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Supply chain effects of China's fast growing marine economy on greenhouse gas emissions

Man Li[1], Kuishuang Feng[1,2,*], Heran Zheng[3], Chen Pan[4], Jing Meng[5], Jiashuo Li[1], Dabo Guan[6] and Yuan Li[1,*]

[1] Institute of Blue and Green Development, Weihai Institute of Interdisciplinary Research, Shandong University, Weihai 264209, People's Republic of China
[2] Department of Geographical Sciences, University of Maryland, College Park, MD 20742, United States of America
[3] Industrial Ecology Programme, Department of Energy and Process Technology, Norwegian University of Science and Technology, Trondheim 7010, Norway
[4] School of Public Policy and Management, Tsinghua University, Beijing 100084
[5] The Bartlett School of Construction and Project Management, University College London, London WC1E 7HB, United Kingdom
[6] Department of Earth System Science, Tsinghua University, Beijing 100084, People's Republic of China
[*] Authors to whom any correspondence should be addressed.

E-mail: fengkuishuang@gmail.com **and** liyuancolour@gmail.com

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Abstract

The marine economic activities has become a vital economic driving force for development of China's economy. However, the trajectory of greenhouse gas (i.e. GHG) emissions associated the fast growing marine economy and its role in emission mitigation remain unclear. Through compiling high-resolution and time-series environmental input–output tables for 2002, 2007, 2012 and 2017, this study quantify development of 13 key marine industries in driving national economic development and its supply chains, and assesses the direct and indirect contributions of marine industries to the national economy and GHGs emissions. Our results show that the total emissions of marine economy increased by 2.3 times from 2002 to 2017, and the share of that in national total emissions increased by 43.3%. The economic output of marine economy may lead to up to 1.8 times of the total economic output in the upstream industries, while the indirect emissions of major marine economy embodied in the upstream supply chains is on average 3.5 times of direct emissions from marine industries. Our findings highlight the necessity of considering total supply chain GHGs emissions associated with the fast growing marine economy to better achieve China's climate mitigation targets.

1. Introduction

China is a vital player in global production, consumption, and trade of maritime products. The global marine economy, measured according to marine-based industries' contribution to economic output and employment, is substantial (OECD: Organisation for Economic Co-Operation and Development 2017). For example, China is the leading aquaculture and ship producer in the world, accounting for 58% (Brodie Rudolph *et al* 2020) and 40.07% (UNCTAD STAT 2020) of the global total seafood and ship production in 2018, respectively. Since the beginning of the 21st century, developing marine economy (or 'ocean economy') has become a critical part of national strategies in most coastal countries, and China is no exception (Jiang *et al* 2014, He *et al* 2015, OECD: Organisation for Economic Co-Operation and Development 2017, To and Lee 2018). China has approximately 14 500 km coastline, ranking the 11th in the world (WorldAtlas 2020). In 2018, China's marine GDP reached 8.3 trillion yuan, accounting for 9.3% of the national GDP (Department of Marine Strategic Planning and Economics, Ministry of Natural Resources 2007), close to Australia's GDP in the same year (8.8 trillion). Under the guidance of the Buliding Maritime Superpower strategy (Hu 2012, Xi 2017), the Chinese government plans to futher unlock growth potential of marine economy through implementing supply-side structural reforms, and aims to take it as a new power horse of future economic development (National Development and Reform Commission, and State Oceanic Administration 2017). Therefore, China's marine economy will play a more vital role in the future of national economic development (text S1 and figure S1 (available online at stacks.iop.org/ERL/16/054061/mmedia)).

The United Nations (UN) (United Nations Conference on Trade and Development 2014) and the World Bank (2017) have recently proposed the concept of 'Blue Economy' successively, advocating for the sustainability of marine economic growth (Fenichel *et al* 2020). It has been also proved that blue economy and UN's sustainable development goals are highly interdependent (Lee *et al* 2020). Thus developing low-carbon marine economy (Johnson *et al* 2018, OECD: Organisation for Economic Co-Operation and Development 2019, Unit 2016) is internal requirements for sustainable development of marine economy.

Meanwhile, it is worth noting that the 'Blue acceleration'(Jean-Baptiste Jouffray *et al* 2019) is already faced growing challenges and pressures for having major climate consequences as marine economic activities are accompanied by a large amount of greenhouse gas (i.e. GHG) emissions (Corbett 2003, Johansson *et al* 2017, Mohan 2018, Parker *et al* 2018). Previous studies have focused on reducing emissions in the traditional energy sectors. However, marine industries, such as marine oil and gas exploitation and processing industry, marine fishery, marine transportation and tourism, are energy intensive industries in particular when taking account their supply chain effects. To achieve the overall national emission migration targets, it is necessary to explore the potential contribution of marine sectors to climate change. Some existing studies have focused on emissions caused by marine industries themselves, such as ocean shipping (Corbett 2003, Bouman *et al* 2017) and fisheries (Parker *et al* 2018), but the supply chain effects of the marine industries have been largely ignored.

In addition to the direct impact on GHG emission, marine industries can also cause GHG emissions of their upstream suppliers via inter-sectoral linkages (Liu *et al* 2018, Yuan *et al* 2018). In fact, the marine economy and the inland economy are interdependent and mutually reinforcing (Yin *et al* 2018, Schlüter *et al* 2020). But the economic and environmental supply chain effects of China's marine economy is rarely studied. Assessing the total effects of China's marine economy on GHG emissions from the perspective of supply chain could greatly benefit low carbon development and sustainable supply chain management of China's marine economy.

Environmentally extended input–output (IO) analysis (Leontief 1970, Hawkins *et al* 2015) is a popular tool that captures the whole supply chain effects of a sector or product and thus lay a good foundation for accounting for total GHGs emissions (Fei and Lin 2017, Ma *et al* 2019). Because the sectors in the aggregate (IO) table will lose some detailed information of the marine industries (that is 'aggregation deviation problem'), it is superior to disaggregate maritime sectors from the IO table to improve the accuracy of the modeling results (Kymn 1990, Lindner *et al*). Several efforts have been made to develop marine economic IO model (MEIO model) and accounts for marine economy and related activities over the past decades at national level (Kwak *et al* 2005, Morrissey and O'Donoghue 2013, Lee and Yoo 2014, Wang and Wang 2019), regional level (Hoagland *et al* 2005), as well as provincial level (Chiu and Lin 2012). Unfortunately, there are several challenges of employing MEIO model on the environmental impacts of blue ocean economy due to the constraints of data availability (Song *et al* 2013). Specifically, most IO tables do not distinguish detailed sub-marine sectors. Moreover, no consistent IO tables cover for long time period. Thus, there is a urgent need to compile and develop high-resolution, long-term coverage, and comparable list of China's marine economic IO tables, which may be used to systematically evaluate GHGs emissions from each marine industry.

To fill this gap, this study aims to assess direct and supply chain effects of marine economic development and associated GHGs emissions embodied in the marine economy by building up relatively complete MEIO model. Here, we first disaggregate 13 marine sectors from national industries to construct consistent and detailed MIOTs for the years 2002, 2007, 2012 and 2017. Second, environmentally extended MIOTs coupling six major GHGs are developed to compute different emission coefficients. Third, by employing linkage (including forward and backward), multiplier and environmental related theories, we analyze the linkages between each marine industry and other non-marine economic sectors, and then assess total GHGs emissions. Last, we discuss the policy implications about low carbon development of marine economy.

2. Methods and data

2.1. Building China National marine IO table (MIOT)

China's marine and marine-related industries include three parts (text S2): (a) major marine industries; (b) marine scientific research, education and management services industries; and (c) marine related industries. Due to the large differences in the production structure of different marine industries, it is important to disaggregate them from the IO table.

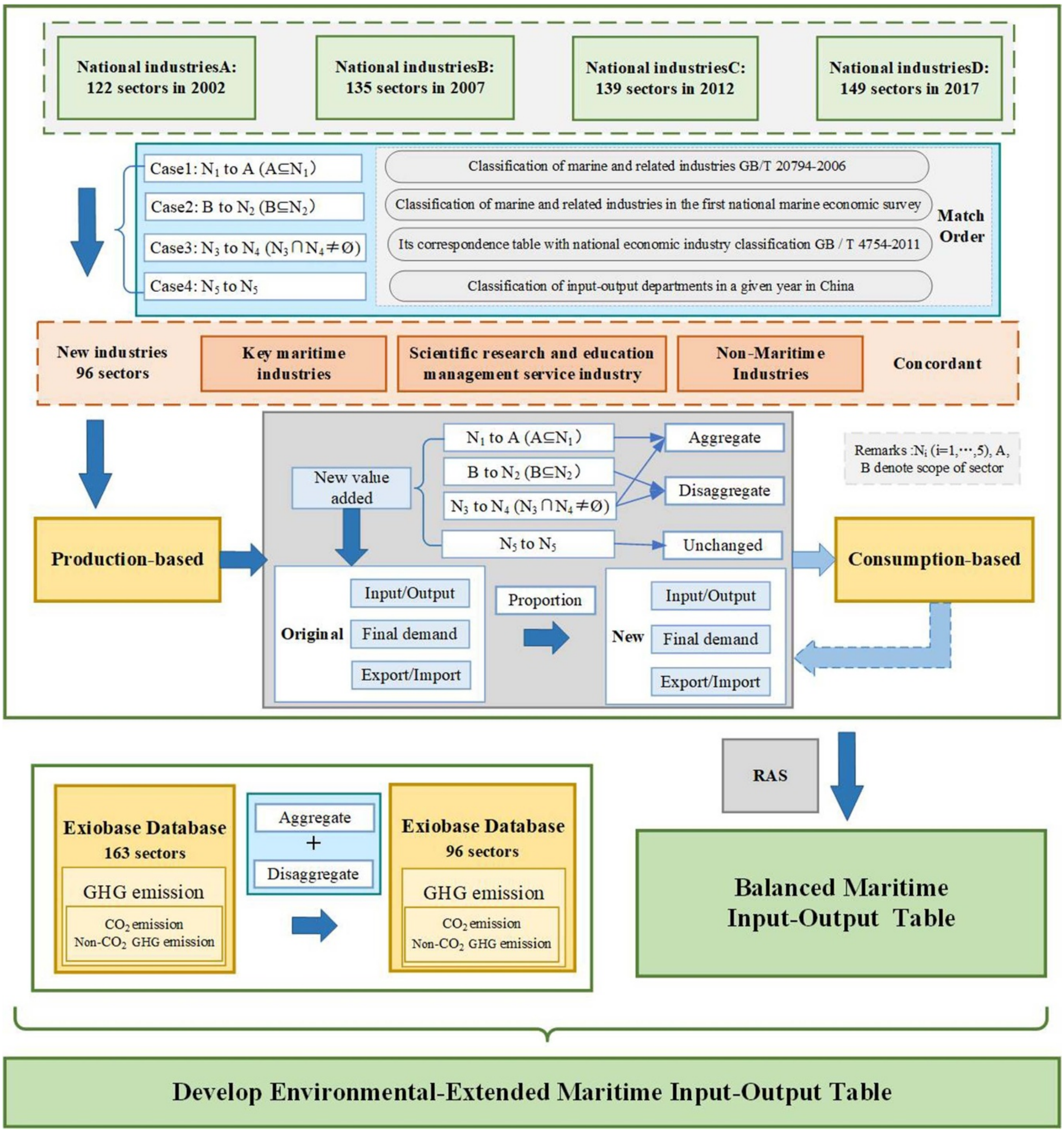

Figure 1. Schematic example of disaggregating marine sectors from national IOT.

2.1.1. Matching sectors in IOTs

In this study, we use IO tables that are collected every 5 years from 2002 to 2017. And then, sectors in the four national IOTs are aggregated into the same resolution according to their classification. As all IOTs are sufficiently detail, the final consistent IOTs are in 96 sectors (method S1 and table S1).

2.1.2. Disaggregating 13 marine sectors from consistent national IOTs

There are differences between environmental account with 163 sectors from the EXIOBASE database and the unified national IOTs with 96 sectors. To unify the data, we aggregate GHGs emissions from EXIOBASE into 96 sectors to match with the sectors in the unified national IOTs (see detailed methods in method S2).

The input and ouput information as well as GHGs emissions of 13 marine sectors are disaggregated from the China's national IO tables (method S3, figure S2), and 109-sectors China MIOTs nested with six types of GHGs emissions inventories (table S2) are constructed (Lenzen 2011, Lindner *et al* 2013b) (figure 1). The contructed MIOT show the amount of flow between marine and non-marine sectors and the GHGs emission accounts. Methodological limitations are illustrated in text S3.

2.1.3. Balancing MIOTs

MIOTs are equilibrium in principle. However, for caution's sake, the RAS approach is used to balance and revise MIOTs until it reaches the final equilibrium (Toh 1998).

2.2. Inter-sectoral linkages

2.2.1. Inter-sectoral linkages of industries' output

To assess the interdependency of marine sectors and other economic sectors, we apply backward and forward linkages and the corresponding coefficients of variation from both the demand side and supply side based on Leontief input–output model and Ghosh IO model. The measurement (San Cristóbal and Biezma 2006, Miller and Blair 2009, Harada 2015, Freytag and Fricke 2017) of them can be expressed as follows.

Firstly, we calculate the direct backward linkages and forward linkages which estimates the direct links between all marine industries and non-marine sectors.

$$\underset{j=\{1,\ldots,13\}}{\mathrm{BL}(d)_j} = \sum_{i=1}^{n} \underset{\substack{i=\{1,\ldots,n\}\\ j=\{1,\ldots,n\}}}{a_{ij}} \quad \text{with}$$
$$\boldsymbol{A} = \left[a_{ij}\right],\ \boldsymbol{A} = \boldsymbol{Z}\hat{\boldsymbol{x}}^{-1}, \tag{1}$$

$$\underset{i=\{1,\ldots,13\}}{\mathrm{FL}(d)_i} = \sum_{j=1}^{n} \underset{\substack{i=\{1,\ldots,n\}\\ j=\{1,\ldots,n\}}}{b_{ij}} \quad \text{with}$$
$$\boldsymbol{B} = \left[b_{ij}\right],\ \boldsymbol{B} = \hat{\boldsymbol{x}}^{-1}\boldsymbol{Z} \tag{2}$$

where the $\boldsymbol{Z}$ terms represent interindustry or intermediate sales matrix, $\boldsymbol{x}$ terms denotes output vector. $\boldsymbol{A}$ and $\boldsymbol{B}$ express direct-input coefficients matrix (or direct technical coefficient matrix) and direct-output coefficients matrix (or direct distribution coefficient matrix) of MIOT, respectively. n is 109. $\underset{j=\{1,\ldots,13\}}{\mathrm{BL}(d)_j}$ denotes direct backward linkages, representing marine industries are interrelated with their related industries and thus have a demand-pulling influence from input perspective. Specifically, the marine industries have a direct or indirect correlation mechanism to those industries or departments that supply them with production factors (services or products), and takes this as intermediate consumption of marine industries. $\underset{i=\{1,\ldots,13\}}{\mathrm{FL}(d)_i}$ is direct backward linkages, representing marine industries are interrelated with their related industries and thus have a supply-pulling influence from output perspective. Specifically, the marine industries has a connection mechanism with those industries that have direct or indirect demand for products of these industries, and takes this as intermediate input of marine industries.

Secondly, taking into account the integrated linkages between all sectors, total (output multiplier) backward linkages and forward linkages of marine industries can be shown as:

$$\underset{j=\{1,\ldots,13\}}{\mathrm{BL}(t)_j} = \sum_{i=1}^{n} \underset{\substack{i=\{1,\ldots,n\}\\ j=\{1,\ldots,n\}}}{l_{ij}} \quad \text{with}$$
$$\boldsymbol{L} = \left[l_{ij}\right],\ \boldsymbol{L} = (\mathbf{I}-\boldsymbol{A})^{-1} \tag{3}$$

$$\underset{i=\{1,\ldots,13\}}{\mathrm{FL}(t)_i} = \sum_{j=1}^{n} \underset{\substack{i=\{1,\ldots,n\}\\ j=\{1,\ldots,n\}}}{g_{ij}} \quad \text{with}$$
$$\boldsymbol{G} = \left[g_{ij}\right],\ \boldsymbol{G} = (\mathbf{I}-\boldsymbol{B})^{-1} \tag{4}$$

where matrix $\boldsymbol{L}$ is generally called the *Leontief inverse* matrix or the total demand coefficient matrix of MIOT. l_{ij} is the total consumption coefficient between sector i and sector j, showing the sum of the direct input of the sector products corresponding to the total output of the unit in the jth sector and the indirect input of the sector products corresponding to the industrial association with other sectors. The matrix $\boldsymbol{G}$ is Ghosh inverse or t*otal supply coefficient* matrix of MIOT (Ghosh 1958). g_{ij} is the *total distribution coefficient* between sector i and sector j, showing the amount directly and indirectly allocated to the corresponding sector in the total output of the ith sector, including the amount directly allocated to the corresponding sector in the total output of the unit sector as well as the amount indirectly allocated to the corresponding sector through inter-sector association. $\boldsymbol{I}$ represents identity matrix, $\boldsymbol{L}$-$\boldsymbol{I}$ is total consumption coefficient, and $\boldsymbol{G}$-$\boldsymbol{I}$ is total distribution coefficient.

Thirdly, here is total normalized backward linkages and forward linkages indexes. They respectively represent the driving force to upstream industries and the pushing force to downstream industries per unit of output.

$$\underset{j=\{1,\ldots,13\}}{\overline{\mathrm{BL}(t)_j}} = \frac{\sum_{i=1}^{n} \underset{\substack{i=\{1,\ldots,n\}\\ j=\{1,\ldots,n\}}}{l_{ij}}}{\left(\frac{1}{n}\right)\cdot \sum_{j=1}^{n}\sum_{i=1}^{n} \underset{\substack{i=\{1,\ldots,n\}\\ j=\{1,\ldots,n\}}}{l_{ij}}} \tag{5}$$

$$\underset{i=\{1,\ldots,13\}}{\overline{\mathrm{FL}(t)_i}} = \frac{\sum_{j=1}^{n} \underset{\substack{i=\{1,\ldots,n\}\\ j=\{1,\ldots,n\}}}{g_{ij}}}{\left(\frac{1}{n}\right)\cdot \sum_{i=1}^{n}\sum_{j=1}^{n} \underset{\substack{i=\{1,\ldots,n\}\\ j=\{1,\ldots,n\}}}{g_{ij}}} \tag{6}$$

where $\underset{j=\{1,\ldots,13\}}{\overline{\mathrm{BL}(t)_j}}$ is backward linkages or the power of dispersion, representing the extent to which the production demand for various sectors of the national economy is affected by the addition of a unit of final product in marine sector j. $\underset{i=\{1,\cdots,13\}}{\overline{\mathrm{FL}(t)_i}}$ is forward linkages or the sensitivity of dispersion, representing outputs provided by marine sector i for the production of other sectors when all sectors of the national economy add one unit of final product.

Here, our calculation sectoral linkages include the interactions between among the 13 key marine industries as well as the between marine and non-marine sectors. The direct linkages include all purchases of the 13 key marine industries from marine and non-marine sectors and the sales of the 13 key marine industries to marine and non-marine sectors (captured by equations (1) and (2)). This is the same for total backward and forward linkages as we used the entire A matrix for the multiplier calculation.

The upstream non-marine economic sectors refer to the upstream suppliers of one marine industry. The upstream suppliers include the direct suppliers of the studied marine industry and the suppliers of the suppliers for the studied marine industry. Similarly, the upstream supply chains also means upstream suppliers of the marine industries. For example, to produce one dollar of seafood, marine fishery industry needs to purchase input products, such as aquatic feed, petroleum products, electricity, machinery and equipment and many other products, from its suppliers, and these suppliers also need to purchase products from their suppliers. All of these suppliers are the upstream industries of the studied marine industries. The output of the marine industries may lead to economic outputs of their upstream suppliers and associated carbon emissions from their upstream suppliers.

We use environmentally extended IO model to capture the effects of marine industries on their upstream suppliers' production and associated environmental impacts. A standard IO framework shows the inter-sectoral flows among all industries in the entire economy and by introducing the Leontief inverse, we are able to estimate the total impacts of the marine industries on their upstream industries (Miller and Blair 2009). Therefore, the marine industries and non-marine sectors are inter-dependent on each other and change in marine industries would ultimately impact on the output of the sectors along its upstream supply chain.

2.2.2. Inter-sectoral linkages of industries' GHGs emissions

$$\underset{j=\{1,\ldots,13\}}{\mathrm{BL}\,(t)_j^E} = \sum_{i=1}^{n}\Big(\mathrm{CoefGHG_j}\cdot \underset{\substack{i=\{1,\ldots,n\}\\ j=\{1,\ldots,n\}}}{l_{ij}}\Big) \text{ with}$$

$$\boldsymbol{L}=\left[l_{ij}\right],\ \boldsymbol{L}=(\mathbf{I}-\boldsymbol{A})^{-1} \tag{7}$$

$$\underset{i=\{1,\ldots,13\}}{\mathrm{FL}\,(t)_i^E} = \sum_{j=1}^{n}\left(\mathrm{CoefGHG_j}\cdot \underset{\substack{i=\{1,\ldots,n\}\\ j=\{1,\ldots,n\}}}{g_{ij}}\right) \text{ with}$$

$$\boldsymbol{G}=\left[g_{ij}\right],\ \boldsymbol{G}=(\mathbf{I}-\boldsymbol{B})^{-1} \tag{8}$$

$$\overline{\underset{j=\{1,\ldots,13\}}{\mathrm{BL}\,(t)_j^E}} = \frac{\sum_{i=1}^{n}\left(\mathrm{CoefGHG}_j\cdot \underset{\substack{i=\{1,\ldots,n\}\\ j=\{1,\ldots,n\}}}{l_{ij}}\right)}{\left(\frac{1}{n}\right)\cdot\sum_{j=1}^{n}\sum_{i=1}^{n}\left(\mathrm{CoefGHG}_j\cdot \underset{\substack{i=\{1,\ldots,n\}\\ j=\{1,\ldots,n\}}}{l_{ij}}\right)} \tag{9}$$

$$\overline{\underset{i=\{1,\ldots,13\}}{\mathrm{FL}\,(t)_i^E}} = \frac{\sum_{j=1}^{n}\left(\mathrm{CoefGHG}_j\cdot \underset{\substack{i=\{1,\ldots,n\}\\ j=\{1,\cdots,n\}}}{g_{ij}}\right)}{\left(\frac{1}{n}\right)\cdot\sum_{i=1}^{n}\sum_{j=1}^{n}\left(\mathrm{CoefGHG}_j\cdot \underset{\substack{i=\{1,\ldots,n\}\\ j=\{1,\ldots,n\}}}{g_{ij}}\right)} \tag{10}$$

where $\mathrm{CoefGHG}_j$ is the direct impact coefficient matrix of GHG j emission, reflecting the fixed parameter of the intensity of GHG emission produced by all sectors. Compared with formulas (3)–(6), the only difference between formulas (7)–(10) and formulas (3)–(6) is that they represent the relationship between industries' GHGs emissions rather than economic output. Backward linkages, in terms of GHGs emissions, represents the capacity of maritime sector j to influence GHGs emissions in sectors providing direct or indirect inputs to maritime sector j. Forward linkage, in terms of GHGs emissions, represents the capacity of maritime sector i to stimulate the production of other sectors, and thus the emissions of GHGs.

2.3. Total output and total emissions related to marine industries

$$\begin{bmatrix}\boldsymbol{x}_{\text{marine}}\\ \boldsymbol{x}_{\text{non-marine}}\end{bmatrix} = \boldsymbol{A}\cdot\begin{bmatrix}\boldsymbol{x}_{\text{marine}}\\ \boldsymbol{x}_{\text{non-marine}}\end{bmatrix} + \begin{bmatrix}\boldsymbol{Y}_{\text{marine}}\\ \boldsymbol{Y}_{\text{non-marine}}\end{bmatrix},$$

$$\boldsymbol{A}=\begin{bmatrix}\boldsymbol{A}_{ii}\ \boldsymbol{A}_{ij}\\ \boldsymbol{A}_{ji}\ \boldsymbol{A}_{jj}\end{bmatrix} \tag{11}$$

where $\boldsymbol{x}_{\text{marine}}$ and $\boldsymbol{x}_{\text{non-marine}}$ represent total output of marine sectors and non-marine sectors (the same below), respectively. i and j represent non-marine sectors and marine sectors (the same below), respectively. $\boldsymbol{Y}$ is final demand.

The total output related to output of each marine industry can be expressed as follows:

$$\begin{bmatrix} \boldsymbol{x}^{\text{Total}}_{\text{marine}} \\ \boldsymbol{x}^{\text{Total}}_{\text{nonmarine}} \end{bmatrix} = \sum_{n}^{i=1} \left[(\mathbf{I} - \boldsymbol{A})^{-1} * \begin{bmatrix} \widehat{\boldsymbol{x}_{\text{marine}q,1}} \\ o_{p,1} \end{bmatrix} \right]_{m \times n}, \tag{12}$$

Where m and n are both the number of all industries. p and q are the number of non-marine sectors and the number of marine industrues, respectively (the same below).

The proportion of total output related to output of each marine industry in national economy can be expressed as follows:

$$\text{Proportion } \boldsymbol{x}^{\text{Total}}_{\text{marine}} = \boldsymbol{x}^{\text{Total}}_{\text{marine}} / \left(\sum_{i=1}^{p} x_p + \sum_{i=1}^{q} x_q \right). \tag{13}$$

The total emission of GHG j from each marine industry can be expressed as follows:

$$\text{GHG}_{\text{emission},j} = \sum_{j=1}^{n} \left[\text{coef}GHG_j \cdot (\mathbf{I} - \boldsymbol{A})^{-1} \cdot \begin{bmatrix} \widehat{\boldsymbol{x}_{marineq,1}} \\ \boldsymbol{o}_{p,1} \end{bmatrix} \right]_{m \times n}. \tag{14}$$

The proportion of total emissions of GHG j from each marine industry is expressed as follows:

$$\text{Proportion GHG}_j = \text{GHG}_j / \left(\sum_{r=1}^{p} \text{GHG}_r + \sum_{s=1}^{q} \text{GHG}_s \right). \tag{15}$$

2.4. Data sources

This study required two types of data: the IO table and GHG emission data for China. The national IO table for 2002, 2007, 2012 and 2017 were downloaded from the website of the National Bureau of Statistics of China (National Economic Accounting Department of the National Bureau of Statistics 2006, 2010, 2015, 2019). Marine economic data was obtained from China Marine Statistical Yearbook (State Oceanic Administration of China 2004, 2009, 2014) and China Marine Economic Statistics Bulletin (Department of Marine Strategic Planning and Economics, Ministry of Natural Resources 2007, 2008, 2013, 2018, 2019), including output data and value-added data of each marine sector.

GHG emissions of 96 national economic sectors are calculated based on existing environmental account. The environmental account used for creating the extensions of IO table shall be collected at the highest resolution practicable (De Koning *et al* 2015). As MRIO databases are being fueled by increasingly more detailed data (Bjelle *et al* 2020), it can offer high quality information about IO table. The EXIOBASE database stands out as one of the most popular Environmentally extended multi-regional IO (EE-MRIO) databases. (a) It is compatible with multiple environmental satellite accounts (Tukker and Dietzenbacher 2013, Merciai and Schmidt 2018, Stadler *et al* 2018, Wood *et al* 2018). In our study, environmental emissions include six major GHGs (i.e. CO_2, CH_4, N_2O, SF_6, HFC, PFC). (b) Different types of GHGs emissions come from different sources (CO_2: combustion, non-combustion, agriculture, waste; CH_4: combustion, non-combustion, agriculture, waste; N_2O: combustion, agriculture; SF_6: air; HFC air; PFC air). Such detailed emission inventories may effectively improve the accuracy of the estimates. (c) Compared with other global-scale databases such as GTAP, GRAM, Eora and WIOD, EXIOBASE's environmental and economic activities data is the most sectorial detailed with widely pollutants spectrum, thus increasing data accuracy in the process of constructing OIOTs. The updated EXIOBASE3 was released in 2019 with open access (Stadler *et al* 2018). All GHG emissions are converted to CO_2 equivalence using 20 year time span Global Warming Potential values.

3. Results

3.1. Inter-industrial linkage analysis between marine and non-marine industries

The marine industries and non-marine sectors are largely inter-linked through economics flows. A detailed listing of the results on mutual economic interconnectedness between marine sectors and other non-marine sectors is shown in figure 2. The backward linkages show how a sector's output change impact on the outputs of the sector's upstream supplying industries (the pulling power), while the forward linkages show that a sector supply inputs to other sectors through the entire economy (the pushing power). The normalized backward linkages illustrate how a one unit rise in output influences a sector's suppliers, while the normalized forward linkages quantify the extent to which sectors supply inputs to other sectors throughout the whole economy (Yu *et al* 2010). If the normalized backward linkage is greater than 1, it denotes that one unit change in output of one sector, will result in an above-average increase in the output of all sectors in the entire economy. In contrast, if the normalized forward linkage is greater than 1, a unit change in all sectors' output will lead to an above-average increase in the output of that sector. These sectors with the backward and forward linkage indexes greater than 1 are key sectors in terms of output through the whole supply chain.

As illustrated in figure 2, marine industries generally show the high interdependency with other national economic sectors. Among them, the forward economic linkages (FL for short, the same below)

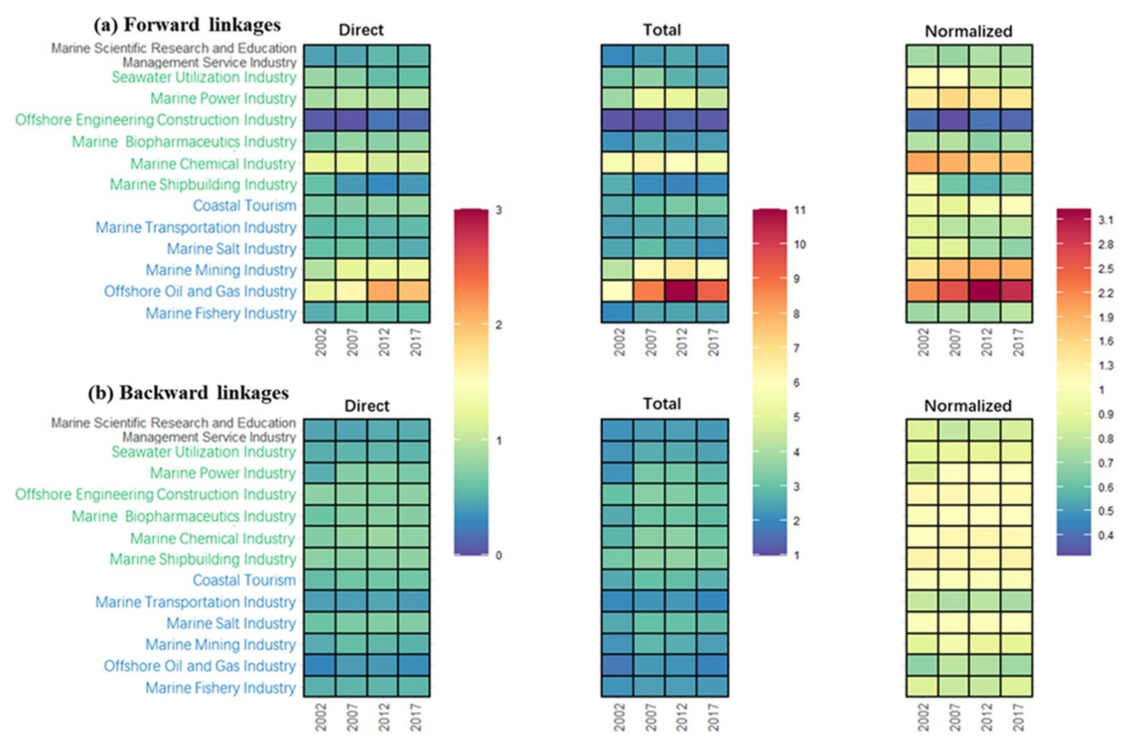

Figure 2. Backward linkages and forward linkages of marine industries in 2002, 2007, 2012 and 2017. Note: lables with blue color correspond to traditional marine sectors, while lables with green color correspond to emerging marine sectors (the same below).

changed over time but backward linages remained almost no change, which indicates that the pushing power of marine industries is getting stronger but the pulling power remains stable.Moreover, traditional marine sectors have strong forward linkages. Specifically, the forward economic linkage of offshore oil and gas industry ranks top, followed by marine chemical industry, and then marine mining industry, which indicates that these marine industries have more pushing effect. Coastal tourism involves many industries such as tourism, catering, entertainment and leisure, real estate development, etc, and thus has a strong industrial driving force. The coastal tourism industry has become one of the leading sectors since 2017. In emerging industries, only marine power industry and marine chemical industry dependent on interindustry demand obviously and perform a relatively strong pushing effect. Seawater utilization industry have high sensitivity of dispersion only in 2002 and 2007. The increase in this sector's production would stimulate other sectors.

The backward economic linkages (BL for short, the same below) of marine shipbuilding industry ranks top with BL index of 1.267 in 2017, followed by marine salt industry, coastal tourism industry, marine chemical industry, marine biopharmaceutics industry and offshore engineering construction industry with little difference in the index. Futhermore, both BL and FL of marine chemical industry and marine power industry are large than 1, which indicates that they have a high degree of agglomeration and a high degree of integration in the industrial chain, thus they are classified as key sectors. Since 2017, the coastal tourism industry, as one of the emerging industries, has also become a key sector. These industries highly depend on interindustry supply. They had generally increased their connection with other sectors and started playing critical roles in national economic development by boosting other related industries.

Figure 3 shows there is a strong pulling effect of marine economy in GHG emissions. The offshore oil and gas industry and marine mining industry in traditional industries, as well as marine biopharmaceutics industry in emerging industries have strong backward and forward linkages with both linkage indices larger than 1, thus these industries are key sectors for GHG emissions. In terms of CO_2 emissions, sectors shows similar linkage effects as GHG emissions. While there are a big variation for non-CO_2 GHG emissions.

The GHGs emission FL and BL indices of several marine industries are greater than their economic linakges. This denotes that these marine sectors play a stronger role in driving and promoting GHG emissions in other sectors than that their impacts on the economy. In particular, the marine biopharmaceutics industry, marine mining industry and offshore oil and gas industry show weak linkage in economy and strong correlation in emission. While the economic linkages of marine transportation industry, marine chemical industry, offshore engineering construction industry, marine power industry, seawater utilization industry, marine scientific research and education

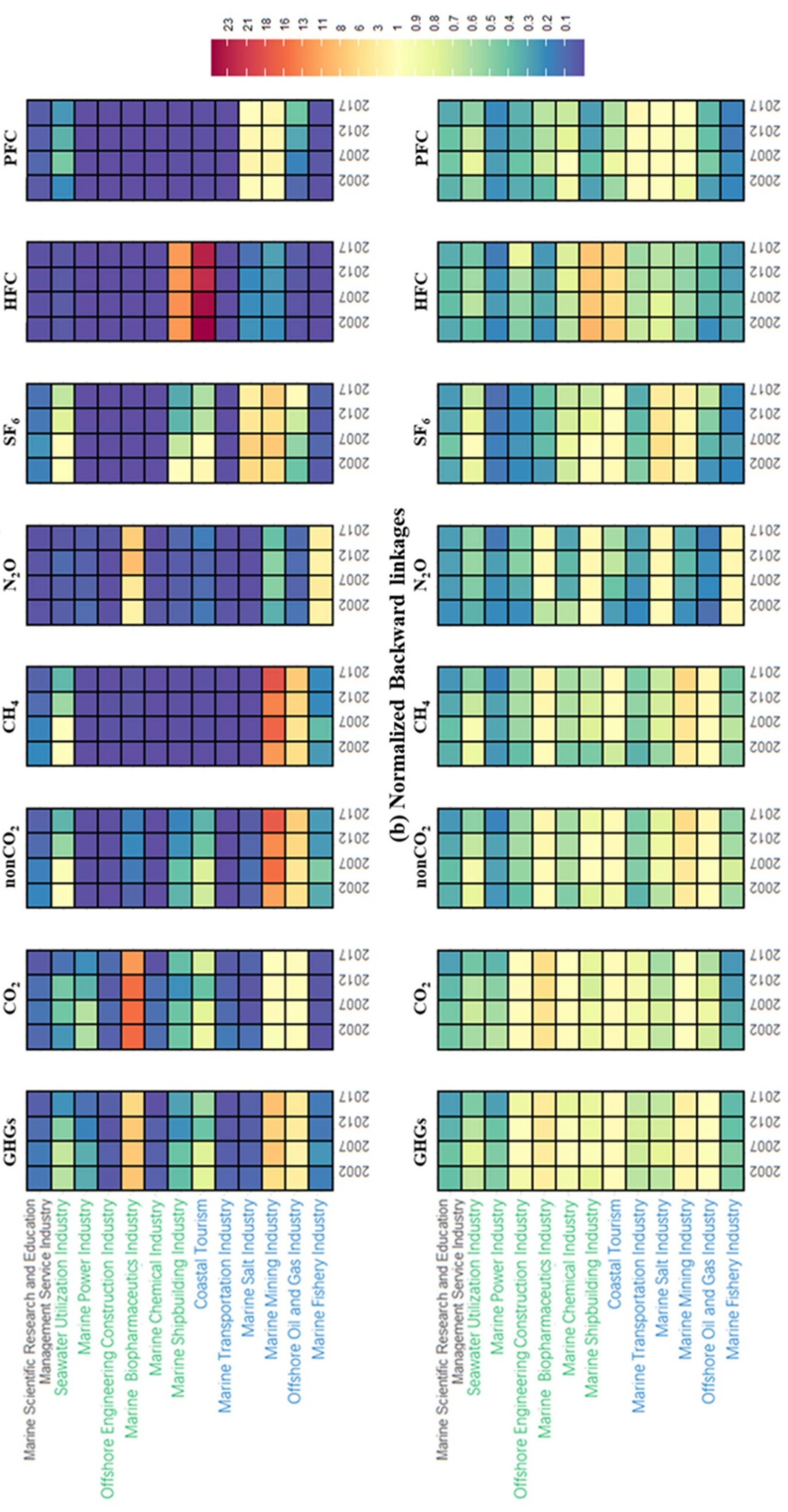

Figure 3. Normalized backward linkages and forward linkages of GHGs emissions in 2002, 2007, 2012 and 2017.

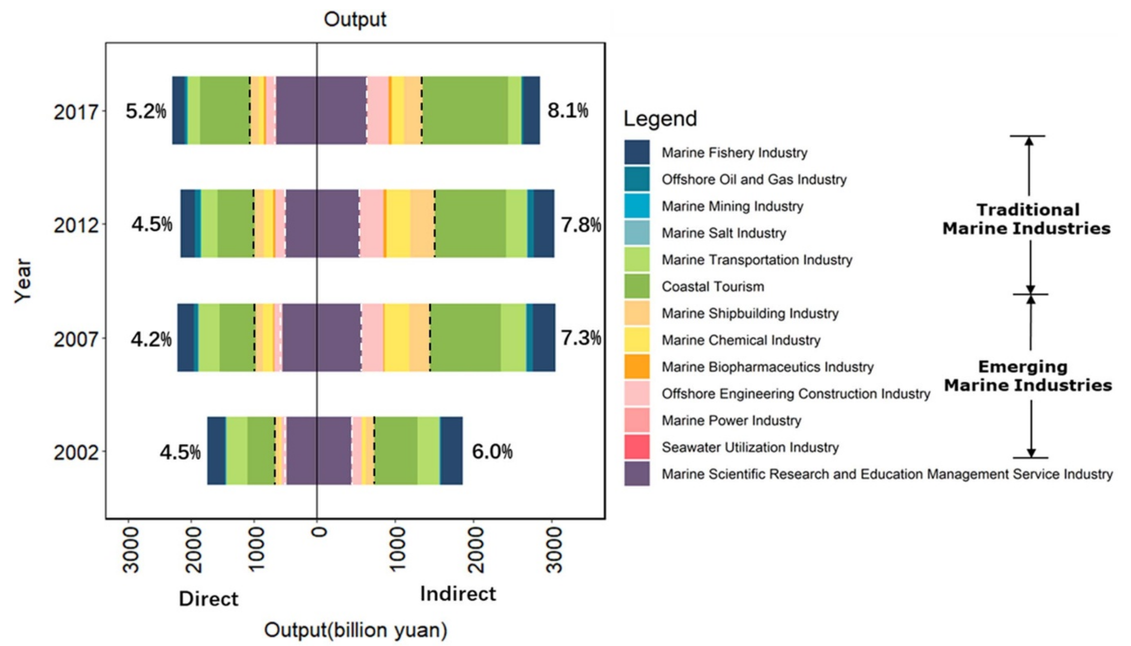

Figure 4. Direct output of marine industries and indirect output of marine-related economic output (in constant price, base period = 2002). Percentages above column plots represent proportion of direct or total output from marine economy in total output from national economy. Dish lines are used to separate the traditional and emerging marine industris.

management service industry are larger while the emissions linkages are lower, because of their low total emission intensity per unit of industry output. Further development of these marine industries may lead to higher economic output along the supply chain but cause much lower GHG emissions. Therefore, from the perspective of ensuring high economic growth and low emissions, these marine industries need to be vigorously developed.

It is worth noting that backward normalized linkages (BNL for short, the same below) of some marine industries on GHGs emissions reaches over 1 generally, which indicates their strong pulling effects on their upstream suppliers' emissions. For example, the large BNL of marine biopharmaceutics sector on CO_2 emissions is largely due to the high percentage inputs from the carbon intensive power, thermal production and supply sector sector, to produce one unit output of the marine biopharmaceutics product. For marine mining sector, the large BNL is on CH_4 emissions given that the inputs from its upstream suppliers are mainly coal mining and washing industry with high CH_4 emissions intensity in their productions.

3.2. Total output and GHGs emissions of marine industries

3.2.1. Direct and indirect economic output of the marine economy

The direct and total output of marine industries are shown in figure 4. We can see that the direct output of marine industry accounts for a relatively small proportion of the national economy, ranging from 4.5% to 5.2% between 2002 and 2017. However, there are close economic interdependencies between specific marine industry and other national economic sectors, and marine economy generally show the characteristics of strong driving force of national economy. When all the upstream driving influences are added together, the economic scale and economic impact will be at least doubled. Specifically, the development of marine economic sectors have driven 1.3–1.8 times of their economic output in non-marine economic sectors. Among them, emerging marine industries like marine shipbuilding industry (321.1 billion yuan) and marine chemical industry (302.4 billion yuan) and offshore engineering construction industry (275.0 billion yuan) are the top three industries with the largest indirect driving force, up to 2.6 times, 2.6 times and 2.5 times of direct output. And marine biopharmaceutics industry, offshore engineering construction industry and marine power industry may lead to higher upstream industrial output but still have space for growth. The share of the total economic output (both direct and indirect) of marine industries in the national economic increased from 10.4% in 2002 to 13.2% in 2017 with potentially continuing growth in the future, according to China's next 5 year plan. Therefore, both direct and supply chain effects need to be taken into account when analyzing the potential economic contribution of the further development of marine industries.

3.2.2. Direct and indirect GHGs emissions of 13 marine industries

High GHGs emissions are basically consistent with high industrial output except for some specific

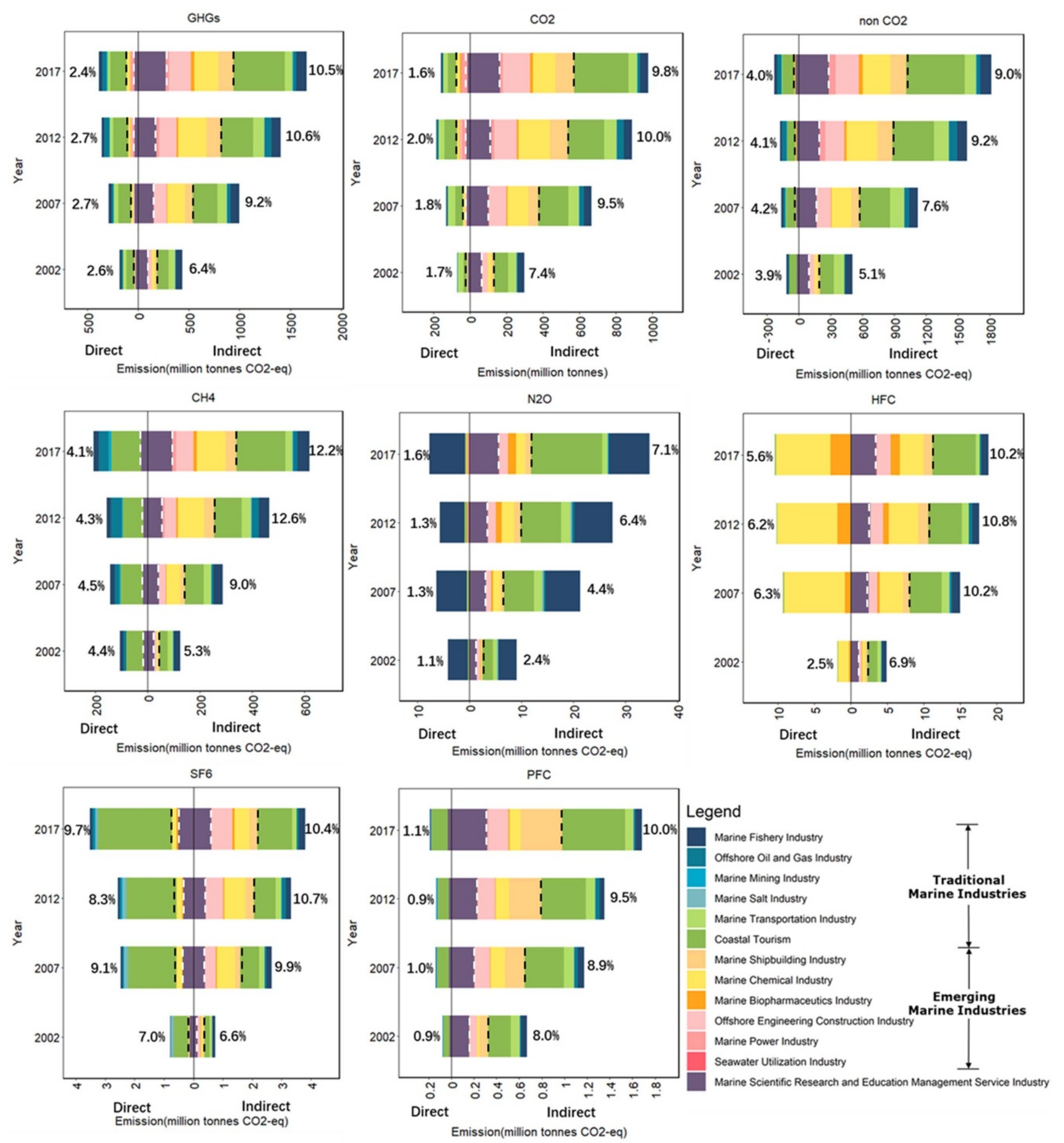

Figure 5. Direct and indirect GHGs emissions of marine industries. Percentages above column plots represent proportion of direct or total GHGs emissions from marine economy in total GHGs emissions from national economy. Dish lines are used to separate the traditional and emerging marine industris.

industries. Direct and total impact of production activities of marine sectors on GHGs emissions are shown in figure 5. The top three industry, in terms of direct GHG emissions, are coastal tourism and offshore oil and gas industry in traditional industries, as well as marine scientific research and education management service industry, which accounted for only 1.0%, 0.3% and 0.2% of the national total in 2017, respectively. The indirect GHG emissions of major marine economy embodied in the upstream supply chains is on average 3.5 times of direct emissions from marine industries. For different types of GHG emissions, the ratio of indirect emission to direct emission are 6.2 (CO2), 3.3 (CH4), 4.7 (N2O), 2.1 (SF6), 3.0 (HFC), 10.2 (PFC) and 4.5 (GHG) of direct emissions, respectively. Furthermore, the total emissions of each major GHGs are increasing over 2002–2017, up to 11.3 times of direct emission. That is to say, when taking into account the supply chain emissions, the share of marine economy in the national total emissions increased to more than 10%. The top three marine industries contributed to about 57.5% of the total marine economy related GHG emissions in average. Additionally, the marine fishery industry is an important source of N_2O, and the marine chemical industry is an important source of HFC. Therefore, ignoring the supply chain emissions of the marine economy would significantly underestimate the impacts of marine economy development on the national total GHG emissions. The emissions transfer along the supply chains of marine industries can be tracked in figure S3.

With regard to CO_2, almost all sectors increased their emissions over time (figure 5). Firstly, direct emissions from coastal tourism industry has obvious characteristics of high consumption. It ranks the first in total direct emissions with the amount of 341.6 Gt CO_2, followed by marine scientific research and education management service industry and offshore engineering construction industry (149.0 Gt/CO_2), accounting for 3.4%, 1.8% and 1.5% of CO_2 emission respectively. As the market forces and R&D investment continues to increase, the manufacturing capacity of the manufacturing industry represented by the marine engineering construction industry remains high. However, when taking into account their supply chain emissions, the growth rate of total CO_2 emission is larger than economy and GHG emission. and it can increase up to 7.2 times the direct emissions. The 13 marine industrial activities take up to 11.3% (1137.4 Gt/CO_2) share of total emissions, which is up to 7.2 times of that of direct emission.

Interestingly, the direct CO_2 emission fells by 13.9% from 2012 to 2017, which is driven by offshore oil and gas industry, marine shipbuilding industry, offshore engineering construction industry, marine transportation industry, coastal tourism and marine scientific research, and education management service industry. It is consistent with national results of datasets including China Emission Accounts and Datasets (i.e. CEADs)and Multi-resolution Emission Inventory for China (i.e. MEIC) (Shan *et al* 2020). The total CO_2 emission shows an increase trend by 6.1%. Coastal tourism holds the top position of CO_2 emission from 2007. It is worth noting that although direct and total emissions from marine power industry have soared 35.5-fold and 46.3-fold in 15 years respectively, their growth rate has slowed down since 2012, which can be partly attributed to the rapid growth of using of renewable energy. Direct and total CO_2 emissions from marine transportation industry and marine salt industry all have decreased. As to offshore engineering construction industry, its direct instead of indirect emissions decrease.

Non-CO_2 GHGs emissions in various sectors induced by each marine industry are shown in figure 5. There are large differences in non-CO_2 GHGs emissions from different marine industries. The HFC emission from 13 marine industries increase gradually, with the rate of rise decreasing. The total emissions are 2.6–3.7 times that of direct emissions, and the gap is narrowing over time. The marine chemical industry is always the largest emission industry, and its indirect emissions are up to 7.6% of all industries. Direct and total HFC emissions from marine salt industry all have fallen the most. The total PFC emissions are much higher than direct emissions, reaching 11.3 times of direct emission, and it is mainly driven by development of coastal tourism (698.1 Mt/CO_2-eq, 12.9%), marine shipbuilding industry (367.8 Mt/CO_2-eq, 6.8%) and marine scientific research and education management service industry (344.2 Mt/CO_2-eq, 6.4%).

Except for SF_6, for all other GHGs, the promotions of direct emissions to total emissions are greater than those of direct output to total output. This could be explained by strong linkages and large-scale emissions. (a) For these GHGs emissions, their BL and FL linkages are higher than those of economy linkage. (b) The large scale of CO_2 and CH_4 emissions plays an important role in GHG emissions.

GHGs emissions from non-marine sectors caused by inter-industry linkages are also important sources of emissions. The indirect emissions of marine industries has nearly quadrupled from 2002 to 2017. Next, we elaborate the sectors that cause high indirect emissions in detail.

Marine sectors have imposed a huge amount emissions to their upstream supplier (text S4). As can be seen in figures 6, figures 4 and S3–S5, in addition to itself, the upstream high emissions of marine industry are concentrated in non-marine sectors, rather than other marine industries. Among marine industries, marine chemical industry in emerging industries, marine fishery industry, marine transportation industry and coastal tourism industry in traditional industries, as well as marine scientific research and education management service industry cause the largest number of indirect high-emission sectors. The production of the marine power industry and seawater utilization industry may lead to relatively small economic output in their upstream supply chain but cause much more emissions. By contrast, the marine shipbuilding industry and offshore engineering construction industry have more indirect output and less emissions along the upstream supply chains. For offshore oil and gas industry, marine mining industry, marine salt industry and marine biopharmaceutics industry, their indirect output and indirect emissions are all relatively small. The high indirect emissions of other GHGs caused by marine industries are mainly concentrated in agriculture industry, animal husbandry industry, coal mining and washing industry, inland oil and gas extraction industry and mining ancillary services and other mining products. Almost all marine sectors have significant indirect emissions from power sectors and coal mining and washing industry, due to large energy demand for their production.

4. Discussions

By compiling detailed sectors, time series, and consistent Chinese Environmentally Extended Marine IO Tables, this study emphasizes the important role of marine economic development in the overall economic system and climate change mitigation. Our

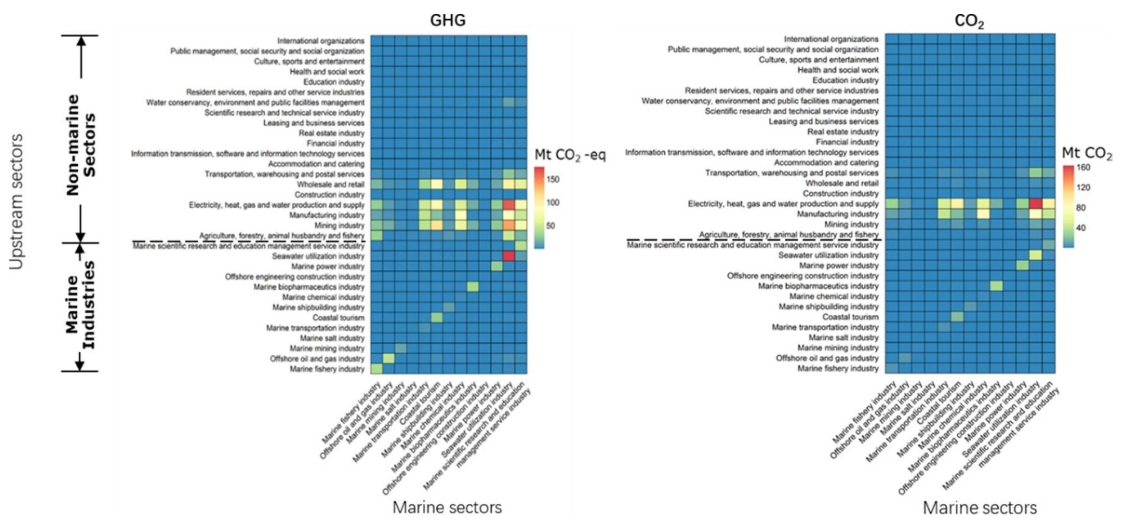

Figure 6. GHG and CO_2 emissions in sectors induced by each marine industry in 2017. The 96 non-marine economic sectors are classified to 20 sectors according to Classification of Marine and Related Industries (GB/T 4754-2017), which is shown in ordinate.

results show that there is a high degree of interdependence between marine industry and other national economic sectors. One unit economic output of marine economy may lead to up to 1.8 times of the total economic output in the upstream industries. In terms of emissions, the direct emission of marine industries in 2017 is 386.9million tonnes CO_2-eq. The marine sectors play a greater role in promoting GHGs emissions in their upstream sectors. Specifically, the indirect emissions of major marine economy embodied in the upstream supply chains is 3.5 times of direct emissions from marine industries. The total emissions of marine economy increased by 2.3 times from 2002 to 2017, and the share of that in national total emissions increased by 43.3%. This study also provides a methodological reference for the compilation and application of provincial, municipal and bay area IO tables with different resource endowments and economic development characteristics with limited data.

Our study reveals the contradictory situation by emphasizing the significance role of marine economy as future development supports for national economies and critical sources for climate change. According to the report by the IPCC High Level Panel for a Sustainable Ocean Economy, five ocean-based climate action areas like marine renewable energy, marine transportation, marine fishery, aquaculture industries may reduce GHGs emissions by one fifth.[55] However, our findings indicate that to effectively control global warming in the coming decades, the marine sector is still faced with challenges. Today the blue economy has gradually become a new economic growth point. Even in the Post-COVID-19 world, China's marine economy still have a recovery growth under the government's positive fiscal and monetary policies (Chen 2020). Therefore, while achieving high-quality development and adjusting the structure of marine industries, attentions should also be given to advanced intervention as well as smooth transition from 'blue economy' to 'green economy' to ensure high speed and green sustainable development of marine economy.

Although blue carbon ecosystems play an important role in mitigating and adapting to climate change (Macreadie *et al* 2019), the adjustment and optimization of the marine industrial structure also cannot be ignored. The marine economy should bear certain responsibilities for the attribution of GHGs emissions. Marine industry emissions account for 12.9% of China's GHGs emissions. This reminds policy makers to incorporate targeted emission reduction measures for marine industries into the climate governance system and actively explore the low-carbon development mode characterized by low emissions while paying attention to the energy consumption decline of traditional industrial unit added value.

Critically, our results also show that the indirect production relationship which has a significant impact on GHGs emissions cannot be ignored. As to the marine fishery, marine transportation and coastal tourism in the traditional marine industry, their indirect GHGs emissions are on average 3.5 times, 2.6 times and 2.1 times that of direct emissions, respectively. The emerging marine industries are new growth point for the future marine economy. However, they also bring great pressure on indirect GHGs. Among them, for ocean chemical industry and ocean scientific research, education, management and service industry, their indirect GHGs emissions are 10.5 times and 5.2 times that of direct emissions, respectively.

Therefore, while exploring negative emission technology for marine sectors and developing blue carbon sinks, it is necessary to implement more sustainable supply chain management by identifying alternative upstream suppliers with lower emission intensity. To be specific, first, research and develop of low-carbon technologies for marine sectors, including marine renewable energy technologies, marine fishery for carbon sink and comprehensive utilization of seawater, and accelerate the development of modern marine industries characterized by low-carbon consumption. Second, it is important to cultivate and form a low-carbon industry supply layout in coastal tourism industry that is more replying on marine renewable energy. Last but not least, because the indirect emissions of marine industry are mainly from transportation, warehousing and postal services industry, electricity, heat, gas and water production and supply industry, manufacturing industry and mining industry industries, there is a win-win solution between marine sectors and energy sectors by promoting low carbon energy technologies related to the structural transformation of the energy sector.

Data availability statement

The data that support the findings of this study are available upon reasonable request from the authors.

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Conflict of interest

The authors declare no competing financial or non-financial interests.

ORCID iDs

Chen Pan https://orcid.org/0000-0003-1856-5424
Jing Meng https://orcid.org/0000-0001-8708-0485

References

Bjelle E L, Többen J, Stadler K, Kastner T, Theurl M C, Erb K-H, Olsen K-S, Wiebe K S and Wood R 2020 Adding country resolution to EXIOBASE: impacts on land use embodied in trade *J. Econ. Struct.* **9** 14

Bouman E A, Lindstad E, Rialland A I and Strømman A H 2017 State-of-the-art technologies, measures, and potential for reducing GHG emissions from shipping—a review *Transp. Res. Part Transp. Environ.* **52** 408–21

Brodie Rudolph T, Ruckelshaus M, Swilling M, Allison E H, Österblom H, Gelcich S and Mbatha P 2020 A transition to sustainable ocean governance *Nat. Commun.* **11** 3600

Chen S Y 2020 Economic Battle 'Epidemic': The Impact of Novel Coronavirus Pneumonia on the Economy and Countermeasures (Shanghai: Fudan University Press)

Chiu R-H and Lin Y-C 2012 The inter-industrial linkage of maritime sector in Taiwan: an input–output analysis *Appl. Econ. Lett.* **19** 337–43

Corbett J J 2003 Updated emissions from ocean shipping *J. Geophys. Res.* **108** 4650

De Koning A, Bruckner M, Lutter S, Wood R, Stadler K and Tukker A 2015 Effect of aggregation and disaggregation on embodied material use of products in input–output analysis *Ecol. Econ.* **116** 289–99

Department of Marine Strategic Planning and Economics, Ministry of Natural Resources 2007 China Marine Economic Statistical Bulletin (2002)

Department of Marine Strategic Planning and Economics, Ministry of Natural Resources 2008 China Marine Economic Statistical Bulletin (2007)

Department of Marine Strategic Planning and Economics, Ministry of Natural Resources 2013 China Marine Economic Statistical Bulletin (2012)

Department of Marine Strategic Planning and Economics, Ministry of Natural Resources 2018 China Marine Economic Statistical Bulletin (2017)

Department of Marine Strategic Planning and Economics, Ministry of Natural Resources 2019 China Marine Economic Statistical Bulletin (2018)

Fei R and Lin B 2017 The integrated efficiency of inputs–outputs and energy—CO_2 emissions performance of China's agricultural sector *Renew. Sustain. Energy Rev.* **75** 668–76

Fenichel E P, Addicott E T, Grimsrud K M, Lange G-M, Porras I and Milligan B 2020 Modifying national accounts for sustainable ocean development *Nat. Sustain.* **3** 889–95

Freytag A and Fricke S 2017 Sectoral linkages of financial services as channels of economic development—an input–output analysis of the Nigerian and Kenyan economies *Rev. Dev. Finance* **7** 36–44

Ghosh A 1958 Input–output approach in an allocation system *Economica* **25** 58

Harada T 2015 Changing productive relations, linkage effects, and industrialization *Econ. Syst. Res.* **27** 374–90

Hawkins J, Ma C, Schilizzi S and Zhang F 2015 Promises and pitfalls in environmentally extended input–output analysis for China: a survey of the literature *Energy Econ.* **48** 81–8

He Q *et al* 2015 Economic development and coastal ecosystem change in China *Sci. Rep.* **4** 5995

Hoagland P, Jin D, Thunberg E and Steinback S 2005 Economic activity associated with the northeast shelf large marine ecosystem: application of an input–output approach *Large Marine Ecosystems* 13 (Amsterdam: Elsevier) pp 157–79

Hu J 2012 Report at 18th Party Congress (Beijing: People's Publishing House)

Jean-Baptiste Jouffray R B, Norström A V, Österblom H and Nyström M 2019 The blue acceleration: the trajectory of human expansion into the ocean *One Earth* **2** 43–54

Jiang X-Z, Liu T-Y and Su C-W 2014 China's marine economy and regional development *Mar. Policy* **50** 227–37

Johansson L, Jalkanen J-P and Kukkonen J 2017 Global assessment of shipping emissions in 2015 on a high spatial and temporal resolution *Atmos. Environ.* **167** 403–15

Johnson K, Dalton G and Masters I 2018 Building industries at sea:'Blue Growth'and the new maritime economy (Denmark: River Publishers)

Kwak S-J, Yoo S-H and Chang J-I 2005 The role of the maritime industry in the Korean national economy: an input–output analysis *Mar. Policy* **29** 371–83

Kymn K O 1990 Aggregation in input–output models: a comprehensive review, 1946–71 *Econ. Syst. Res.* **2** 65–93

Lee K-H, Noh J and Khim J S 2020 The blue economy and the United Nations' sustainable development goals: challenges and opportunities *Environ. Int.* **137** 105528

Lee M-K and Yoo S-H 2014 The role of the capture fisheries and aquaculture sectors in the Korean national economy: an input–output analysis *Mar. Policy* **44** 448–56

Lenzen M 2011 Aggregation versus disaggregation in input–output analysis of the environment *Econ. Syst. Res.* **23** 73–89
Leontief W 1970 Environmental repercussions and the economic structure: an input–output approach *Rev. Econ. Stat.* **52** 262
Lindner S, Legault J and Guan D 2013 Disaggregating the electricity sector of China's input–output table for improved environmental life-cycle assessment *Econ. Syst. Res.* **25** 300–20
Liu S, Tian X, Cai W, Chen W and Wang Y 2018 How the transitions in iron and steel and construction material industries impact China's CO_2 emissions: comprehensive analysis from an inter-sector linked perspective *Appl. Energy* **211** 64–75
Ma -J-J, Du G and Xie B-C 2019 CO_2 emission changes of China's power generation system: input–output subsystem analysis *Energy Policy* **124** 1–12
Macreadie P I *et al* 2019 The future of Blue Carbon science *Nat. Commun.* **10** 3998
Merciai S and Schmidt J 2018 Methodology for the construction of global multi-regional hybrid supply and use tables for the EXIOBASE v3 database: methodology of MR-HSUTs for the EXIOBASE database *J. Ind. Ecol.* **22** 516–31
Miller R E and Blair P D 2009 *Input–Output Analysis: Foundations and Extensions* 2nd edn (Cambridge: Cambridge University Press)
Mohan R R 2018 Time series GHG emission estimates for residential, commercial, agriculture and fisheries sectors in India *Atmos. Environ.* **178** 73–9
Morrissey K and O'Donoghue C 2013 The role of the marine sector in the Irish national economy: an input–output analysis *Mar. Policy* **37** 230–8
National Development and Reform Commission, and State Oceanic Administration 2017 *The 13th Five Year Plan for National Marine Economic Development* (Beijing, China Ocean Press)
National Economic Accounting Department of the National Bureau of Statistics 2006 *Input—output tables of China (2002)* (Beijing, China Statistics Press)
National Economic Accounting Department of the National Bureau of Statistics 2010 *Input—output tables of China (2007)* (Beijing, China Statistics Press)
National Economic Accounting Department of the National Bureau of Statistics 2015 *Input—output tables of China (2012)* (Beijing, China Statistics Press)
National Economic Accounting Department of the National Bureau of Statistics 2019 *Input—output tables of China (2017)* (China Statistics Press, Beijing)
OECD: Organisation for Economic Co-Operation and Development 2017 *The Ocean Economy in 2030* (Paris: OECD Publishing)
OECD: Organisation for Economic Co-Operation and Development 2019 *Rethinking Innovation for a Sustainable Ocean Economy* (Paris: OECD Publishing)
Parker R W R, Blanchard J L, Gardner C, Green B S, Hartmann K, Tyedmers P H and Watson R A 2018 Fuel use and greenhouse gas emissions of world fisheries *Nat. Clim. Change* **8** 333–7
San Cristóbal J R and Biezma M V 2006 The mining industry in the European Union: analysis of inter-industry linkages using input–output analysis *Resour. Policy* **31** 1–6
Schlüter A, Van Assche K, Hornidge A-K and Văidianu N 2020 Land-sea interactions and coastal development: an evolutionary governance perspective *Mar. Policy* **112** 103801
Shan Y, Huang Q, Guan D and Hubacek K 2020 China CO_2 emission accounts 2016–2017 *Sci. Data* **7** 54
Song W L, He G S and McIlgorm A 2013 From behind the Great Wall: the development of statistics on the marine economy in China *Mar. Policy* **39** 120–7
Stadler K *et al* 2018 EXIOBASE 3: developing a time series of detailed environmentally extended multi-regional input–output tables: EXIOBASE 3 *J. Ind. Ecol.* **22** 502–15
State Oceanic Administration of China 2004 China Marine Statistical Yearbook (2003) China Statistics Press, Beijing
State Oceanic Administration of China 2009 China Marine Statistical Yearbook (2008) China Statistics Press, Beijing
State Oceanic Administration of China, 2014 China Marine Statistical Yearbook (2013). China Ocean Press, Beijing
To W-M and Lee P 2018 China's maritime economic development: a review, the future trend, and sustainability implications *Sustainability* **10** 4844
Toh M-H 1998 The RAS approach in updating input–output matrices: an instrumental variable interpretation and analysis of structural change *Econ. Syst. Res.* **10** 63–78
Tukker A and Dietzenbacher E 2013 Global multiregional input–output frameworks: an introduction and outlook *Econ. Syst. Res.* **25** 1–19
UNCTAD STAT 2020 Maritime transport (available at: http://unctadstat.unctad.org/wds/ReportFolders/reportFolders.aspx) (Accessed 15 October 2020)
Unit E I 2016 The blue economy: growth, opportunity and a sustainable ocean economy (available at: www.eiuperspectives.economist.com/sustainability/blue-economy/white-paper/blue-economy) (Accessed 7 July 2015)
United Nations Conference on Trade and Development, 2014. The ocean economy: opportunities and challenges for small island developing states United Nations Conference on Trade and Development
Wang Y and Wang N 2019 The role of the marine industry in China's national economy: an input–output analysis *Mar. Policy* **99** 42–49
Wood R, Stadler K, Simas M, Bulavskaya T, Giljum S, Lutter S and Tukker A 2018 Growth in environmental footprints and environmental impacts embodied in trade: resource efficiency indicators from EXIOBASE3: growth in environmental impacts embodied in trade *J. Ind. Ecol.* **22** 553–64
World Bank 2017 *The Potential of the Blue Economy: Increasing Long-term Benefits of the Sustainable Use of Marine Resources for Small Island Developing States and Coastal Least Developed Countries* (Washington, DC: World Bank)
WorldAtlas 2020 Countries with the longest coastline (available at: www.worldatlas.com/articles/countries-with-the-most-coastline.html) (Accessed 1 February 2020)
Xi J 2017 Report at 19th Party Congress (Beijing: People's Publishing House)
Yin K, Xu Y, Li X and Jin X 2018 Sectoral relationship analysis on China's marine-land economy based on a novel grey periodic relational model *J. Clean. Prod.* **197** 815–26
Yu Y, Hubacek K, Feng K and Guan D 2010 Assessing regional and global water footprints for the UK *Ecol. Econ.* **69** 1140–7
Yuan R, Behrens P and Rodrigues J F D 2018 The evolution of inter-sectoral linkages in China's energy-related CO_2 emissions from 1997 to 2012 *Energy Econ.* **69** 404–17