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RESEARCH ARTICLE

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Tensions between the carbon, employment and value added generated by marine sectors: Triple bottom line analysis using a novel input–output table for the UK

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Abstract

Effective coordination of activities within marine areas is crucial for achieving economic, social and environmental goals. However, the socio-economic and environmental objectives of the marine economy often come into conflict. Consequently, marine policies need to confront and manage these conflicts. In this paper, we provide empirical insights into conflicts between the marine economy and the marine environment, based on the triple bottom line (TBL) foundations, by constructing a highly detailed marine input–output model for the United Kingdom. The model has 20 marine focussed sectors, including 8 fishing fleet segments. We apply the model to an empirical analysis of potential conflicts between greenhouse emissions, employment and gross value added (GVA) in marine-focussed industries. Based on this empirical work, we identify various clusters of marine sectors with different connections between environmental and socio-economic objectives and propose different policy approaches to them. Research findings indicate that certain industries have the capacity to reduce greenhouse gas emissions while simultaneously generating employment opportunities. Conversely, there are specific sectors that may not offer the same potential for expansion without causing significant environmental harm or providing minimal economic benefits in terms of employment or GVA. By examining these clusters, marine planners can better understand how their marine policies affect communities and the environment on a larger scale and prioritise their efforts accordingly.

KEYWORDS
conflicting objectives, greenhouse emissions, input–output model, marine planning, marine sector clusters, multipliers analysis

1 | INTRODUCTION

The marine environment is intrinsically linked to society and the broader economy; as such, the impacts of climate change on the marine sector will have wide-ranging consequences. Recent work identifies climate signals in a number of fishing sites' waters and suggests the loss of marine conditions supporting a range of commercial fishing species (Queirós et al., 2021). This will impact the people and communities that depend on these species for their livelihoods (Stebbings et al., 2020). But the connection between climate change and marine-related economic activity is not one-way: marine-related industries also contribute to climate change.

Globally, marine-related industries are an important source of carbon emissions. Greer et al. (2019) estimate that burning fuel in the industrial fishing sector emitted ~159 million tonnes of CO2 in 2016, a Figure 4 times greater than in 1950. The international shipping industry consumes around 289 million metric tons of fuel annually (Corbett & Koehler, 2003) and emits 3% of annual global carbon emissions (Bouman et al., 2017). The maritime transport sector is considered an important source of total emissions in the EU, with ships being responsible for releasing 13.5% of total emissions in the EU transport industry in 2018 (EMSA and EEA, 2021). Consequently, governments around the world have committed to making changes to reduce marine industry carbon emissions. For instance, the UK government has set out a Clean Maritime Plan to cut carbon emissions and other pollutants from the sector (Department for Transport, 2019).

Marine sectors depend upon the natural marine environment to provide livelihoods and support local economies, but they also threaten the marine environment by contributing to climate change. One of the implications of climate change for marine resources is that altering seawater temperature or oxygen levels affects the distribution and abundance of fish stock biomass (Brander, 2010). These fish stock changes imply that reducing marine resource availability in some regions increases the likelihood of overfishing, negatively affecting food provision and job creation (Burden & Fujita, 2019).

Managing economic activities related to the marine environment, such as fisheries, has become increasingly complex due to the need to consider economic, social and ecological sustainability factors (Anderson et al., 2015). However, the lack of reliable data on the marine economy has limited research into the environmental and economic impact of marine strategies (EC, 2020). Additionally, more data availability would facilitate contrafactual assessments by isolating the impact of marine policies from those that would have occurred without marine strategy implementation (EC, 2020). Therefore, there is a need for more accurate and comprehensive marine economic data to predict the changes that may occur in marine policies due to revisions or amendments after their implementation (Marine Management Organisation-MMO, 2014). Providing updated and new IO multipliers, including those from new disaggregated marine industries, could be very useful in refining initial estimates or updating them (Stebbings et al., 2020) when designing marine plans.

This study contributes to filling the empirical gap in the literature by developing a new marine-focussed input–output table for the UK and presenting a set of marine-focussed IO multipliers that can be used to identify possible economic, environmental and social impacts related to marine economic development. Moreover, this study also aims to identify potential hotspots within the industry to evaluate any economic, environmental, and social impacts related to marine economic development in the UK, particularly in the context of climate change adaptation and mitigation measures. Section 2 reviews the triple bottom line (TBL) and input–output model literature as examples of marine economy policy tools. Section 3 outlines the development of a UK input–output table with 20 marine-focussed sectors. Using this table, in Section 4, we present an empirical analysis of the tensions between an environmental indicator (greenhouse gas [GHG] emissions), an economic indicator (gross value added) and a livelihoods indicator (employment). Based on the empirical analysis, Section 5 identifies groupings of marine policy-relevant sectors, discussing them in Section 6 regarding sectors that may be more amenable to shrinkage and those where technological innovation may be more desirable. Finally, Section 7 concludes.

2 | TRIPLE BOTTOM LINE ANALYSIS

Sustainability is commonly conceptualised as having three components ‘Environment’, ‘Society’ and ‘Economy’ (e.g. Clift et al., 2022). In 1994, John Elkington coined the term TBL. The TBL expands the scope of conventional impact assessment by encompassing economic, environmental and social dimensions.

Examples of TBL assessments include To and Lee (2017), who examined the socioeconomic and environmental implications of the logistics industry in Hong Kong using a set of normalised indicators within the TBL framework. The results underscored the complex interplay within the logistics sector, which significantly contributed to the national gross domestic product (GDP) and workforce while accounting for a substantial portion of GHG emissions. Kumar et al. (2019) explored the sustainability of short food supply chains (SFSCs), highlighting the numerous economic, cultural, and environmental advantages that emerged when intermediaries between producers and consumers were minimised.

In fisheries management, Liu et al. (2021) took a detailed approach, employing 14 fishery-related indicators to assess the sustainability of fisheries management practices. Their findings illuminated managerial disparities in environmental and economic sustainability within the catching sectors, although differences in social sustainability and post-production industries were less pronounced. In the maritime sector, where the environmental dimension has often commanded the spotlight (Karakasnaki et al., 2023), Fasoulis and Rafet (2019) conducted a quantitative research study on the perspectives and opinions of the maritime industry regarding the TBL approach to sustainable development. Their findings underscored the maritime sector's rapid adaptation to this approach and a growing willingness among marine sector representatives to adopt it as part of their corporate social responsibility strategy.

In the context of marine and fishery industries, empirical research faces the challenges posed by data constraints (Kildow & McIlgorm, 2010). This is particularly the case where studies look to understand the supply chain as well as its immediate impacts. Like all economic activity, marine sectors depend on complex supply chains. Fishing employs not just the people on the boat but also those who make the boat, repair the boat and insure the boat (and so on). Mapping these supply chains using a process-based approach can be very time-consuming. Consequently, a useful first step is to apply ‘top-down’ tools like input–output analysis to screen initial relationships, provide contextual information on marine sectors, and point to areas for more detailed on-the-ground analysis.

An extensive body of literature applies the TBL and input–output-based approaches to explore sustainability. Some of these studies have delved into the links between sustainability and logistics operations within the supply chain (Weber & Matthews, 2008), end-user consumption and investments (Cellura et al., 2013; Kucukvar et al., 2014), or production industries and operations (Egilmez et al., 2013). Collectively, these studies emphasise the intricate interconnections that shape sustainability across various domains.

3 | THE EMPIRICAL GAPS IN THE MARINE FOCUSSED IOT

Input–output models have proven invaluable for assessing the environmental implications of economic activities (Albino et al., 2002; Mair et al., 2019; Minx et al., 2009). Notably, given China's role as a major global producer and a significant carbon emitter, several studies have explored the environmental consequences of Chinese supply chains (Liu et al., 2017; Xu et al., 2017). Some researchers have focused on sector-level environmental impacts, as exemplified by Acquaye and Duffy (2010), who estimated direct GHG emissions from the Irish construction sector and their downstream environmental consequences. A rare but valuable approach within the realm of input–output models has involved an examination of the environmental impacts of the marine economy with Bagoulla and Guillotreau (2020) identifying the freight and passenger marine transport sectors as significant contributors to NOx and SO2 emissions among French industries.

Input–output models also serve as a framework for synthesising economic data pertinent to the marine economy (Stebbings et al., 2020). This framework facilitates the convergence of economic and environmental analyses. For instance, Mair et al. (2016) delved into the distribution of carbon emissions, employment, income, and gross value added (GVA) across Western European clothing supply chains. Jackson (2017) harnessed input–output models to analyse the relationship between hours of work and GHG emissions, advocating for policies that support sectors characterised by low emissions and high employment. Research conducted by Llop (2022) using a multi-country input–output model aims to estimate the impact of international trade on job markets and employment incomes. The research findings suggest that while exports have a minor role in creating employment in the US, international trade significantly influences work creation and worker's income in the EU and China. Furthermore, input–output models offer a quick and relatively straightforward means of estimating impacts, an attribute of significant importance in guiding the implementation of policies (Miller & Blair, 2009). These models enable ex-ante assessments, which are instrumental in maximising potential benefits and minimising unwarranted costs (OECD, 2017).

In the context of marine and fishery industries, empirical research faces the challenges posed by data constraints (Kildow & McIlgorm, 2010). Nonetheless, a substantial body of literature employs input–output models to study the contributions of marine sectors to national economies (Morrissey and O'Donoghue, 2013; Kwak et al., 2005). In a recent article, Roca and Padilla (2023) examined the implications of removing fishing subsidies in Spain, shedding light on the economic aspects of the marine environment. However, it is noteworthy that these studies often overlook the environmental impacts of the marine economy.

Although the empirical exploration of the UK's marine-related sectors is limited, several researchers have used input–output analysis to amalgamate diverse data sources to shed light on the UK Marine Economy. In a study conducted by Cebr (2017), the economic impact of marine leisure sectors within the UK was evaluated through an Input–Output (I-O) model. The findings underscore the substantial economic footprint of the UK's marine leisure industry, with direct contributions amounting to approximately £3.4 billion in turnover, £1.2 billion in GVA, and job opportunities for around 33,000 individuals. Likewise, Pugh (2008) delved into the marine industry's complexity by dissecting it into 18 sectors. Their study revealed that marine-related sectors constituted 4.2% of the UK's total GDP, translating to a remarkable £46 billion in value and providing employment for 890,000 workers between 2005 and 2006. A more recent analysis by Stebbings et al. (2020) utilising input–output methodology and data from 2014 further illuminated the significance of marine-related activities in the UK. Their research indicates that these activities contribute approximately 10% to the overall national GVA and roughly 5% to the national output. In concert with these empirical investigations, Midmore et al. (2006) adopted Dietzenbachere (1992) approach to scrutinise the robustness of intersectoral linkages using financial data extracted from Input–Output tables for the Welsh economy. Their research uncovered valuable insights, leading to the identification of industry clusters and demonstrating the economic intricacies within the marine sector.

In this study, we develop a highly detailed marine-focussed input–output table for the UK, using the most up-to-date data available from various sources. We maximise the benefits of the input–output framework, based on the TBL foundations, by empirically analysing the relationships between environmental, economic and livelihood impacts in marine-focussed sectors. To do this, we plot measures of economic benefit (GVA) and livelihoods (employment) against an indicator of environmental impact (GHG emissions).

4 | METHODOLOGY: A MARINE-SPECIFIC UK INPUT–OUTPUT MODEL

Since it was created by Leontief (1936), input–output models have been widely applied in social, environmental and economic impact assessment (for example, Mair et al., 2016; Wang et al., 2020), being developed for other research purposes (Ghosh, 1958; Miyazawa, 1966, 1971; Sonis et al., 1997; Sonis & Hewings, 1999). In this section, we outline the core elements of the IO Model, multipliers (a key analytic statistic derived from the model) and our addition of information to develop a marine-specific IO table for the UK. The final table has 20 Marine-specific sectors and a total of 114 sectors (see Table S2 for a full list). It is available to download at: https://pure.york.ac.uk/portal/en/datasets/the-uk-marine-focussed-input-output-table-version-10.

4.1 | An introduction to input–output models

An IO model is a linear representation of all intersectoral flows given in an economy, usually within a temporal frame of 1 year. The information is recorded in squared matrix-form (IO) tables, which capture, by columns, intermediate and primary inputs demanded by sectors to produce their output. Likewise, rows depict the supply of each sector's production to other industries and on final demand.

The following expression depicts all transactions between industries:

$$x = y + Ax, \tag{1}$$

where x is a vector that represents all industry outputs in the economy, y is the final demand vector, A matrix embeds inputs coefficients that are represented by a_{ij}. These coefficients are estimated by dividing each element of A, by the total output x. They represent how much input the industry needs from other supplier industries to produce one output unit.

Rearranging (1), we obtain total industry output in terms of the final demand:

$$x = (I - A)^{-1} y, \tag{2}$$

where I is the identity matrix and $(I - A)^{-1}$ is the Leontief Inverse Matrix. The Leontief matrix allows analysts to assess all direct and indirect economic impacts due to an exogenous demand shock through multipliers estimation.

4.2 | Multipliers

This study presents input–output multipliers that can give insight into potential consequences in the UK economy given a policy implementation. This information is valuable for policymakers to simulate their policies and advance likely outcomes (Miller & Blair, 2009). Multipliers describe the impact of a change in demand across the full supply chain. For example, the employment multiplier for Demersal trawlers and seiners provides an estimate of the number of workers needed to produce 1 unit of output on board the trawler or seiner itself, and the workers employed in building the boat, workers employed in catering services serving workers building the boats and so on.

Following Miller and Blair (2009), we can describe input–output multipliers as;

$$m(Z) = z'_{c} L. \tag{3}$$

Equation (3) is a general formula for multipliers, where z'_{c} stands for the vector of coefficients as a result of combining data on the impact of interest (value added, employment or GHG emissions), For instance, when the carbon emission vector satellite is divided by the vector of industry outputs (x), we obtain multipliers that depicts the amount (i.e. in tonnes) of emissions by a unit of industry output. For the purpose of this study and to facilitate the reader's interpretation of results, we briefly define the concept and measure units behind each multiplier.

The greenhouse emission (GHG) multipliers are estimated using data provided by the Office for National Statistics (ONS, 2022a), constructed according to the System of Environmental Economic Accounting (SEEA) standards. Results are given in 1000 tonnes of carbon dioxide equivalent per year. They include all GHGes under the Kyoto Protocol: carbon dioxide, methane, nitrous oxide, hydrofluorocarbons, perfluorocarbons, nitrogen trifluoride and sulphur hexafluoride (ONS, 2022a).

GVA multiplier is an economic indicator of a sector's contribution to an economy's GDP. This metric is calculated as the difference between the market value of an industry's total output and the market value of its intermediate inputs used in the production process (ONS, 2018a). For this study, units are given in £ million.

The employment multiplier is the total number of workers per unit of output. Employment data collected for fishing fleet segments from the Seafish website was provided in full-time employment (FTE) equivalent. The FTE is the unit of measurement used, where a person who works full-time counts as one FTE, while part-time workers/students are counted proportionally to the worked hours. However, the employment data collected for fishing fleet segments from the Seafish (2020a) website was provided in FTE, while the data for other sectors, found on the NOMIS (2021) website, was given in the number of workers. To harmonise both databases, we estimated each fleet segment's share of full-time and part-time employees based on figures in the Seafish (2022) report. Assuming that a full-time employee works 40 hours a week and a part-time employee works 20 hours (Seafish, 2019, p.37), a part-time worker accounts for 0.5 (20 hours) of FTE. As a result, the total workers per fleet segment equals the FTE minus the share of part-time workers times 0.5 employment factor.

4.3 | Data and sector disaggregation

The standard UK IO table (ONS, 2022b) only contains high-level information on marine-focussed sectors. Consequently, we collect data from several sources to disaggregate these high-level sectors. Table 1 summarises marine-focussed sectors in the original table, our disaggregation, and the data sources used.

To disaggregate the marine-focussed sectors, we based our preselection on the Marine Scotland Directorate (Scottish Government, 2022; Table S1). Besides sectors present in this report, we also included the Wholesale of other food, including fish, crustaceans and molluscs sector (46.38) and the Retail sale of fish

TABLE 1 Marine-focussed sectors before and after disaggregation.

Original sector	Marine-focussed sectors after disaggregation	Data sources used
Fishing and aquaculture (3.1 and 3.2)	Demersal trawlers and seiners (3.11); Nephrons (3.12); Beam trawlers (3.13); Scallop dredges (3.14); Passive gears (3.15); Boats under 10 m (3.16); Low activity (3.17); Pelagic Trawlers (3.18); Aquaculture (3.2)*	ONS (2018b); Seafish (2019); Scientific, Technical and Economic Committee for Fisheries (STECF) (2019); Seafish (2020a); Seafish (2022); Turrell (2020)
The processing and preserving of fish, crustaceans, and molluscs (10.2) and fruit and vegetables (10.3)	The processing and preserving of fish, crustaceans, and molluscs (10.2)[1]	ONS (2016, 2018b, 2022a); NOMIS (2021)
The building of ships and boats (30.1)	The building of ships and floating structures (30.11); The building of pleasure and sporting boats (30.12)	ONS (2016, 2018b, 2022a); NOMIS (2021)
Repair of fabricated metal products, machinery and equipment (33.1)	Repair and maintenance of ships and boats (33.15)[1]	ONS (2016, 2018b, 2022a); NOMIS (2021)
Construction industries (41 to 43)	Construction of water projects (42.91)[1]	ONS (2016, 2018b, 2022a); NOMIS (2021)
Wholesale trade, except motor vehicles and motorcycles (46)	Wholesale of other food, including fish, crustaceans and molluscs sector (46.38)[1]	ONS (2016, 2018b); NOMIS (2021)
Retail trade, except for motor vehicles and motorcycles (47)	Retail sale of fish crustaceans and molluscs in specialised stores (47.23)[1]	ONS (2016, 2018b, 2022a); NOMIS (2021)
Water transport sector (50)	Sea and coastal passenger water transport (50.10); Sea and coastal freight water transport (50.20)[1]	ONS (2016, 2018b, 2022a); NOMIS (2021)
Warehousing and support activities for transportation (52)	Service activities incidental to water transportation (52.22)[1]	ONS (2016, 2018b, 2022a); NOMIS (2021)
Rental and leasing activities sector (77)	Renting and leasing of water transport equipment (77.34)[1]	ONS (2016, 2018b, 2022a); NOMIS (2021)

[1] Disaggregation of these factors results in both marine-focussed and non-marine sectors. For simplicity, only the marine-focussed sector is included in this table. But the full model includes both marine-focussed and non-marine sectors.

*SIC codes assigned to fishing disaggregated fleets are used as a reference for this research.

crustaceans and molluscs in specialised stores (47.23) to achieve a broader analysis. Conversely, some sectors were excluded based on a lack of data availability. Support activities for petroleum and natural gas extraction were discarded, as information for these sectors was unavailable due to the suppression of information to avoid disclosure (ONS, 2018b). The Miscellaneous fleet segment was ruled out due to difficulty in collecting information (more details, see Seafish, 2020b, p.6). Due to a lack of data, we excluded the marine tourism industry (see Scottish Government, 2022; Table S1).

We use the weight-estimation approach outlined in Equation (4) to disaggregate the marine-focussed sectors:

$$w_{ij} = \frac{x_i}{x_i + x_j}, \tag{4}$$

where x_j is given by:

$$x_j = v_j + z_j, \tag{5}$$

where v_j is GVA at basic prices provided by Seafish (2019), and z_j is total purchases of goods, materials and services. We applied this approach using data from the 2014 Annual Business Survey (ABS) (ONS, 2016) until the 4-digit Satandard Industry Classification level. Using this approach, we could estimate the weights on output, GVA and intermediate consumption and then apply them to the 2018 ABS (ONS, 2018b) data (Table 1). We gathered employment estimates from a detailed database of the Business Register and Employment Survey (BRES) available on the Nomis website (NOMIS, 2021). We also used this employment data for non-marine sectors, and the GHG data for the marine and non-marine sectors was collected from ONS (2022a).

In order to perform a deeper analysis of the fishing sector (3.1), we further break it down into eight fleet segments, following the same approach defined in Equation (4) and using detailed data from various sources (Seafish, 2019; Seafish, 2020a; Seafish, 2022; STECF, 2019; Turrell, 2020). Total intermediate consumption can be estimated as the difference between total turnover and GVA (ONS, 2012; Central Statistics Office, 2022). We followed this approach to calculate this economic indicator for almost all fleet segments (Table S1). However, for the Pelagic Trawler sector, we had to rely on the GVA information reported by the STECF (2019) as a reference. They point out that the total GVA for the UK Pelagic Trawler was €111 million in 2017. We converted this to British Pounds and used the UK consumer price index (CPI) 2005 index (ONS, 2018c) to adjust it to 2018 prices. Lastly, GHG emission data for the fishing subsectors was obtained from the Marine Scotland database (Turrell, 2020), assuming that fuel consumption and engine efficiency remained constant between 2017 and 2018.

4.4 | Limitations of the study

It is worth noting that our model does not account for certain spatial issues that may arise when managing marine sectors. While it is feasible to include spatial economic effects in an IO model (such as Zhang et al., 2016) or connect ecological and economic aspects in an IO model for a marine ecosystem (like Jin et al., 2003), this was beyond the scope of the initial project. However, we believe the detailed model here could be used as the basis for more regionally focussed tables, enabling a more spatially sensitive approach in future.

Although the IO model is an adaptable and powerful analytical tool (permitting a detailed analysis of industry linkages, a deep disaggregation of sectors, or its potential extensions to undertake, among others, value chain or environmental and economic impact analysis), it is based on a set of assumptions that need to be considered when interpreting the results. For instance, there is a linear proportion between input and output, representing the constant returns of scales of the model. Moreover, it does not contemplate the possibility of substitution between inputs to improve production processes, represented by fixed technological coefficients. Likewise, homogenous productivity implies that each sector produces a unique product using an equal input structure (Miller & Blair, 2009).

5 | RESULTS

5.1 | Overview of marine sector estimations

Before presenting our multiplier analysis (Section 4.2), we provide a snapshot of the final UK Marine focussed Input–Output Table. This is a reference point for comparison and ensures a comprehensive understanding of the study's findings.

The 20 marine-focussed sectors, shown in Table 1, in our table, generate approximately £14 billion of combined GVA. This figure differs significantly from the £132 billion estimated by Stebbings et al. (2020) in their extensive IO analysis of UK marine activity using 2014 data. The distinction between our study and Stebbing's study is that they estimate the proportion of activity that can be classified as ‘marine related’ in any given economic sector, whereas we focus on a subset of ‘marine-focussed’ sectors. That is, we consider all or almost all of the activity in our marine focussed sectors to be ‘marine’.

Our study also indicates that our 20 marine-focussed sectors directly produce ~16,000 tonnes of GHG emissions, representing ~3% of the UK's total territorial GHG emissions (~560,000). It is worth noting that the two marine transport sectors are responsible for ~90% of these emissions, with passenger transport accounting for ~50% of the total.

In terms of employment, our 20 marine-focussed sectors directly employed ~130,000 individuals in 2018, representing ~0.5% of the total employment in the UK (~30,000,000). The top three marine sectors in terms of the total direct marine sector employment share are Service activities incidental to water transportation (~20%), Building of ships and floating structures (~17%), and Wholesale of other food, including fish, crustaceans, and molluscs (~15%).

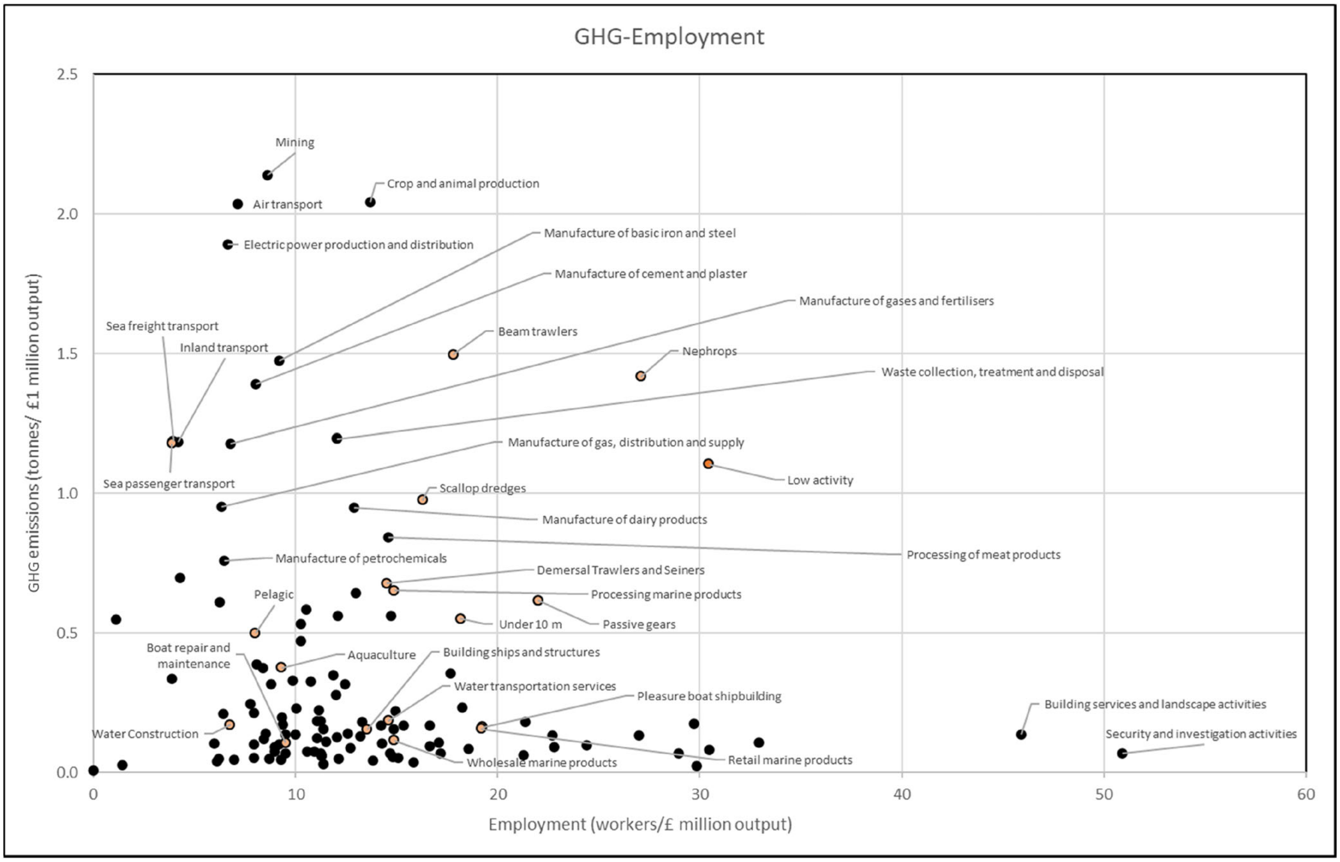

FIGURE 1 Greenhouse gas (GHG) and employment multipliers of the UK sectors. Employment multipliers are represented by values on the *x*-axis and are given in the number of workers. GHG multipliers are shown on the *y*-axis and are measured in tones.

5.2 | Multipliers

In this section, we present multipliers for GVA (Figure 1), employment (Figure 2), and GHGs (Figure 3) for our 20 marine-focussed sectors. Each multiplier represents the additional impact (direct and indirect) of a £1 million increase in final demand for the respective sector.[1]

The chart in Figure 1 shows the GHG and employment multipliers of various industries in the UK, with marine industries being highlighted in orange. On closer inspection, it becomes clear that many industries in the UK have medium to low GHG and employment multipliers (bottom-left quadrant). Interestingly, none of the marine industries have the highest GHG and low employment intensities, which are found in the Mining (8.60 workers and 2.14 tonnes), Air Transport (13.69 workers and 2.04 tonnes), and Electric sectors (7.16 workers and 2.03 tonnes). Similarly, marine industries are not among the sectors that show the highest employment multipliers with low GHG intensities, such as Buildings and Landscape Activities (45.90 workers and 0.13 tonnes) or Security and Investigation Activities (50.91 workers and 0.06 tonnes).

Figure 2 illustrates the correlation between the GHG and GVA multipliers for the entire UK sector. While the GHG multipliers show equal intensities, as shown in Figure 1, the GVA multipliers cause the scatter plots to be more varied and show significant fluctuations. The mining and electricity production sectors still have the highest intensities, but crop and animal production, hunting, and related service activities are among the top industries. It is also noteworthy that some UK industries have GVA values ranging from 0.5 to 0.85 £ million and emit 1.5 to 0.5 GHG tonne emissions for every £1 million output. 11 marine-related sectors have intensities within these ranges. Other UK sectors such as the Manufacture of cement, lime, plaster and articles of concrete, cement and plaster (£0.73 million and 1.39 tonnes), the Manufacture of basic iron and steel (£0.60 million and 1.47 tonnes) or the production of industrial gases, inorganics and fertilisers (£0.50 million and 1.178 tonnes) also show varying intensities.

Figure 3 shows that the amount of GVA generated per £1 M of additional final demand varies between sectors. Boat Repair and Maintenance is the most GVA-intensive sector, producing £0.92 million for every £1 million invested. According to estimates, 75% (£0.69 million) of the GVA in this sector is directly generated, while the remaining 25% (£0.24 million) is indirectly created in other sectors. The effects on GVA differ from sector to sector, with some sectors significantly impacting GVA. For example, in the wholesale sector, the total effect on GVA is £0.84 million per £1 million output, with most effects being created directly (£0.66 million) and only a small impact on GVA generated in other sectors (£0.18 million).

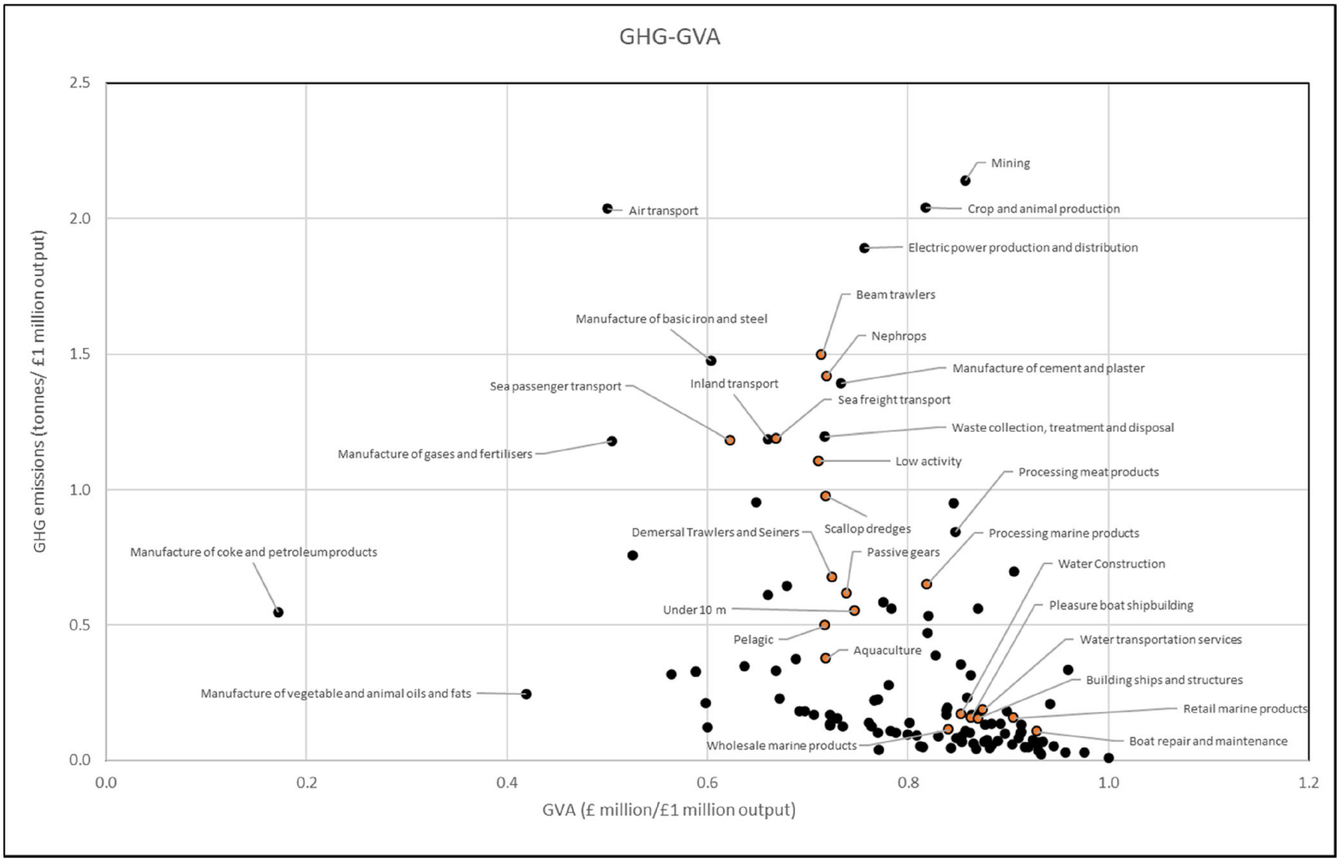

FIGURE 2 Greenhouse gas (GHG) and gross value added (GVA) multipliers of the UK sectors. GVA multipliers are represented by values on the *x*-axis and are given in £ million. GHG multipliers are shown on the *y*-axis and are measured in tones.

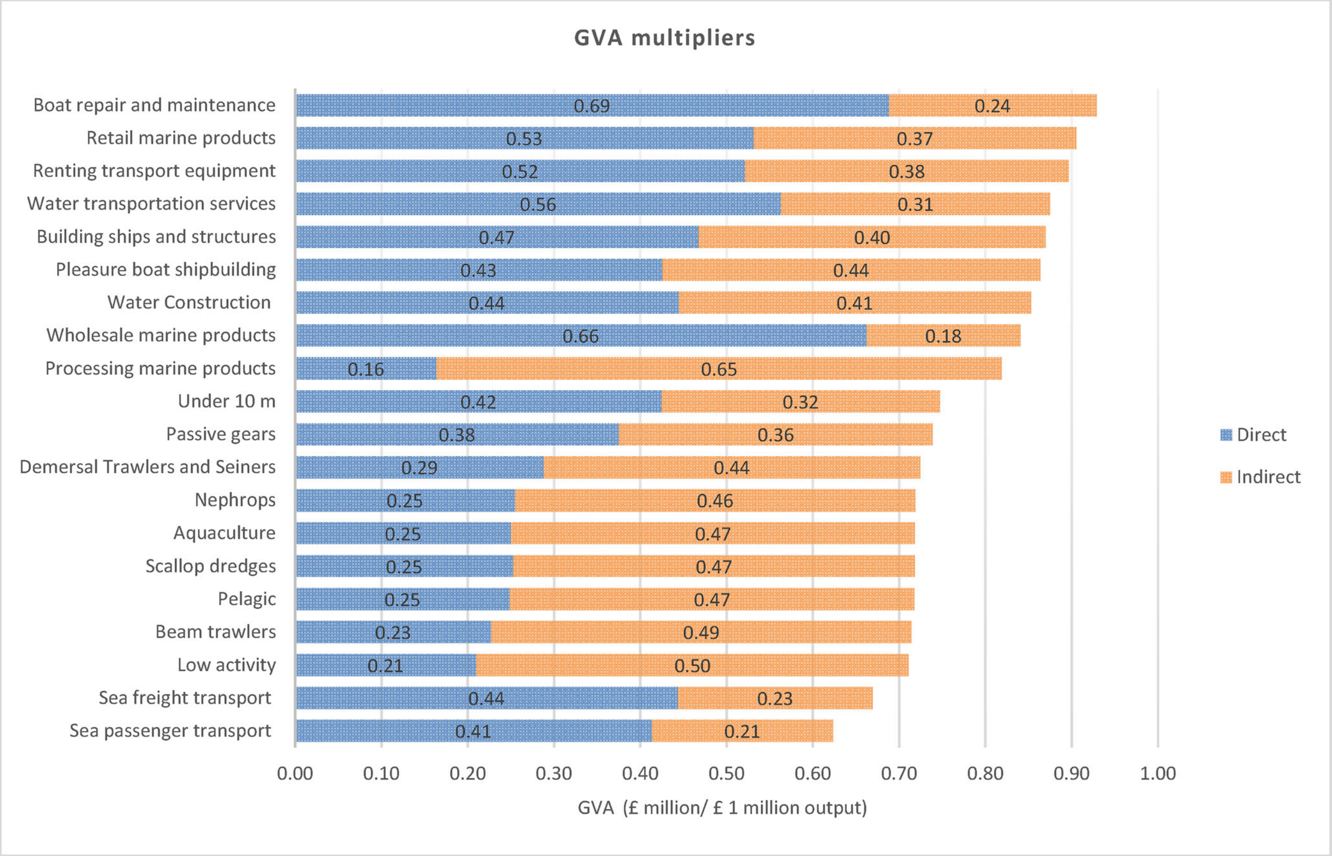

FIGURE 3 Gross value added (GVA) multipliers of marine-focussed sectors. Each sector's name appears on the *y*-axis, while GVA multipliers are shown from the lowest to the highest on the *x*-axis, measured in £ million.

Likewise, in the marine transport sector, almost two-thirds of the GVA is produced directly in each sector (£0.41 million in the passenger sector and £0.44 million in the freight sector), while only £0.21 and £0.23 million are generated indirectly from a total GVA effect of £0.62 and £0.67 million, respectively, per £1 million output. However, the processing sector is different. Only 20% (£0.16 million) of the total GVA effect of £0.81 million is created directly, while 80% (£0.65 million) is generated indirectly.

The employment multipliers in Figure 4 vary from ~30 workers per million of final demand to ~4 workers per million of final demand. The highest estimate is in the Low activity sector, which creates a total impact of 30 workers, from which around 23 workers are created directly and less than 8 indirectly, per a £1 million increase in demand. Similarly, the Nephrops sector follows closely with 27 workers, bringing about almost 20 workers directly, and the rest of the employment effects, over 7 workers, are indirectly fostered in other sectors. Although other sectors also show similar employment effects, processing is the only one that markedly implies higher indirect effects than indirect effects in terms of employment. It is observed from a total effect of 14.9 workers, less than 4 workers are given in this sector directly, while more than 11 of employment is generated in other sectors for each £ 1 million in output. In contrast, it is remarkable that a group of sectors ranked at the bottom (from the aquaculture to the marine transport sectors) are characterised for having the greatest employment impacts on the rest of the sector and scarcely direct effects on themselves. Among them, the principal exponent is the water construction sector, which generates more than 89% (around 6 workers) indirectly and less than one worker (0.072) directly of the total employment effect (6.77 workers).

According to the GHG multipliers presented in Figure 5, we can divide the sectors into two categories depending on their influence on direct and direct carbon emission intensities released per £ million increase in the final sector demand.

The first group, comprising the top-ranked Beam trawlers to the Scallop Dredges sectors at the 7th, has higher GHG direct impacts. The marine transport sector within this group is responsible for over 90% of GHG emissions, generating around 1.07 tonnes directly. However, the freight sector shows slightly higher indirect effects (0.12 tonnes) than the transport sector (0.11 tonnes). It is worth noting that the Beam trawlers and Nephrops sectors, which belong to this top-ranked group, have the highest direct impacts among the fishing fleet sectors, with 1.28 and 1.21 tonnes, respectively, of the total multiplier of 1.50 tonnes and 1.43 tonnes.

The second group includes those sectors that cause more indirect effects regarding GHG emissions. The sector group at the bottom (from water transportation services to renting transport equipment)

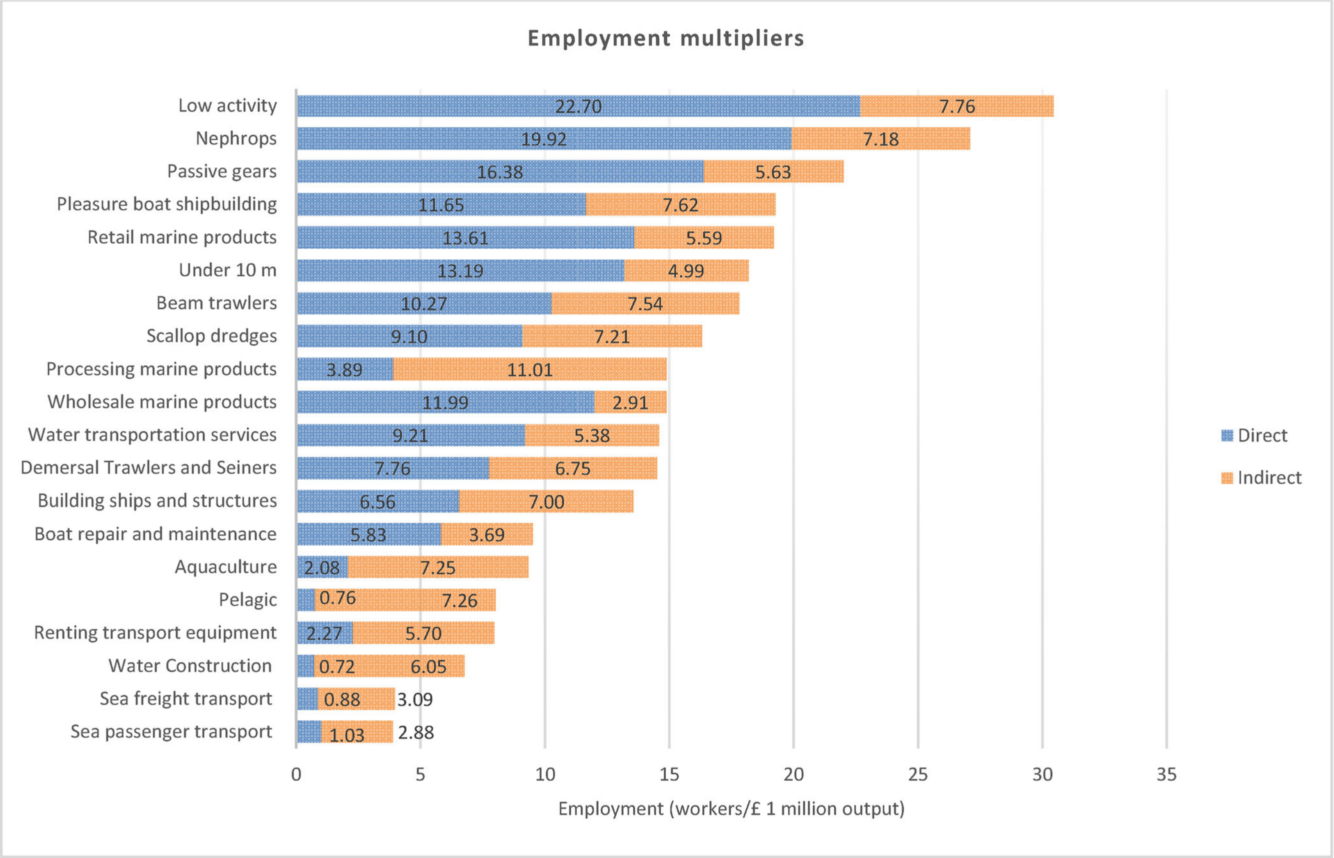

FIGURE 4 Employment multipliers of marine-focussed sectors. Each sector's name appears on the *y*-axis, while employment multipliers are shown from the lowest to the highest on the *x*-axis, measured in the number of workers.

shows the most significant direct impacts of GHG. Regarding them, the boat repair and maintenance sector stands out from the rest, indirectly causing over 91.5% of emissions (0.11 tonnes) in other sectors. The water transportation services sector is slightly behind, indirectly generating 80.7% of its emissions (0.15 tonnes) out of a total of 0.19 tonnes. Although not being in the most ranked sectors, the processing sector generates approximately 83.3% of its total GHG emissions (0.65 tonnes) in other sectors, representing 0.54 tonnes, while only 0.11 tonnes are caused directly (16.7%).

5.3 | Identifying conflicts in marine-Focussed sectors

To better understand potential conflicts between economic and environmental objectives, we plot GHG emission multipliers against GVA (Figure 6) and employment multipliers (Figure 7) for the marine focussed sectors only.

Figure 6 shows the relationship between GHG and GVA multipliers is strikingly linear. Higher GHG emissions per £ of final demand are strongly associated with lower GVA per £ final demand. Notably, the bottom right quadrant of the figure (low GHG and high GVA) is populated with manufacturing and service industries, while the top left (high GHG and low GVA) consists of 4 fleet segments and two transport sectors. This aligns with other work identifying primary resources sectors as environmentally intensive and low-value-added sectors (Clift et al., 2022).

Figure 7 shows a more dispersed relationship between the intensities of GHGs and employment across different sectors. The top left quadrant indicates high GHG and low employment intensity sectors. Sea transport-related sectors populate this, along with Beam Trawlers and Scallop Dredges. In the top right quadrant, we can see the Low activity and Nephrops sectors with high employment and GHG intensity. However, most sectors are in the bottom left, with low GHG and employment intensity.

6 | DISCUSSION AND POLICY RECOMMENDATIONS

This analysis focuses on 20 marine-focussed sectors in the UK economy. These sectors have a significant impact on the UK's economy, contributing £13,945 million and providing employment for 126,570 workers. It is worth noting that these sectors also have notable environmental implications, with a total GHG emissions of 15,721 tonnes. While the marine sectors are essential for the country's economic

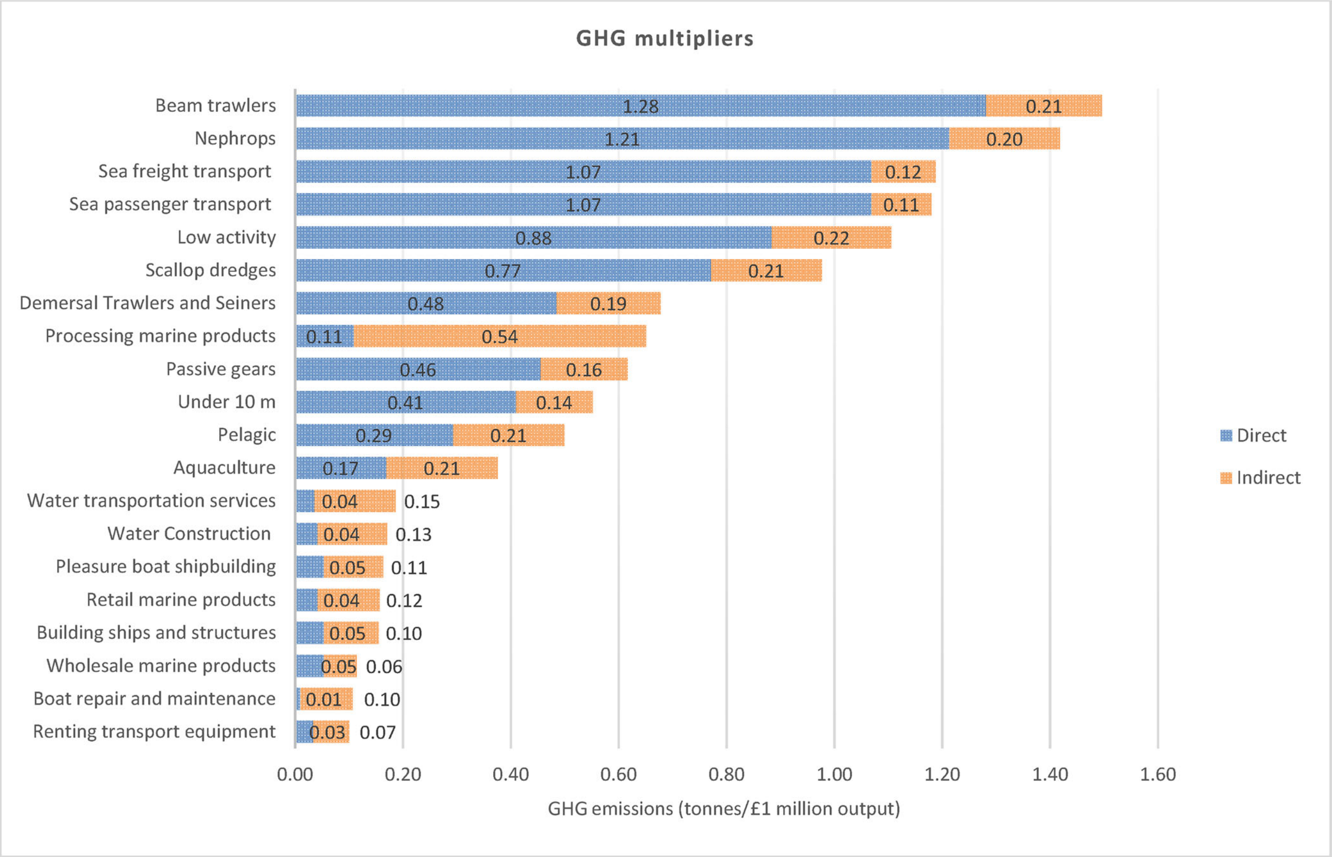

FIGURE 5 Greenhouse gas (GHG) multipliers of marine-focussed sectors. Each sector's name appears on the *y*-axis, while GHG multipliers are shown from the lowest to the highest on the *x*-axis, measured in tons.

development and livelihoods, it is crucial to reduce their carbon emissions, which currently account for 2.8% of the UK's total carbon emissions. One of the key elements in achieving sustainable development globally is to take measures to mitigate or reduce the impacts of climate change. To promote sustainability in marine areas, actions have been taken to reduce carbon emissions. One of the strategies that are being implemented is to reduce these emissions to net zero by 2050[2] (Department for Transport, 2019).

Our analysis shows that different marine sectors in the UK have different impacts on both the economy and the environment. As a result, opportunities to achieve environmental objectives and to manage environment-economy conflict can markedly vary, with different potential trade-offs between economic growth and environmental sustainability (Castro & Nielsen, 2003; Redpath et al., 2013). To tackle environmental concerns effectively, it is crucial to carefully consider how different sectors impact both the economy and the environment. Balancing economic growth and reducing carbon emissions can be challenging, as the two are positively correlated (Du et al., 2019). Consequently, several authors have proposed ‘degrowth’ as a potential solution (D'Alisa et al., 2015; Ertör & Hadjimichael, 2020; Martínez-Alier et al., 2010; Schneider et al., 2010). On both sides of the green growth and degrowth debate, there is a recognition that some sectors will have to grow and others shrink (e.g. Jackson, 2017; Pollin, 2019).

Based on our multiplier analysis, we can identify sectors with limited economic and livelihood benefits for their high GHG intensities. We suggest that these sectors could be the focus of further efforts to explore the feasibility of ‘degrowth’ strategies. Such strategies aim to reduce demand and shrink the sectors. Sectors here include Beam Trawlers, Scallop Dredges and transportation. The high GHG intensities, low GVA, and low employment intensities suggest that they may be good candidates for policies that aim to reduce consumption and shrink the sector. This may include proposals such as altering consumer behaviour (Xue, 2014), levying GHG emissions taxes (Kallis and March, 2014; Van Griethuysen, 2012), or capping GHG emissions (Martínez-Alier et al., 2010). These measures would affect the economic performance of the sectors, leading to impacts on prices, for instance. These potential knock-on effects would require further analysis.

Conversely, Nephrops and Low activity have high GHG intensities and low GVA intensities but high employment intensities. Consequently, our analysis points to the need for further work exploring the possibility of growth in terms of livelihoods. Decarbonising the marine economy would require focussing efforts to reduce the GHG intensity of these sectors through technological improvements to reduce their carbon footprint, such as adopting low-carbon fuels and less carbon-intensive technologies (The Secretary of State for Business, Energy & Industrial Strategy, 2021).

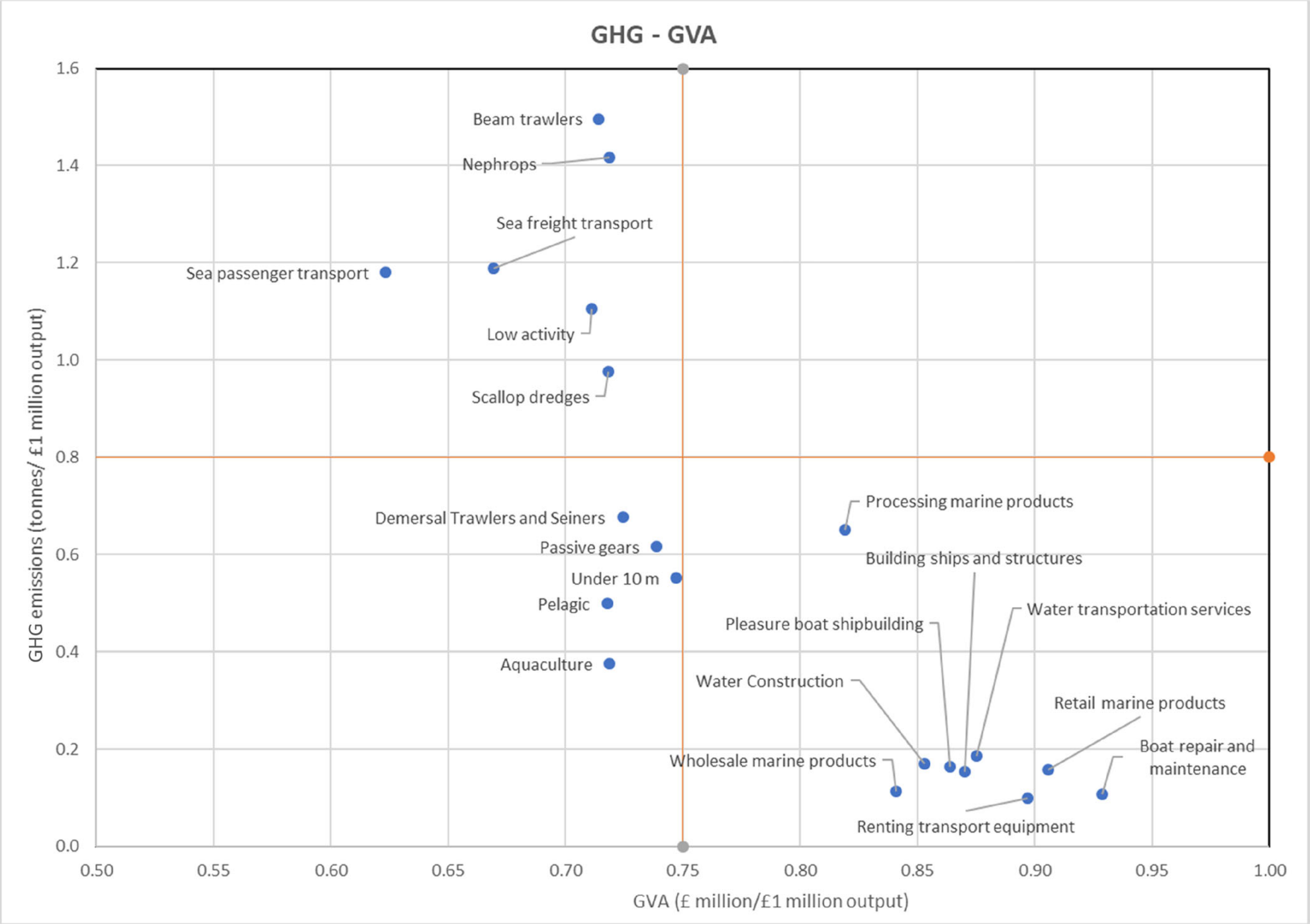

FIGURE 6 Greenhouse gas (GHG) and gross value added (GVA) multipliers of marine-focussed sectors. GVA multipliers are represented by values on the *x*-axis and are given in £ million. GHG multipliers are shown on the *y*-axis and are measured in tones.

Our analysis does not immediately point to a 'sweet spot' of good marine work of the type identified by Jackson (2017) in the more general UK economic context. In other words, there is only one marine-focussed sector with low GHG emissions and high employment: the passive gear sector. This is likely because the marine-focussed sectors are dominated by manufacturing and primary resource activities, while Jackon's sweet spot is composed primarily of service industries. One notable exception here is the presence of repair and maintenance sectors. These are typically thought to be high labour intensity and relatively low carbon and as such, are a key part of many circular economy proposals (Clift et al., 2022). However, in the UK Marine context, boat maintenance and repair (although low carbon) has relatively low labour intensity. Consequently, we suggest that the viability of servicisation as a strategy to green the UK marine economy is an open question.

Finally, it is worth highlighting that the transition to a net zero economy is expected to have a significant impact on employment in various sectors (Broome et al., 2022). The sectors we have highlighted as potential focuses for technological innovation (i.e. sectors that have high GHG emissions and employment rates but low GVA—such as Nephrops and low-activity industries)—may be particularly susceptible to transition effects. However, these sectors can be transformed to positively impact the economy by implementing policies that support job creation and wealth generation for workers. Encouraging workers to transition between related sectors can be an effective strategy, allowing them to reuse their skills and knowledge (Neffke & Henning, 2013). Such policies can be especially effective in regions where related sectors exist (Eriksson et al., 2016).

7 | CONCLUSIONS

In this study, we have investigated the potential conflicting interests that may arise in marine sectors when attempting to address economic, social and environmental objectives. Our analysis provided an in-depth overview of the tensions that must be considered when developing marine plans.

Specifically, we research the potential impact of prioritising carbon emission mitigation targets on marine-focussed sectors in the UK and their socio-economic implications. We constructed an Input–Output model to analyse 20 marine-focussed sectors, including eight fleet segments in the fishing industry. The results underscored the marine sectors' significant socioeconomic and environmental implications on the UK economy. Policymakers must consider each sector's

FIGURE 7 Greenhouse gas (GHG) and employment multipliers of marine-focussed sectors. Employment multipliers are represented by values on the *x*-axis and are given in the number of workers. GHG multipliers are shown on the *y*-axis and are measured in tones.

unique characteristics when creating marine policies to address GHG emissions.

It is noteworthy that some sectors offer the potential to reduce GHG emissions while also generating employment opportunities. This may help policymakers reconcile conflicting interests and align marine plans with the UK's objective of achieving net zero emissions by 2050 (Department for Transport, 2019). However, besides overcoming barriers to decarbonisation (Department for Transport, 2022), the transition towards decarbonisation will inevitably result in job displacement, particularly in sectors with high pollution levels or those that require skilled workers in low-carbon technologies. As such, policymakers must consider the impact of decarbonisation policies on workers as they implement these measures.

Certain sectors may not provide similar opportunities for expansion without causing significant environmental harm or providing minimal economic benefits in terms of employment or GVA. In such cases, demand-side policies or taxes linked to production or emissions may be viable alternatives to reduce GHG emissions. The results of this study can also serve as a benchmark to evaluate how specific sectors adapt to specific marine policies within a regional context.

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CONFLICT OF INTEREST STATEMENT

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ENDNOTES

[1] Final demand is made up of final consumption expenditure by government, households, and non-profits serving households, gross fixed capital formation, changes in inventories, exports of goods.

[2] The government's net zero 2050 target covers all sectors of the UK economy. Where sectors are unable to achieve full decarbonisation by 2050, GHG removals will be required to compensate for the residual emissions that remain (Department for Transport, 2022).

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SUPPORTING INFORMATION

Additional supporting information can be found online in the Supporting Information section at the end of this article.

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