Ecosystem services

Sustainability Goals:

Subject links:
Science, Geography, ICT

Age: 14-16

Curriculum links:
Ecosystems, Habitats, Biodiversity, Interdependence, Coastal management, Sustainability, Human impact, Economic activity, Natural resources, Maps, Data analysis

Ocean Literacy Principles:
2. The ocean and life in the ocean shape the features of Earth.
3. The ocean is a major influence on weather and climate.
4. The ocean made the Earth habitable.
5. The ocean supports a great diversity of life and ecosystems.
6. The ocean and humans are inextricably interconnected.

Aim:
Pupils will begin to understand the many services that ocean ecosystems provide us, including the ocean's ability to provide food, store carbon, create oxygen, and sustain livelihoods.

Learning Objectives:
Main lesson:
- Describe what the term 'ecosystem services' means
- Give examples of services provided by the ocean and categorise them
- Create an infographic to educate and inform others about the value of ecosystem services

Extension activities:
- Explore and interpret online interactive mapping tools
- Analyse and interpret data on the marine economy in the UK
- Create a persuasive writing piece on the needing to protect the ocean

Resources provided:
- Ecosystems Services Fact File
- Ecosystem Services PowerPoint
- Ecosystem Services Worksheet
- Worksheet answers
- Ecosystem Services cards
- Marine economy of the UK
- Bringing nature back into our lives

Step 1 Background

Ecosystem services are defined as the benefits people derive from ecosystems. We rely heavily on the sea to provide us with food, water, oxygen, to regulate our climate, and to provide transport, to name a few services.

It is clear that our ocean provides us with extensive economic, environmental, ecological and cultural benefits. Our seas support thousands of jobs in numerous different industries and provide us with many of the resources we use daily. More information can be found in the Ecosystem Services Fact File.

Step 2 Set the Scene

Start by defining the term 'ecosystem'. A definition is given in Ecosystem Services PowerPoint.

Step 3 Activities

Activity 1 – What are ecosystem services?

Watch the video on ecosystem services in the PowerPoint. While watching the video, students should complete the associated ecosystem services worksheet. By the end of the video, students should also be able to define the following terms: indirect services, direct services, and ethical and aesthetic services.

Resources required: Ecosystem services PowerPoint, Ecosystems services worksheet, Ecosystem services worksheet answers

Activity 2 - Examples of the indirect, direct and ethical services

Split the class into small groups of 2-3 and hand out the ecosystem cards to each group. Students should read through the cards and then create a mind map of the indirect services, direct services, aesthetic and ethical services all these ecosystems provide.

They could also add to the mind map with knowledge gained from watching the video in Activity 1 and any of their own ideas. For example, for direct services, they could say that seagrass beds are nurse habitats for commercial fish. For ethical services, they could say that beaches provide recreational activities.

Once students have had time to draft their ideas, discuss each service as a class and create a large mind map for direct, indirect and aesthetic services on your whiteboard, incorporating students' ideas and adding any services that may have been missed using information provided in the fact file.

Resources required: Ecosystem cards (print slides 6-10 of the PowerPoint to form cards)

Step 3 Activities

Activity 3 – Creating an ecosystems infographic

Show the oyster infographic on the PowerPoint. Go through the infographic together, which shows how oysters are a key species that provide many ecosystem services like water filtration and habitat formation.

Students should use the infographic as inspiration for creating their own. Their infographic should showcase one of the habitats featured in the ecosystem cards. The infographic should highlight the ecosystem services of this habitat. To further enhance and provide facts to their infographics, students could also research their chosen habitat online. Infographics should include any indirect, direct or cultural services.

Students could work independently or in small groups of 2-3. The website below has lots of infographic templates students could either directly use or use as inspiration:

Recommended website:
https://www.canva.com/design/play?category=tACFahzNhT4&locale=en-GB

Resources required: Ecosystem Services PowerPoint, Ecosystem cards (print slides 6-10 of the PowerPoint to form cards), Laptops

Extension activity ideas

Mapping ecosystem services
There are some fantastic online interactive mapping tools to assess ecosystem services across the UK or on your nearest stretch of coast. The maps could be analysed in a number ways. One activity could be for students to draw comparisons between maps. For example, students could compare wastewater with bathing quality and tourism, or compare species distribution with habitat distribution.

England: https://explore-marine-plans.marineservices.org.uk/

Wales: http://lle.gov.wales/apps/marineportal/#lat=52.5145&lon=-3.9111&z=8&tgt=false
If you are unable to use laptops we have provided a selection of maps from the Welsh National Marine Plan in the Ecosystem Services PowerPoint.

Scotland: https://marinescotland.atkinsgeospatial.com/nmpi/?region=SW

Resources required: Laptops, Ecosystem services PowerPoint

Marine Economy
Students should analyse and interpret data provided in the Marine economy of the UK table. Students could create a visual representation of the total outputs for each broad economy sector.

Resources required: Marine economy of the UK table

Extension activity ideas

30x30 Biodiversity strategy
The Bringing nature back into our lives fact sheet summaries the European Commission's biodiversity strategy to increase protection of ecosystems both on land and in the sea to 30% by 2030. Students could use facts and figures in the fact sheet, along with knowledge gained in this lesson, to write a newspaper-style article about the biodiversity strategy, promoting the campaign for 30x30 and discussing why protecting ecosystems and their services is so important. Students could also add to the article by analysing the graph in the PowerPoint which shows the conservation status of habitats in coastal ecosystems.

Resources required: Ecosystem services PowerPoint, Bringing nature back into our lives

Step 4 Reflect

Can you describe what the term 'ecosystem services' means? Give an example of an indirect, direct and aesthetic service provided by the ocean. Why are infographics an important tool in science communication?

Step 5 Follow up

Our Biodiversity lesson will help students learn more about some of the key habitats and incredible marine species living in our coastal seas and how they are all interlinked.

Our Ocean threats lesson gives students an overview of the key threats to our ocean, and highlights ways in which we can reduce these threats and recover the health of our seas.

Ecosystem Services Fact File

Ecosystem services

'Ecosystem services' are defined as the benefits people derive from ecosystems.

We rely heavily on the sea to provide us with food, water, oxygen, to regulate our climate, and to provide transport. It's clear that our ocean provides us with extensive economic, environmental, ecological and cultural benefits. Our seas also support thousands of jobs in numerous different industries which provide us with many of the resources we use daily.

Our actions are having devastating impacts on ecosystems on land and in the ocean. We need to increase the understanding that damaging activities not only affect biodiversity but also affect services these ecosystems provide, and therefore affect humans too. To learn more about the impact humans are having on our ocean, take a look at our Threats to the ocean resource pack.

Fishery worker
© NOAA

Seagrass habitat ©
Benjamin L. Jones

Protecting our seas will help ensure that we can continue to enjoy and benefit from them in the future. One way to reduce threats and protect an ecosystem is by establishing Marine Protected Areas (MPAs) and banning damaging activities in these areas.

It's estimated that, in Europe, for every euro invested into MPAs there could be a return of €3 due to the value of the services they provide. (1) This is one of the driving forces behind nations across the world committing to protecting 30% of the sea by 2030.

1. Marine Biodiversity objectives, European Commission, 2021

MARINE CONSERVATION SOCIETY

Ecosystem Services Fact File

There are three main categories of services we gain from ecosystems:

1. **Provisioning services or direct services** – including harvestable goods

Food - Millions of people around the world consume fish, making it an incredibly important food source. As the population grows, so will the demand for food, putting fish stocks at risk. The fishing industry in the UK accounts for around 12,000 jobs. (2) In 2020, UK boats landed approximately 623 tonnes of fish with a value of £831 million. (3)

Fish and chips
© Meelan Bawjee

Minerals & sediment - The ocean provides us with many valuable resources including oil, gas, sediments and minerals. Each year in the UK around 15-20 million tonnes of marine sediments are removed. (4) In 2019, 18% of marine aggregate removal was used for beach nourishment. (5)

Sandy seabed
© Martin Lopatka

Medicines - Medicines are largely derived from natural sources, many terrestrial but some from marine flora and fauna. It is thought that with the ever growing demand for new medicines marine species could provide sources for new medicines.

Some sponges and corals can be used in medicines © Richard Ling

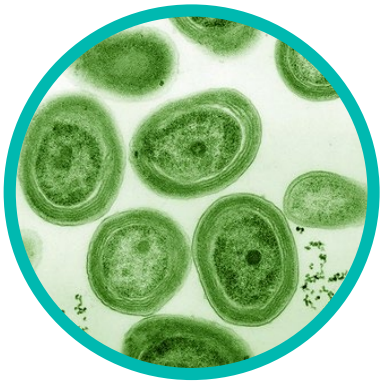
2.& 3. Fishing industry in 2020 statistics published, Marine Management Organisation 2021
4.& 5. Marine accounts, natural capital, UK, Office for National Statistics, 2021

MARINE CONSERVATION SOCIETY

Ecosystem Services Fact File

2. Regulating or indirect services

Oxygen – Plants, algae and even some bacteria in the ocean photosynthesise, and therefore produce oxygen. One litre of seawater can contain thousands of microscopic algae known as phytoplankton. Even smaller still is a species of cyanobacteria called Prochlorococcus, which is the smallest and probably most abundant photosynthetic organism on earth. Prochlorococcus produces around 20% of the oxygen in our atmosphere.



Prochlorococcus
© Chisholm Lab

Blue Carbon – Carbon that is removed from the atmosphere and stored by ocean ecosystems is referred to as blue carbon. Habitats found in the UK like seagrass beds, salt marshes and kelp beds, and mangrove forests found in tropical waters, are particularly good at absorbing carbon dioxide from the atmosphere through photosynthesis. These habitats absorb and store more carbon per metre than forests on land.

Kelp forest
© Natural England

Microscopic algae, called phytoplankton, also take up carbon, and this carbon is then transferred up the food chain to larger fish species. When marine animals die, and when plankton that isn't eaten dies, their bodies could sink down to the seafloor and much of the carbon stored in their bodies would eventually be stored and buried in deep ocean sediments.

Damaging activities such as dredging can release the carbon that has been sequestered over time, along with methane and nitrous oxide, having a negative impact on our climate.

MARINE CONSERVATION SOCIETY

Ecosystem Services Fact File

2. Regulating or indirect services (continued)

Water cycle - The ocean covers 70% of the earth's surface and holds 97% of the total water on the planet, playing a major role in the water cycle. The ocean also circulates water, nutrients and heat around the globe through ocean currents. The ocean provides water to the atmosphere as evaporated water, and due to its size, accounts for most of Earth's water evaporation.

Open ocean
© Berenice Melis

Climate - The ocean plays a major role in regulating the earth's climate. Ocean currents transport water around the globe, moving cold water from the poles and warm water from the tropics. This mixing of sea temperatures helps to regulate the climate, and helps avoid extreme climate conditions in many areas of the world. Evaporation from the sea surface also helps with the movement of heat in the atmosphere.

© Ivan Bandura

Reduce pollution - Coastal ecosystems such as seagrass beds, saltmarshes, oyster beds and mussel beds can help to reduce pollution by filtering water. One oyster can filter 180 litres of water per day! Water filtration helps to reduce the amount of land-based nutrients entering the open ocean, improving water quality in coastal areas. However, too much pollution will harm these ecosystems, and will render them unable to provide this service.

Oyster bed
© Nathan Adams

MARINE CONSERVATION SOCIETY

Ecosystem Services Fact File

2. Regulating or indirect services (continued)

Coastal protection - Many coastal areas are facing difficulties with erosion, and climate change is expected to lead to a rapid increase in erosion. The UK spends millions per year on manmade coastal defences, but many marine ecosystems, including kelp beds, seagrass meadows and saltmarshes act as natural coastal barriers. Though these habitats don't provide as fool proof protection as manmade defences, they still provide a valuable service in reducing wave energy. Protecting these ecosystems will therefore help to reduce the amount of money spent on manmade defences.

Saltmarsh © Doug Beckers

3. Cultural services or ethical, spiritual and aesthetic services

Our beautiful beaches and coastline across the UK attract huge numbers of tourists. Over 5.3 million residents live in coastal towns in England and Wales (6), and approximately 40% of the Scottish population live in coastal areas. (7) With so many people enjoying coastal scenery and activities, healthy seas are vital for our health and wellbeing.

Before the Covid pandemic, coastal tourism generated an incredible £17.1 billion per year in Britain, but during 2020 there was a loss of £10.23 billion. (8) Pre-Covid, coastal tourism supported 285,000 jobs in Great Britain but approximately 179,000 jobs were lost during 2020. (9)

6. Coastal towns in England and Wales: October 2020, Office for National Statistics, 2020
7. Scotland's coastal assets, The James Hutton Institute, 2016
8 & 9. Coastal tourism, National coastal tourism academy, November 2020

MARINE CONSERVATION SOCIETY

Ecosystem Services Fact File

Supporting services

Underpinning all other services ecosystems provide humans are the supporting services – the services that support biodiversity and maintain ocean life cycles. These services include the process of photosynthesis, primary production and nutrient cycling.

Seaweed
© Elizabeth Gomm

Container ship
© budak

Other benefits

There are several other benefits gained from the ocean that are not directly linked to ecosystems, and do not directly rely on healthy ecosystems. Some of these are:

Seabed telecommunication cabling is extremely important for the digital economy. The impact of the UK electricity subsea cables industry is around £2.8 billion per annum. (10)

Ocean transportation through both commercial shipping and ferries is a huge ocean industry. Shipping alone contributes £10 billion to the UK GDP and supports 240,000 jobs. (11)

Renewable energy in the form of wind, waves and tides. Offshore wind supplies 9.5% of the UK's electricity production. (12)

10. An Economic and Social Evaluation of the UK Subsea Cables Industry, Elliott et al 2016
11. Shipping, Maritime UK, 2021
12. Department for Business Energy & Industrial Strategy, Digest of United Kingdom Energy Statistics, DUKES, 2019

Ecosystems Services

Name: _____

Answer these questions while watching the ecosystems services video.

What are the three main ways in which biodiversity is crucial to humans?

1. _____
2. _____
3. _____

List three things that we get directly from biodiversity:

1. _____
2. _____
3. _____

Name an indirect service we get from mangroves:

_____

_____

What ecosystem services do wetlands provide?

_____

_____

Complete this sentence:

Lost biodiversity is something _____

_____

Ecosystems Services

Name: _____

Answer these questions while watching the ecosystems services video.

What are the three main ways in which biodiversity is crucial to humans?

1. Direct services
2. Indirect services
3. Ethical and aesthetical services

List three things that we get directly from biodiversity:

1. Food
2. Housing/shelter
3. Medicines

(Also – Transportation, Clothing, Energy)

Name an indirect service we get from mangroves:

Protect the coast from wave action and erosion

(Also – Nurseries for different organisms including food sources such as fish)

What ecosystem services do wetlands provide?

Recycle and removed dangerous chemicals from water and clarify and clean water

Complete this sentence:

Lost biodiversity is something we cannot bring back

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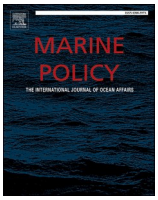

The marine economy of the United Kingdom

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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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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

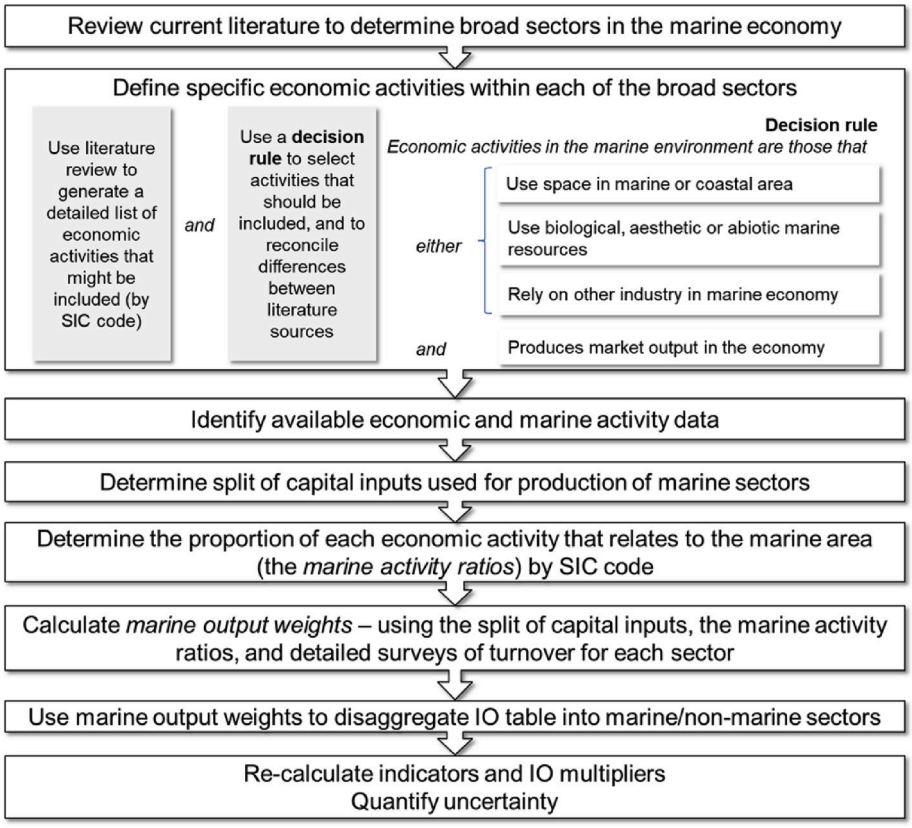

Fig. 1. Systematic approach to defining the UK marine economy and marine IO Table.

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.

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

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

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

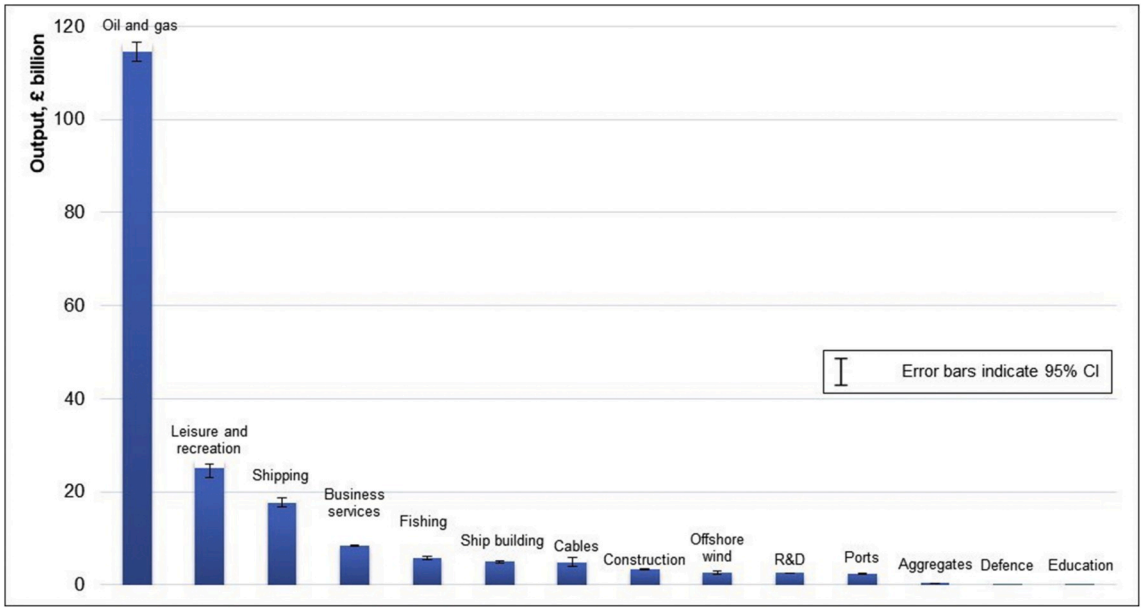

Fig. 2. Output of marine economy sectors in the UK for 2014.

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

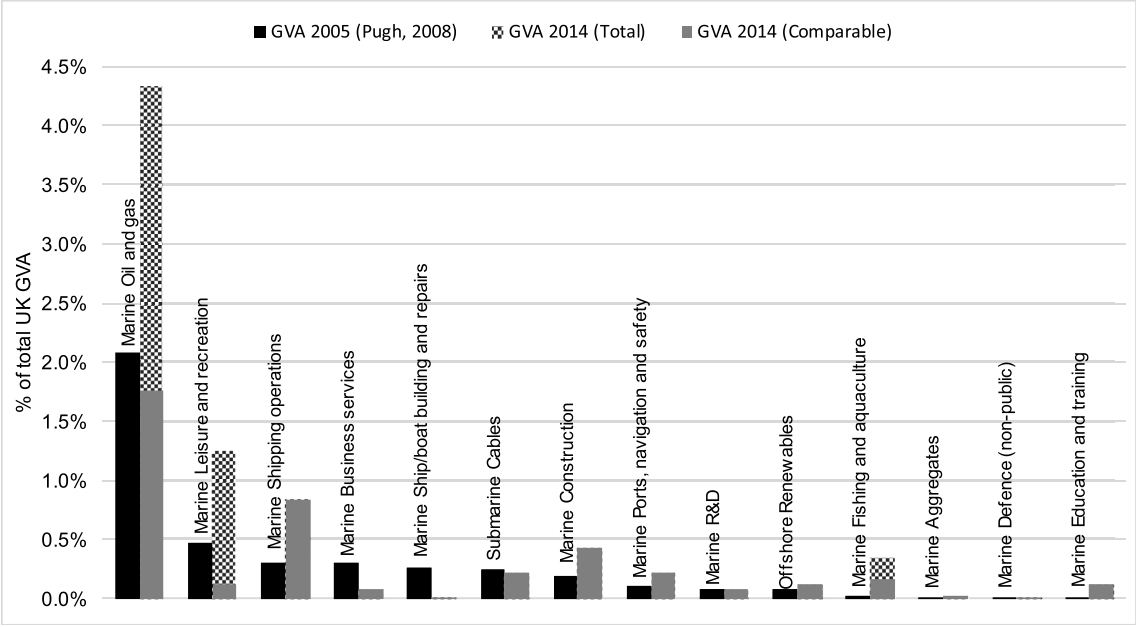

Fig. 3. GVA of UK marine economy sectors as a proportion of total UK GVA.

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.

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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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European Commission

Bringing nature back into our lives

EU 2030 Biodiversity strategy

May 2020
#EUGreenDeal

"Making nature healthy again is key to our physical and mental wellbeing and is an ally in the fight against climate change and disease outbreaks. It is at the heart of our growth strategy, the European Green Deal, and is part of a European recovery that gives more back to the planet than it takes away."

Ursula von der Leyen, President of the European Commission

Climate change, the unprecedented loss of biodiversity, and the spread of devastating pandemics are sending a clear message: it is time to fix our broken relationship with nature.

The Biodiversity Strategy will put Europe's biodiversity on the path to recovery by 2030, for the benefit of people, climate and the planet.

Why do we need to protect biodiversity?

©Pexels

Biodiversity is **essential** for life. Our planet and the economy depend on it. When nature is healthy, it protects and provides.

Biodiversity and ecosystems provide us with food, health and medicines, materials, recreation, and wellbeing. They filter our air and water, help keep the climate in balance, convert waste back into resources, pollinate and fertilise crops and much more.

Nature provides for businesses: half of global GDP, €40 trillion, depends on nature.

We are **losing nature** like never before because of unsustainable human activities.

©Pixabay

The global population of wild species has fallen by **60% over the last 40 years**.

1 million species are at risk of extinction.

Biodiversity loss and the **climate crisis** are interdependent and they exacerbate each other.

Restoring forests, soils and wetlands and creating green spaces in cities is essential to achieve the climate change mitigation needed by 2030.

The new EU-wide Biodiversity Strategy will:

Establish protected areas for at least:

30%
of land in Europe

30%
of sea in Europe

With stricter protection of remaining EU primary and old-growth forests legally binding nature restoration targets in 2021.

Restore degraded ecosystems at land and sea across the whole of Europe by:

Increasing organic farming and biodiversity-rich landscape features on agricultural land

Halting and reversing the decline of pollinators

Restoring at least 25 000 km of EU rivers to a free-flowing state

Reducing the use and risk of pesticides by 50% by 2030

Planting 3 billion trees by 2030

Unlock 20 billion EUR/year for biodiversity through various sources, including EU funds, national and private funding. Natural capital and biodiversity considerations will be integrated into business practices.

Put the EU in a **leading position in the world** in addressing the global biodiversity crisis. The Commission will mobilise all tools of external action and international partnerships for an ambitious new UN Global Biodiversity Framework at the Conference of the Parties to the Convention on Biological Diversity in 2021.

Curriculum Links - England

Key Stage 3

Science

- Interactions and interdependencies
    - Relationships in an ecosystem
    - The interdependence of organisms in an ecosystem, including food webs and insect pollinated crops

Geography

- Aims
    - Collect, analyse and communicate with a range of data.
    - Geographical skills in analysing and interpreting different data sources.

- Human and physical geography
    - Human geography relating to: population and urbanisation; international development; economic activity in the primary, secondary, tertiary and quaternary sectors; and the use of natural resources
    - Understand how human and physical processes interact to influence, and change landscapes, environments and the climate; and how human activity relies on effective functioning of natural systems.

- Geographical skills and fieldwork
    - Build on their knowledge of globes, maps and atlases and apply and develop this knowledge routinely in the classroom and in the field
    - Use Geographical Information Systems (GIS) to view, analyse and interpret places and data
    - Analyse and draw conclusions from geographical data, using multiple sources of increasingly complex information

Computing

- Create, re-use, revise and re-purpose digital artefacts for a given audience, with attention to trustworthiness, design and usability
- Understand a range of ways to use technology safely, respectfully, responsibly and securely, including protecting their online identity and privacy; recognise inappropriate content, contact and conduct and know how to report concerns.

Curriculum Links - England

Key Stage 4

Science

- Ecosystems
    - Some abiotic and biotic factors which affect communities; the importance of interactions between organisms in a community
    - The importance of biodiversity
    - Positive and negative human interactions with ecosystems.

Geography

Maps, fieldwork and geographical skills

- Maps
    - The use of a range of maps, including the use of Geographical Information Systems (GIS), to obtain, illustrate, analyse and evaluate geographical information.

- Use of data
    - Data should include both qualitative and quantitative data and data from both primary and secondary sources: fieldwork data; GIS material; written and digital sources; visual and graphical sources; and numerical and statistical information. Using data should include its collection, interpretation and analysis, including the application of appropriate quantitative and statistical techniques (a list of required skills and techniques is given in the Appendix); it also includes the effective presentation, communication and evaluation of material.

- Place: processes and relationships
    - Geography of the UK – Knowledge and understanding of the UK's geography, both in overview and with some in depth study, to include its physical and human landscapes, environmental challenges, changing economy and society, the importance of cultural and political factors, and its relationships with the wider world.

- People and environment: processes and interactions
    - Global ecosystems and biodiversity – An overview of the distribution and characteristics of large scale natural global ecosystems. For two selected ecosystems, draw out the interdependence of climate, soil, water, plants, animals and humans; the processes and interactions that operate within them at different scales; and issues related to biodiversity and to their sustainable use and management.
    - Resources and their management – An overview of how humans use, modify and change ecosystems and environments in order to obtain food, energy and water resources

Computing

- Develop their capability, creativity and knowledge in computer science, digital media and information technology

Curriculum Links - Wales

Progression Step 4

Science

- Being curious and searching for answers is essential to understanding and predicting phenomena.
    - I can explain how the impact of our actions contribute to the changes in the environment and biodiversity.
- The world around us is full of living things which depend on each other for survival.
    - I can describe the interdependence of organisms in ecosystems and explain how this affects their chances of survival.

Humanities

- Enquiry, exploration and investigation inspire curiosity about the world, its past, present and future.
    - I can analyse, present and reflect on my findings, describing patterns and explaining relationships across data and sources.
- Our natural world is diverse and dynamic, influenced by processes and human actions.
    - I can understand and explain how human actions affect the physical processes that shape places, spaces, environments and landforms over time.
    - I can understand and explain how significant places, spaces environments and landforms in the natural world are associated with economic, historical, political, and religious and non-religious beliefs and practices.
    - I can describe and explain the distinctive features of places, spaces and landscapes at a variety of scales, in my locality and in Wales, as well as in the wider world, along with the processes at work in them.
- Informed, self-aware citizens engage with the challenges and opportunities that face humanity, and are able to take considered and ethical action.
    - I have an understanding of my own and others' environmental, economic and social responsibilities in creating a sustainable future.

Digital Competence Framework

- Citizenship
    - I can understand copyright and can explain the legal and ethical dimensions of respecting creative work, e.g. exploring the ethical and legal ramifications of piracy and plagiarism and know that they are irresponsible and disrespectful, and I can apply my understanding of the rules and regulations to different scenarios.
    - I can act responsibly as creator and user of creative work, e.g. exploring decisions that creators make when exercising their creative rights and responsibilities, giving consideration to ethical, real-life issues.
- Interacting and collaborating
    - I can independently select and use a range of online collaboration tools to create a project with others in one or more languages, e.g. making use of online technology to share and present ideas to others.
- Producing
    - I can search a variety of sources using relevant search techniques with increased complexity.
    - I can evaluate the reliability of sources of information, justify my opinions and reasons for choices, and reference using appropriate methods.
    - I can select and use a variety of appropriate software, tools and techniques to create, modify and combine multimedia components for a range of audiences and purposes such as:
        - text and images, e.g. explore and use effectively image manipulation techniques; explore and use appropriately the many aspects of document layout; use animation, video and audio effects such as echo, tempo, envelope, layering, frame rate, key frames
        - presentation, e.g. use design tools; adapt themes and colours to suit the purpose; create master templates.
    - I can justify the reasons for choices and explain the advantages and disadvantages of the different digital outputs I create.
    - I can suggest and make improvements that are relevant for audience and purpose, based on feedback and self-evaluation of my digital work.

Curriculum Links - Wales

Progression Step 5

Science

- Being curious and searching for answers is essential to understanding and predicting phenomena.
    - I can evaluate contemporary issues that affect the planet and biodiversity.

- The world around us is full of living things which depend on each other for survival.
    - I can explain how variation of organisms within a changing environment leads to natural selection which drives evolution.

Humanities

- Our natural world is diverse and dynamic, influenced by processes and human actions.
    - I can explain and analyse the wide range of interrelationships and interdependencies between the human actions and physical processes that shape places, spaces, environments and landforms over time.
    - I can evaluate the extent to which economic, social, political, cultural, religious and non-religious beliefs, practices and actions have led to changes to the natural world.
    - I can give comprehensive explanations for the distinctive features of places, spaces and landscapes at a variety of scales in my locality and in Wales, as well as in the wider world, along with the processes at work in them.
    - I can give comprehensive explanations and analysis of how and why places, spaces, environments and landforms have changed over time.

Digital Competence Framework

- Citizenship
    - I can identify the key points required for creative work to be considered fair use and comply with data protection laws by exploring the legal and ethical considerations involved in using the creative work of others.
    - I can understand and reflect on the differences between taking inspiration from the creative work of others and appropriating that work without permission.
    - I can understand individuals' rights and responsibilities as creators and consumers of content, and I can think critically and make ethical decisions about the use of creative works in relation to fair use and reference using formal citation conventions, e.g. Harvard and Oxford.
    - I can understand the legal and ethical debates that surround using other people's creative work; and I consider the points of view of the original creator, potential audiences, and the broader community when using materials belonging to others.

- Producing
    - I can plan my digital work effectively and with increasing complexity.
    - I can consider the benefits and limitations of digital tools and information sources and of the results I produce and use these results to inform future judgements about the quality of my digital work.
    - I can search efficiently for information for my digital work and evaluate the reliability of sources of information, justifying opinions and reasons for choices, and I can reference work using appropriate methods.
    - I can use a variety of software, tools and techniques to create a professional, individual or collaborative project outcome incorporating a range of multimedia components.
    - I can justify reasoning to critical audiences in terms of layout and content of my digital work.
    - I can refer appropriately to sources of information used in my digital work.
    - I can make detailed and specific changes to my digital work, based upon feedback and self-evaluation, as relevant.

Curriculum Links - Scotland

Third-Fourth Level

Science - Third Level
- Biodiversity and interdependence
    - I can sample and identify living things from different habitats to compare their biodiversity and can suggest reasons for their distribution.

Science - Fourth Level
- Biodiversity and interdependence
    - I understand how animal and plant species depend on each other and how living things are adapted for survival. I can predict the impact of population growth and natural hazards on biodiversity.

Social Sciences – Third Level
- People, place and environment
    - I can identify the possible consequences of an environmental issue and make informed suggestions about ways to manage the impact.
    - I can investigate the climate, physical features and living things of a natural environment different from my own and explain their interrelationship.
    - I can use a range of maps and geographical information systems to gather, interpret and present conclusions and can locate a range of features within Scotland, UK, Europe and the wider world.
- People in society, economy and business
    - I can use my knowledge of current social, political or economic issues to interpret evidence and present an informed view

Social Sciences - Fourth Level
- People, place and environment
    - I can discuss the sustainability of key natural resources and analyse the possible implications for human activity.
    - I can develop my understanding of the interaction between humans and the environment by describing and assessing the impact of human activity on an area.
    - Having studied an economic activity, I can explain its development and assess the impact of change within its locality and beyond.
    - I can use specialised maps and geographical information systems to identify patterns of human activity and physical processes.

Technologies – Digital Literacy – Third Level
- Using digital products and services in a variety of contexts to achieve a purposeful outcome
    - I can explore and use the features of a range of digital technologies, integrated software and online resources to determine the most appropriate to solve problems.
- Searching, processing and managing information responsibly
    - Having used digital technologies to search, access and retrieve information I can justify my selection in terms of validity, reliability and have an awareness of plagiarism.
- Cyber resilience and internet safety
    - I can keep myself safe and secure in online environments and I am aware of the importance and consequences of doing this for myself and others.

Technologies – Digital Literacy – Fourth Level
- Using digital products and services in a variety of contexts to achieve a purposeful outcome
    - I can select and use digital technologies to access, select relevant information and solve real world problems.
- Searching, processing and managing information responsibly
    - I can use digital technologies to process and manage information responsibly and can reference sources accordingly.
- Cyber resilience and internet safety
    - I can explore the impact of cyber-crime for business and industry and the consequences this can have on me.

Curriculum Links - Scotland

Senior Phase

Environmental Science – National 4

- Skills, knowledge and understanding
    - Using information handling skills by selecting, presenting and processing information
- Earth's Resources
    - The responsible use and conservation of non-renewable and renewable resources.
- Sustainability
    - The sustainability of key natural resources and possible implications for human activity; the interaction between humans and the environment and the impact of human activity on an area; the role of agriculture in the production of food and raw material and its environmental impacts and sustainability; society's energy needs and the impact of developments in transport infrastructure in a selected area; and development of sustainable systems.

Environmental Science – National 5

- Skills, knowledge and understanding for the course
    - demonstrating knowledge and understanding of environmental science by making statements, describing information, providing explanations and integrating knowledge
    - presenting information appropriately in a variety of forms
    - processing information (using calculations and units, where appropriate)
    - communicating findings/information
- Living Environment
    - Investigating ecosystems and biodiversity
    - Interdependence
    - Human influences on biodiversity

Earth's Resources

- Overview of Earth systems and their interactions
- Biosphere – Oceanic and freshwater resources: economically important species of plants and animals.

- Sustainability
    - Introduction to sustainability

Geography – National 4

- Skills, knowledge and understanding
    - with support, researching and using information collected from a limited range of sources about geographical issues which are familiar
    - using straightforward mapping skills, including the use of Ordnance Survey maps in familiar contexts
    - using and interpreting a limited range of numerical and graphical information in familiar contexts
    - demonstrating knowledge and understanding of the physical environment of Scotland and/or the United Kingdom by giving factual descriptions and straightforward explanations

- Physical Environments
    - location of landscape type; formation of key landscape features; land use management and sustainability; and weather. Learners will study a selection of landscape types from contexts within Scotland and/or the UK. Landscape types will be chosen from: glaciated upland; upland limestone; coastal landscapes; and rivers and valleys.
- Global Issues
    - climate change; the impact of human activity on the natural environment; environmental hazards; trade and globalisation; tourism and health.

Curriculum Links - Scotland

Senior Phase

Geography – National 5

- Skills, knowledge and understanding for the course
    - with guidance, researching and using information collected from a range of sources about geographical issues which are mainly familiar
    - using a range of mapping skills, including the use of Ordnance Survey maps
    - using and interpreting a range of numerical and graphical information
    - demonstrating knowledge and understanding of the physical environment of Scotland and/or the United Kingdom by giving detailed descriptions which are mainly factual with some theoretical content, and giving detailed explanations
    - demonstrating knowledge and understanding of the human environment in a global context by giving detailed descriptions which are mainly factual with some theoretical content, and giving detailed explanations
    - demonstrating knowledge and understanding of selected global issues by giving detailed descriptions which are mainly factual with some theoretical content, and giving detailed explanations

- Physical environments
    - Landscape types

- Global issues
    - Natural regions
        - use and misuse of these environments by people
        - effects of land degradation on people and the environment
        - management strategies to minimise impact/effects

- Environmental hazards
    - the main features of earthquakes, volcanoes and tropical storms
    - causes of each hazard
    - impact of each hazard on people and the landscape
    - management — methods of prediction and planning, and strategies adopted in response to environmental hazards

- Tourism
    - impact of mass tourism and eco-tourism on people and the environment

- Geographical skills
    - Extracting, interpreting and presenting numerical and graphical information which may be: graphs, tables, diagrams, maps

Graphic Communication – National 4

- Initiating and producing simple informational graphics in straightforward and familiar contexts
- Demonstrating visual literacy by interpreting simple and familiar graphic communications

Graphic Communication – National 5

- Computer-aided design techniques
- Initiating and producing simple informational graphics in straightforward, familiar and some new contexts
- Using standard graphic communication equipment, software and materials effectively for simple tasks with some complex features
- Knowledge of a range of computer-aided graphics techniques and practices