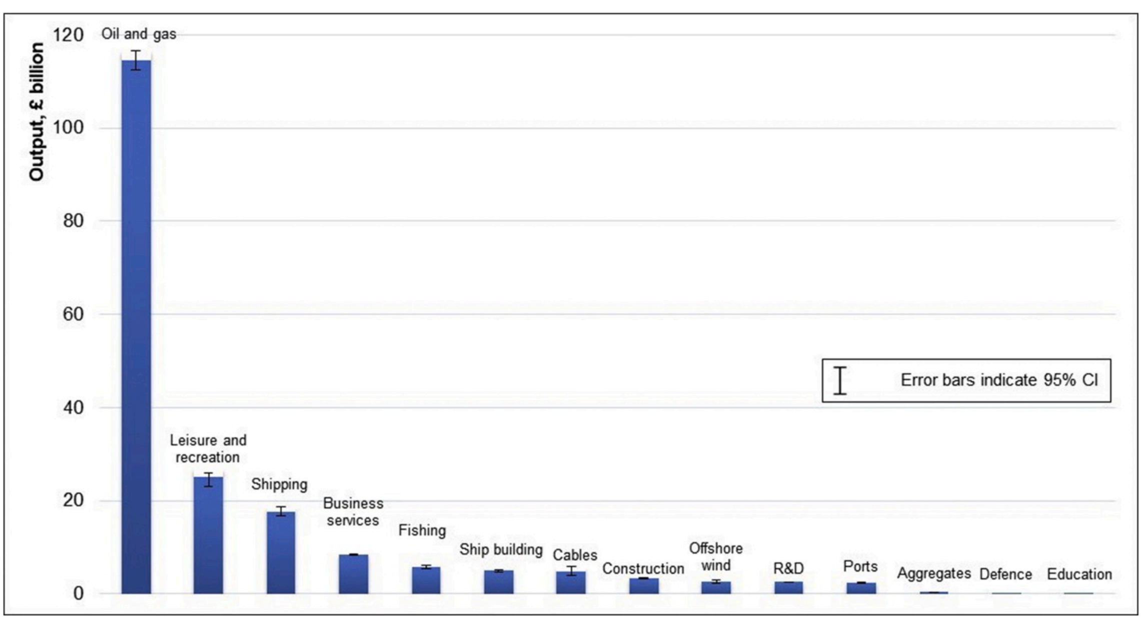

Fig. 2. Output of marine economy sectors in the UK for 2014.

recreational activities such as fishing or wildlife watching also correlate with the quality of the marine ecosystem [74]. The provision of these qualities compete with other activities in the marine area, particularly shipping, fishing, aggregate dredging and renewable energy when they produce pollution or traffic, harm habitats, or obscure scenic views. The trade-offs between spatial and aesthetic marine resource should therefore be an important consideration in marine planning activities, because marine recreational services can contribute not only to human health and wellbeing [75–78], but also significantly to the economy.

Marine fishing and aquaculture contributes a very small proportion

Table 3
Multipliers for marine economy sectors.

Marine sector	Output Multiplier	GVA multiplier
Electricity from marine petroleum	2.47	4.77
Offshore wind	2.19	2.02
Marine cargo handling	2.00	2.27
Fish processing	1.98	2.17
Marine and coastal fishing and aquaculture	1.88	2.12
Marine water transport	1.87	2.15
Distribution of marine gas	1.87	2.11
Marine civil engineering	1.86	1.94
Defence activities on coast and sea	1.81	2.04
Marine ship and boat building	1.77	1.78
Maritime insurance and chartering	1.75	1.94
Sport on water	1.75	2.08
Wholesale of fish	1.70	1.71
Tours and tour operators on water	1.63	1.59
Support activities to marine petroleum	1.62	1.57
Retail of fish	1.60	1.50
Marine repair of boats or ships	1.60	1.48
Marine aggregates	1.59	1.52
Marine and maritime museums	1.59	1.53
Coastal restaurants, food and drink	1.57	1.51
Marine extraction of oil and natural gas	1.57	1.48
Coastal accommodation	1.55	1.49
Marine water transport rental	1.55	1.47
Environmental consulting	1.54	1.53
Research in the ocean	1.49	1.44
Submarine cables	1.41	1.36
Marine legal services	1.39	1.31
Accounting for marine industries	1.31	1.21
Refining of marine crude oil	1.31	2.36
Marine education	1.14	1.08

of total GVA in the UK, but its effect is likely to be important in coastal regions; indeed, fresh seafood is landed in ten port towns in England, eighteen in Scotland, and one each in Wales and Northern Ireland [79]. Yet, this research estimates that the fishing and aquaculture sector is the fourth largest employer in the UK marine economy. In addition, fishing is a primary industry, with many other service sectors relying on its goods in order to produce their own, and this is reflected by the high output multiplier compared to other industries in this analysis. Further analysis of the productive inputs of this sector would improve the evidence base, and future work could include a hypothetical extraction of the fishing and aquaculture sector to analyse its importance as a primary industry in the UK and its significance to regional economies, which could be understated in this work.

The total number of jobs in the marine economy estimated in this study differ significantly from estimates in previous research. It is not possible to reconcile these differences fully, but it seems mostly due to a difference in methodology rather than significant changes to employment in these sectors over time. For example, a more comprehensive set of marine leisure and recreation activities were included in this estimate, and as such, jobs from these sectors are included. Likewise, public sector jobs are omitted from this estimate because the focus of this research was on that of the market economy, but the public sector is expected to provide a large number of jobs in the marine area – for example the Royal Navy employs an estimated 35,000 in 2014 [80]. This research measured employment on the basis of average employees per annum, which might not be the best measure for sectors that have large proportions of part-time, short-term or seasonal workers such as fisheries [79,81] or hospitality [82]. In addition, this analysis focuses on direct jobs, thus avoiding double counting, but this approach may understate the contribution that the marine economy has on employment in the rest of the economy. Additional analysis of indirect and part-time employment is likely to further emphasise the importance of the marine economy to employment in the UK. The nature of employment in the marine economy is also relatively unknown, though skilled jobs in offshore wind are expected to pay more [68], and the jobs in the UK recreation sector are more likely to be low paid [83].

There was a high level of uncertainty in the employment figures within this estimate, and analysis of the average compensation per employee in each sector yielded anomalous results, reflecting this uncertainty. The employment figures provided by this estimate have a coefficient of variation (CV) of 12.7%, with accommodation and hospitality sectors contributing most of the uncertainty for employment in the marine economy. This uncertainty impacts on the labour productivity estimates, which have a combined CV of 14.2%. One of the main causes of uncertainty is that sectoral employment declared by employees in the Labour Force Survey (LFS) can differ from those supplied by businesses in the Business Register and Employment Survey (BRES) dataset by as much as 42% [45,46]. In most instances, the sectoral result from the LFS is higher because it includes those who are self-employed, and captures a three month time frame which is likely to incorporate a

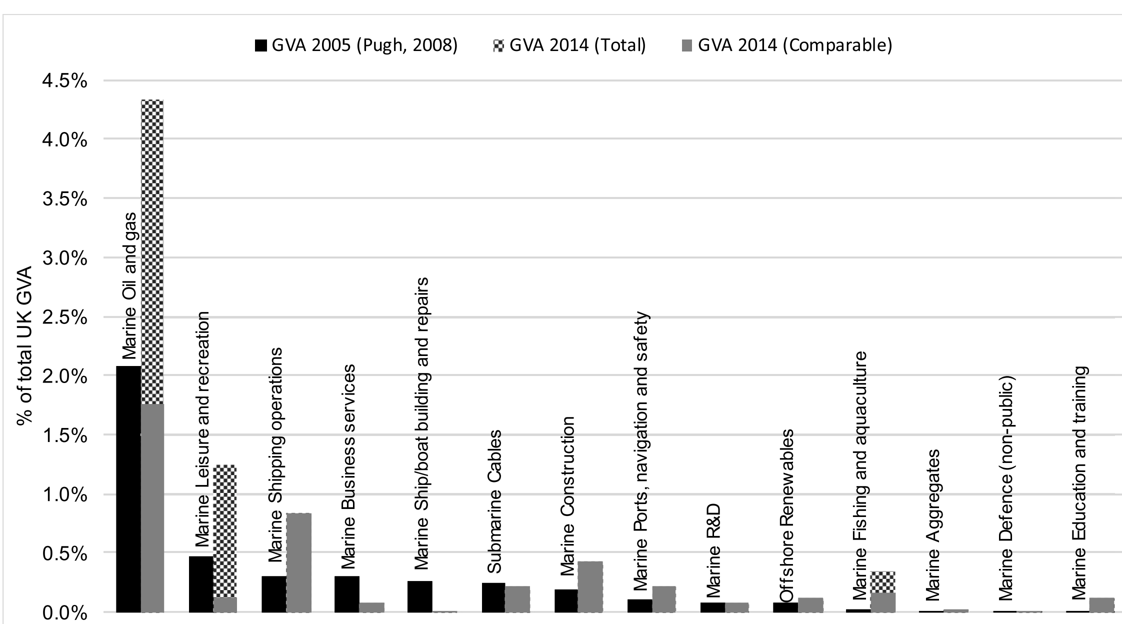

Fig. 3. GVA of UK marine economy sectors as a proportion of total UK GVA.

number of casual or seasonal workers. However, the ABS and BRES datasets estimate the average number of employees in 'Accommodation and food services' to be 2 million in 2014 whereas the LFS result gives a lower estimate of 1.6 million employees on average over the year. Similarly, the number of employed people in administration and support services is lower in the LFS than in the ABS dataset by 1 million employees (42%). It is not possible to determine how much of these differences are due to a broader sample methodology (including the self-employed) and how much is misreported (employees reporting their perceived job industry, whereas the business at which they work is registered in a different SIC code) [44]. Further analysis on the types of employment supported by the marine economy and employee remuneration would therefore be an important extension of this work.

The uncertainty in this estimate of the marine economy was quantified and the overall economic result was found to have a high degree of confidence. However, there are several sources of uncertainty in the data that could not be quantified; firstly where economic data is supressed, either to avoid disclosure of sensitive information when there are few businesses reporting within that sector, or for sensitive sectors like defence. This is a significant factor for consideration since it was found that 8% of turnover data points in the ABS between 2008 and 2017 had been supressed [42], meaning that the economic data was measured and is known, but not published. Secondly, there is uncertainty where an economic activity is within the production boundary but not measured due to survey non-response. For example, in the ABS if a business does not return its results in response [84]. Thirdly, there can be uncertainty due to measurement error, particularly when measuring a large number of transactions in a national economy. Finally, the data sources and surveys being used to determine this marine economy estimate were not designed originally for this purpose, uncertainty may also exist where data is provided at a different level of aggregation or with different definitions. For example, there is likely to be some unquantifiable degree of error in the estimates for coastal recreation, as tourism surveys used in this estimate ask participants whether they took part in activities 'at the coast' or at a 'seaside town', without defining these locations spatially. This might particularly underestimate activities in estuarine areas, which might not be perceived as coastal by survey participants. Similarly, some marine and coastal activities at major estuaries or port towns (e.g. Thames, Avon and Mersey) might be understated because these activities occur further from the coastline than has been defined in this estimate.

Several improvements could be made to this analysis beyond what has already been discussed. Analysing and updating the inputs to production of additional marine economy sectors would give even more insight into the multiplying effects of these activities. Further analysis of exports that form part of the marine economy would also be an important extension. Public data for productive inputs was scarce, but analysis of data available through the ONS' Virtual Microdata Lab might yield more detail about these activities as it has for other pieces of research [13]. Estimating the output of public sectors in IO tables, such as public-sector defence, education and administration in the marine area, would also be of interest. The accuracy of this estimate will benefit from a continued increase in the available economic data, and increased knowledge of activities in the marine area as these become available in the future.

5. Conclusions and policy recommendations

This work systematically defines the economic activities occurring in, and dependent upon, the marine environment and disaggregates these activities from the UK national accounts, estimating that activities in the marine economy account for a much higher proportion of UK economy than was previously thought. This paper therefore demonstrates the feasibility of an IO table for the marine economy, and has several important consequences for marine policy.

Firstly, the estimate can provide a baseline for 'blue' growth initiatives and marine industrial strategy. Applying this systematic approach for future publications of IO tables will allow for temporal comparisons of economic activity within these sectors, while future estimates may use this approach to include emerging marine economy sectors.

Secondly, the IO table and its multipliers indicate that offshore wind has a lower output and value-adding effect than other forms of energy in 2014, but a higher effect on employee wages. This finding is significant in light of the UK's strategic move to the production of low carbon energy. However, many offshore wind farms are still being constructed and the technologies are expected to be increasingly sourced domestically, so the ongoing effect of offshore wind on the economy should be continually evaluated.

Thirdly, this estimate can form the basis of a marine natural capital approach because economic sectors are disaggregated which allows for economic activities to be linked with aspects of marine natural capital [23]. The natural capital approach links the condition of environmental assets with the socio-economic benefits they can provide to society, and is integral to policy-making in the UK, for example as part of England's 25 Year Environment Plan [1,85,86]. Emerging research approaches that integrate the economy with natural capital can show the impact of policy on the environment and on the economy [87], and are expected to improve the understanding of potential trade-offs between economy and the environment [88]. The implementation of the natural capital approach is still in its early stages, though there are plans to release natural capital accounts for the marine area [38,89], which would enable the link between natural capital accounts and marine economy sectors.

Lastly, this estimate may improve the evidence base for marine planning and environmental impact assessments. Marine plans in England currently use baseline assessments for employment and GVA in marine plan areas [40]. However, there is a low level of confidence for some sectors, and one baseline study acknowledges that a detailed IO study of marine economic activities would clarify the contribution of marine plan sectors and the links between them [90]. Our systematic approach can therefore be used to improve upon baseline estimates for marine plans by providing updated estimates of IO multipliers. The marine IO table produced here can also be scaled to specific regions of the UK by applying a 'location quotient' approach [33,51], and therefore produce an estimate of GVA and output within marine plan areas to be used as an economic baseline. The economic sectors defined in this research are mapped to those used for marine planning and are given in the Supplementary Material.

In conclusion, our systematic approach to estimating the effect of economic activities in the marine area could improve the body of evidence used for policy and marine management. While there are some limitations, this estimate can help policy-makers and planners to further understand the economic effects of activities in the marine environment. Meanwhile, continued application of this approach may be useful to measure the effect of a changing structure in the marine economy, and understand its effect on employment. Future work could refine or update this estimate, apply it at a regional level, or incorporate the results into natural capital modelling so that trade-offs between economic output and natural capital production can be investigated.

CRediT authorship contribution statement

Emily Stebbings: Conceptualization, Methodology, Investigation, Visualization, Writing - original draft, Writing - review & editing. **Eleni Papathanasopoulou:** Conceptualization, Methodology, Supervision, Writing - review & editing, Funding acquisition. **Tara Hooper:** Conceptualization, Supervision, Writing - review & editing. **Melanie C. Austen:** Conceptualization, Supervision, Writing - review & editing. **Xiaoyu Yan:** Conceptualization, Supervision, Writing - review & editing, Funding acquisition.

Acknowledgements

This work was funded by a Natural Environment Research Council grant [NE/L002434/1], with additional support from the Marine Management Organisation (MMO). The authors wish to thank Aisling Lannin, for providing comments on the final draft, and to the two anonymous reviewers for their valuable feedback on the manuscript.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.marpol.2020.103905.

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