frontiers | Frontiers in Marine Science

TYPE Policy and Practice Reviews
PUBLISHED 16 February 2023
DOI 10.3389/fmars.2023.1131552

OPEN ACCESS

EDITED BY
Jihong Chen,
Shenzhen University, China

REVIEWED BY
Guangnian Xiao,
Shanghai Maritime University, China
Yi-Che Shih,
National Cheng Kung University, Taiwan

*CORRESPONDENCE
Yu Liu
yuliu@btbu.edu.cn

†These authors share first authorship

SPECIALTY SECTION
This article was submitted to Marine Affairs and Policy, a section of the journal Frontiers in Marine Science

RECEIVED 25 December 2022
ACCEPTED 31 January 2023
PUBLISHED 16 February 2023

CITATION
Yang W, Chen X and Liu Y (2023) Review and reflections of legislation and policies on shipping decarbonization under China's "dual carbon" target. *Front. Mar. Sci.* 10:1131552. doi: 10.3389/fmars.2023.1131552

Review and reflections of legislation and policies on shipping decarbonization under China's "dual carbon" target

Weiming Yang[1†], Xidi Chen[1†] and Yu Liu[2*]

[1]School of Law, Tsinghua University, Beijing, China, [2]School of Law, Beijing Technology and Business University, Beijing, China

Although shipping is a relatively energy-saving and environmentally friendly mode of transportation, the growth rate of its energy consumption and carbon emissions far exceeds that of other industries. As an important response to climate change, shipping decarbonization is not only an important part of achieving the temperature control goal of the Paris Agreement but is also an important direction for the future development of China's ecological civilization construction. China has formulated and promulgated legislation and policies on shipping decarbonization both at the national and local levels. The proposal in 2020 of the goal of carbon peaking and carbon neutrality has accelerated this process. In this context, this paper aims at reflecting on legislation and policies for decarbonization of shipping under China's "double carbon" target, and proposing suggestions for improvement. Firstly, we systematically review China's legislation and policies on shipping decarbonization to outline the normative system of China's shipping carbon reduction. Secondly, this paper evaluates China's legislation and policies on shipping decarbonization from the perspective of both achievements and challenges. Finally, this paper proposes that China's legislation and policies for decarbonization of shipping should be further improved from two aspects: enhancing mandatory force and expanding normative content.

KEYWORDS

shipping decarbonization, carbon peaking and carbon neutrality goals, legislation and policies, review, recommendations

1 Introduction

Climate change, especially global warming, is commonly considered as one of the greatest threats to human society, and is continuously affecting human health, socio-economic development, population, food security, and ecosystems at land and at sea. To address climate change, the Paris Agreement was adopted at the 21st United Nations Climate Change Conference in 2015, setting the target of keeping the global average temperature increase in the 21st century to within 1.5–2 degrees (Paris Goals; Savaresi, 2016; Lee, 2019). As a party

and an active practitioner of the Paris Agreement, China has been committed to action against climate change and has taken proactive initiatives to seek new approaches to low-carbon development. In September 2020, China announced at the 75th UN General Assembly that it would strive to peak carbon dioxide (CO2) emissions by 2030 and work toward achieving carbon neutrality by 2060 goal (Liu, 2022). The introduction of the dual carbon target is both a major strategic decision for China to respond to global climate change and participate in global environmental governance, as well as a key initiative to promote the construction of domestic ecological civilization and build a community with a shared future (Liu, 2022).

The realization of the dual carbon target is related to the energy transformation and industrial upgrading of the whole country and essentially concerns all industries. The shipping industry is not only fundamental to a country's economic development but also plays an important role in international trade and economic development (Zhang, 2017) as a low-cost and widely applicable tool for bulk cargo transportation (Wan et al., 2018). Although shipping is already a more economical, environmentally friendly, and energy-efficient mode of transportation in terms of total carbon emissions, energy consumption, and carbon emissions per unit of turnover (Nast, 2013), its energy consumption and carbon emissions have increased significantly more than those of other industries (Hughes et al., 2017).

The shipping industry currently accounts for about 3% of global CO2 emissions (Sun et al., 2022), and with the yearly increase in the number of ships and the trend toward larger ships, carbon emissions from shipping are climbing at an annual rate of 1.1% to 3.4% (Bloor et al., 2015). The International Maritime Organization (IMO) Fourth Greenhouse Gas Study 2020 shows that, owing to the continued growth of global shipping trade, shipping greenhouse gas emissions have increased from 977 million tons in 2012 to 1,076 million tons in 2018 (an increase of 9.6%), and shipping carbon emissions in the global share of anthropogenic Greenhouse Gas (GHG) emissions has increased from 2.76% in 2012 to 2.89% in 2018. Without effective carbon reduction measures, carbon emissions from shipping will increase by about 90% in 2050 compared to 2018 and by about 90–130% compared to 2008 (IMO, 2020), impeding the global fight against climate change.

Carbon reduction in shipping is not only an important part of achieving the Paris goals (Hedley et al., 2016) but also an important direction for the future sustainable development of the shipping industry. There is coupling effect between port economy and urban environment (Chen et al., 2022a). Up to now, Chinese scholars' research on shipping mainly focused on the application of game theory in the analysis of port coopetition (Xu et al., 2021a), freight forwarding market and inland shipping pollution control (Xu et al., 2021b; Xu et al., 2022a), Some scholars also have studied the mechanism of Covid-19 empirical in the change of shipping industry (Xu et al., 2022b)and container shipping alliance (Chen et al., 2022b), The existing research results not only lack attention to shipping decarbonization, but also lack investigation of relevant legislation and policies of China, which is the significance of this paper. Under the institutional thrust of ecological civilization construction, China has formulated legislation and policies on carbon reduction in shipping at the national and local levels, and the introduction of dual carbon targets has accelerated this process. The purpose of this paper is to examine the latest progress in China's practices on carbon reduction in shipping and to review and reflect on them. Part 2 systematically and comprehensively compares and reviews the existing legislation and policies on carbon reduction in shipping at different levels at national and local aspects, and outlines the regulatory system of carbon reduction in shipping in China. Part 3 first summarizes the achievements of China's legislation and policies on carbon reduction in shipping from the legal system aspect, and further reflects on the shortcomings and challenges of China's legislation and policies on decarbonization of shipping in terms of system characteristics and regulatory content. Part 4 puts forward suggestions for improving the carbon reduction legislation and policies of China's shipping, including enhancing the binding force of the carbon reduction legislation and policies of shipping, expanding the content of regulations, and providing an all-round and full-process legal basis for the carbon reduction of shipping.

2 Normative construction: China's legislation and policies on shipping decarbonization

The decarbonization of shipping refers to reducing the amount of carbon dioxide produced by the shipping industry with the goal of net zero emissions, and the main path is to reduce carbon emissions and supplement these with increasing carbon sinks. Since there are many factors affecting the CO2 emissions of ships, such as ship type (Xiao et al., 2022), hull design (Lindstad and Eskeland, 2015), speed (Eide et al., 2013), operation technology (Xing et al., 2020), shipping path (Shu et al., 2022)and power fuel (Halim et al., 2018). Shipping carbon reduction thus needs cooperation of multiple sections including shipping infrastructure, shipping technology and equipment, shipping organization system, shipping governance mechanism, for instance the design of an intermodal transportation network (Bouchery and Fransoo, 2015), and other aspects (Nast, 2013; Kujanpää and Teir, 2017), with a "multicenter" characteristic (Black, 2008). In addition to technological improvements such as new technologies, fuels, and operational measures, the achievement of carbon reduction in shipping also depends on appropriate laws and policies. Through legal regulations, the certainty, predictability, and compulsory nature of carbon reduction in shipping can be increased, and the carbon reduction effect can be ensured.

2.1 National legislation and policies

In terms of national legislation, China constructs its own legal regulation system of shipping decarbonization through the constitution, laws, and regulatory documents. First, from the constitutional level, the amendment of the constitution in 2018 has written "promoting the coordinated development of material civilization, political civilization, spiritual civilization, social civilization, and ecological civilization" and building a beautiful China into the preamble of the constitution. It requires the Chinese government to follow the concept of "community of life" and "harmonious coexistence between human beings and nature" in the process of achieving carbon neutrality and carbon peaking, and implement green development, low-carbon development, and

sustainable development into industrial structures, production modes, and life styles. As an organic part of social production and human life, shipping carbon emission affects the atmosphere, water, fishery and other natural resources, and is therefore an important issue under the legal regime of "dual carbon." It also provides the fundamental basis and direction for China's shipping carbon reduction legislation.

Second, from the aspect of laws, the legislative provisions on shipping decarbonization are mainly stipulated in the environmental laws, primarily regulating administrative subjects of specific watersheds. For example, Article 66 of the Yangtze River Protection Law stipulates that local governments above the county level along the Yangtze River basin shall promote the upgrading of steel, ships, and other industries to improve the level of technology and equipment, and Article 72 stipulates that they shall coordinate the construction of ship pollutant receiving and transferring. Furthermore, Article 73 provides that the governments at or above the county level in the Yangtze River basin shall coordinate the construction of ship pollutant reception and transfer facilities, ship liquefied natural gas filling stations, and develop plans for the construction and renovation of port shore power facilities and ship receiving power facilities in accordance with the provisions of financial support or policy support. The State Council and the local government should offer help to ship charging facilities in accordance with the provisions of financial subsidies, tariff concessions, and other forms of policy support. Moreover, Article 84 provides that with the conditions for the use of shore power and not in accordance with the relevant state regulations to use shore power ships to be subject to administrative punishment.

The Yellow River Protection Law Article 36 provides that the State Council departments in charge of natural resources, forestry and grassland should work with the relevant departments of the State Council and the people's government of Shandong Province, the organization of the Yellow River Delta wetland ecological protection and restoration, reduce the impact of port shipping and other activities on the estuarine ecosystem, To be more specific, Article 87 and Article 101 say that Local governments shall promote the high-quality development of manufacturing and transformation of resource-based industries, develop clean and low-carbon energy in accordance with local conditions, promote the optimization and adjustment of industrial structure, energy structure, transportation structure, and promote carbon peaking and carbon neutral work. Similarly, the Wetland Protection Law prescribes that tourism, shipping and other utilization activities within the wetland should avoid changing the natural condition of the wetland, and take measures to mitigate the adverse impact on the ecological function of the wetland, and local governments shall take water treatment, vegetation restoration and other measures to enhance the ecological function of wetlands and carbon sink function.

From the policy level, since the 18th National Congress, the ruling party and the central government have released the Opinions on Accelerating the Construction of Ecological Civilization, Overall Plan for the Reform of Ecological Civilization System and Opinions on Completely and Accurately Implementing the New Development Concept playing the role of top-level design. In this context, various departments of the State Council have formulated targeted sectoral normative documents according to their respective responsibilities for different institutional grips of carbon reduction in shipping. For example, in terms of shipping carbon emission monitoring and reporting, in November 2022 the China Maritime Safety Administration developed and released the Measures for the Management of Ship Energy Consumption Data and Carbon Intensity on the basis of the 2018 Measures for the Collection and Management of Ship Energy Consumption Data, which provides for the collection and reporting of ship energy consumption data, the management of carbon intensity of Chinese international voyages, and the supervision and management mechanism.

For port construction, the Ministry of Communications formulated and released the Green Port Evaluation Grade Standard in 2013, which includes low carbon and energy saving as one of the evaluation indexes of green port grade, and has formulated specific evaluation score calculation methods. In order to optimize the shipping organization system, the General Office of the State Council issued the Work Plan for Optimizing the Adjustment of Transport Structure (2021-2025), which proposed to improve the green development policy of transportation in order to promote energy conservation, emission reduction and carbon reduction, specifically including developing Promote the development of multimodal transport and the adjustment of the transport structure of carbon emission reduction policies, encourage the introduction of new energy and clean energy vehicles and vessels to facilitate the passage of policies. In special sensitive protection areas, encourage innovation and promotion of green and low-carbon transport organization mode, to guard the natural ecological security boundary.

2.2 Local legislation and policies

Regarding local legislation, 14 provincial governments in China, including Shanghai, Jiangsu, Anhui, and Hunan, have issued carbon peak implementation plans, and several provinces have incorporated the development of green and low-carbon transformation of shipping into their plans. For example, the Guizhou Carbon Peak Implementation Plan proposes to promote energy conservation and clean energy utilization in ports, accelerate the orderly construction of shore power facilities in existing terminals according to needs, and guide existing ships to speed up the equipping of receiving power facilities and increase the proportion of using shore power facilities. Hunan, Jiangsu, Heilongjiang, Jiangxi, Hainan, and other provinces have proposed promoting the application of green ships and green port construction, promoting new energy and clean power energy ships, accelerating the elimination of low efficiency, high energy consumption of old ships and ship receiving power facilities, and port shore power facilities reform as the key tasks of the implementation plan.

In addition, several provinces and cities have promulgated more targeted and detailed action plans or implementation plans regarding shipping decarbonization. For example, in the Pearl River basin, the Ministry of Transport and the four provinces of Guangdong, Guangxi, Guizhou, and Yunnan jointly released the Action Plan for Promoting the Green Development of Pearl River Waterway Transport (2018–2020) in 2018, which proposed that by 2020,

compared with 2015, the energy consumption per unit transport turnover of operating ships in the Pearl River water system would be reduced by 6%, and the carbon dioxide emissions per unit transport turnover would be reduced by 7%. In 2021, Guangdong Province also released a series of implementation plans on shipping decarbonization consisting of the Overall Division Plan for Guangdong Province to Improve Inland Shipping Capacity and Promote the Green Development of Inland Shipping, the Implementation Plan for Guangdong Province's Inland Shipping Capacity Improvement, and the Implementation Plan for Guangdong Province's Inland Shipping Green Development Demonstration Project, proposing to accelerate the high-quality green development of inland navigation, optimize the port layout and waterway network, and accelerate the popularization of Liquefied Natural Gas (LNG) powered ships. Moreover, as early as 2016, Shenzhen issued the Five Year Action Plan for the Construction of a Green and Low Carbon Port in Shenzhen (2015–2020), which proposed that by the end of 2020, the comprehensive energy consumption of container throughput per unit of port production and operation would be 5% lower than that in 2015, and the carbon emissions of container throughput per unit of port production and operation would be 4% lower than that in 2015. In the Yangtze River basin, Shanghai has successively issued the Three Year Action Plan for Shanghai Green Port (2015–2017), the 13th Five Year Plan for Energy Conservation and Climate Change in Shanghai, and the 14th Five Year Plan for the Construction of the Shanghai International Shipping Center to promote energy conservation and carbon reduction in port construction and ship governance, and proposed the goal of achieving 100% coverage of shore power facilities in specialized berths of ports by 2025. In addition, the People's Government of Zhoushan City, Jiangsu Province, issued Several Opinions on Supporting the High Quality Development of a Modern Shipping Service Industry in 2022 to "support the development of green digital shipping." For important projects that have been identified as directly contributing to "carbon peak, carbon neutral" and "green shipping development in the Yangtze River Economic Belt," appropriate rewards will be granted according to the construction investment of individual projects. See Table 1 for examples of China's local legislation and policies on shipping decarbonization.

3 Normative evaluation: Achievements and challenges of China's legislation and policies on shipping decarbonization

As an important countermeasure against climate change, China has continued to promote the green and low-carbon transformation

TABLE 1 Shipping Decarbonization in China's Local Legislation and Policies.

Normative documents	Green Channel	Green Port	Green Ship	Green Transportation Organization Mode
Action Plan for Promoting Green Development of Pearl River Water Transport (2018–2020) is Jointly formulated by the Ministry of Transport and provincial governments	Build ecological channels	1.Port shore power facilities 2. Decrease the comprehensive energy consumption per unit throughput and the carbon dioxide emissions per unit throughput of port production by 2% in 2020, (compared with 2015).	Compared with 2015, the energy consumption per unit transport turnover of operating ships decreased by 6%, and the carbon dioxide emissions per unit transport turnover decreased by 7%.	1.Multimodal transport system 2. Smart water transport
1.Guangdong Provincial Waterway Development Plan (2020-2035) 2.Overall Division Plan of Guangdong Province for Improving the Capacity of Inland Waterway Shipping and Promoting the Green Development of Inland Waterway Shipping	1.Characteristic channel of ecotourism 2.Waterway ecological restoration project.	1. Port shore power facilities. 2. LNG filling station.	1.Implement ship type standardization project 2. LNG power transformation of inland ships.	1.Improve the river-sea intermodal transport system 2.Multimodal transport.
1. Jiangsu Province's "Fourteenth Five-Year Plan" for Green Transport Development 2. Implementation Opinions on Promoting High-quality Development to Achieve Carbon Peak and Carbon Neutralization	1. Regional channel ecological restoration project 2. Quality Inspection Standard for Ecological Revetment Works of Inland Waterway	1. Jiangsu Province Green Port Evaluation Index System. 2. Normalized use of shore power facilities by ships berthing at the port.	1.Ship fuel emission limit 2. Obsolete ships with high energy consumption and high emissions. 3. LNG power transformation.	1.Multimodal transport. 2.River, sea and river combined transport.
1."The Fourteenth Five-Year Plan" for Comprehensive Transportation Development in Shanghai 2.The 14th Five-Year Plan for the Construction of Shanghai International Shipping Center 3.Three-year Action Plan for Shanghai Green Port (2015-2017)	1. Ecological restoration of water area. 2. Ecological construction of transportation infrastructure.	1.The coverage rate of specialized berth shore power facilities will reach 100% in 2025. 2.Energy conservation and emission reduction technical transformation of container terminal handling equipment.	1.Standard of inland river ship types, and oil. 2. Obsolete ships with high energy consumption and high emissions. 3.LNG filling facilities. 4.Energy efficiency design index (EEDI) for new ships and Energy Efficiency Management Plan (SEEMP) for ships in use.	1.Multimodal transport 2.High-quality integrated collection and distribution network

of the shipping industry on the track of the rule of law, and has formulated and promulgated legislation and policies on carbon reduction in shipping at the national and local levels one after another, providing a normative basis to promote carbon reduction in shipping. In this process, China has made certain achievements but has also had shortcomings and faces a series of challenges.

3.1 Achievements of China's legislation and policies on shipping decarbonization

As we can see above, China has initially established a multi-level shipping carbon reduction regulation system oriented by the double carbon target and unified by the constitution, which covers many aspects and mechanisms. According to the different natures of regulatory instruments, China's legal system of shipping decarbonization can be divided into two types, namely, "command and control" and "incentive and regulation." Both have their respective strengths and cooperate with each other to provide a strong and diversified legal guarantee for carbon reduction in shipping.

First, the "command and control" rules have a high degree of compulsion, and the administrative subject sets a certain "shall" behavior pattern for each shipping subject through compulsory order. "Command and control" rules include the following:

(1) Plans, such as the Guizhou Province Carbon PeakImplementation Plan. It proposes that by 2025 and 2030, to achieve a target in which the proportion of new and updated new energy, clean energy-powered ships will reach 40%, the ship unit conversion turnover of carbon emissions intensity than in 2020 will decrease by about 9.5%. In 2022, the 14th Five-Year Plan for the Development of Tianjin Ports also proposes to achieve the target of the utilization rate of low-sulfur fuel oil for ships in port and the proportion of ships with electricity receiving facilities using shore power in port to reach 100% by 2025;
(2) Standards, such as the Green Port Evaluation Grade Standard and Technical Requirements for Ship Energy Consumption Data Collection and Reporting. Both are transportation industry standards; the former specifies the green port grade evaluation index system, score calculation method, and manner of grade evaluation, among others, while the latter specifies the scope of ship energy consumption data collection, ship energy consumption information and related data collection method, data quality assurance plan, and manner of data reporting, among others;
(3) Licensing, such as the Implementation Opinions on Accelerating the Green and Intelligent Development of Inland Waterway Ships, which proposes studying and implementing the access system of the Energy Efficiency Design Index (EEDI) for new domestic inland waterway ships;
(4) Monitoring, such as the Measures for the Management of Ship Energy Consumption Data and Carbon Intensity, which stipulate the collection and reporting of ship energy consumption data and verification rating;
(5) Administrative punishment, such as the Yangtze River Protection Law. Article 84 of Chapter 8, "Legal Liability," stipulates that if a ship with conditions for using shore power fails to use shore power in accordance with relevant state regulations, the competent department shall order to stop, give a warning, and impose a fine of 10,000 yuan or more than 100,000 yuan; if the circumstances are serious, a fine of If the circumstances are serious, a fine of more than 100,000 yuan and less than 500,000 yuan shall be imposed. The Guidance on Promoting the Green Shipping Development of the Yangtze River Economic Belt proposes to study the establishment of a shipping blacklist system and increase the punishment for non-compliant enterprises.

Second, the "incentive and regulation" rules have a highly voluntary nature, and the administrative subject indirectly guides shipping behavior that is beneficial to carbon reduction by providing economic benefits or navigational convenience. This type of control includes the following:

(1) Financial subsidies, such as the 2022 Shanghai Transportation Energy Conservation and Emission Reduction Special Support Funds Management Measures, which specify that for ship projects using liquefied natural gas instead of fuel oil, a one-time subsidy will be given according to 2500 RMB per ton of standard oil for the replaced fuel, the amount of subsidy for a single ship will not exceed 400,000 RMB, and the amount of subsidy will not exceed 30% of the total investment amount. For electric ship projects, 30% of the cost of the ship's power system shall be subsidized, of which 40% of the operating passenger ships shall be subsidized, and the maximum amount of subsidy for a single ship shall not exceed 5 million yuan. The Implementation Rules of the Interim Measures for the Management of Subsidy Funds for Green Low-carbon Port Construction in Shenzhen, which came into effect in 2018, states that for the construction of port shore power facilities and the transformation of ship shore power receiving facilities shall be subsidized according to 30% of the project construction and transformation costs, and the power supply demand fees for port shore power facilities shall be fully subsidized according to the actual generation;
(2) Tax relief, such as Article 4 of the Vehicle and Vessel Tax Law, which stipulates that vehicles and vessels that conserve energy and use new energy may be reduced or The Notice on Preferential Policies for Energy-saving and New Energy Vehicles and Vessels issued by the Ministry of Finance and other four departments in 2018 clearly exempts vessels whose main propulsion power unit is pure natural gas engine" from vehicle and vessel tax. In addition, the China (Zhejiang) Pilot Free Trade Zone Extended Area Program promulgated by the State Council in 2020 stipulates that LNG is allowed to enjoy a bonded policy as fuel for international vessels. With reference to the Interim Measures for the Operation and Management of Bonded Oil for International Vessels in China (Zhejiang) Pilot Free Trade Zone, LNG as fuel for international voyages can enjoy tax incentives of 9% VAT on import links and 1% import tariffs and consumption taxes;
(3) Economic incentives, such as the Opinions on Supporting the High-Quality Development of Modern Shipping Service Industry issued by the People's Government of Zhoushan City, Jiangsu Province in 2022. It is clearly stipulated that

green shipping projects that are recognized as directly related to carbon peak and carbon neutral shall be appropriately rewarded according to the construction investment of individual projects, and the standard of reward may be appropriately increased. The proportion of reward for a single project shall not exceed 30% of the construction investment, and the total amount shall not exceed 3 million yuan;

(4) Facilitation of navigation, such as in Guangdong Province and Jiangsu Province, which have both introduced specific implementation measures for LNG-powered vessels to have priority in passing through their gates. The Guidance on Priority Passage of LNG-powered Vessels by the Guangdong Provincial Department of Transportation stipulates that operating units shall give priority to accept, arrange, and dispatch LNG vessels' passage. The Management Measures for Priority Passage of Ships on Inland Waterways in Jiangsu Province states that LNG-powered ships are given priority passage and exempted from priority passage fees on the Beijing-Hangzhou Canal and Huaihe Waterway in Jiangsu Province, and LNG-powered ships pass the locks after dangerous cargo ships, container ships, and key emergency material ships. Other provinces are also studying the policy of giving priority to LNG-powered vessels; for example, the Shanghai Municipal People's Government proposed in the Three-year Action Plan for the Construction of the Shanghai International Shipping Center (2018–2020) to give priority to new energy and clean energy vessels in navigating through the locks, and the Anhui Provincial People's Government proposed to promote the implementation of transport structure adjustment and study the introduction of LNG-powered ships priority through the locks, priority berthing, and other support policies.

As China's legislation and policies on shipping decarbonization have been implemented diversely in local regions with different progress and for a relatively short period, there are no comprehensive national statistics on their implementation effects. However, the existing data show that several pieces of legislation and policies have achieved good results regarding certain aspects of shipping decarbonization. For example, in terms of shore power construction, dozens of Chinese ports have adopted command or incentive control systems to promulgate distinctive legislation and policies on port decarbonization (see Table 2 below). Among them, Tianjin Port, under the incentive of relevant preferential policies, has increased the use of shore power from 19 times in 2019 to 278 times in 2021 by taking measures such as wind and photovoltaic power generation, building a clean energy fleet, building a comprehensive energy management and control service platform, and promoting the use of shore power. The use rate of shore power and low-sulfur oil for its own ships has reached 100%. In 2021, compared with 2012, the cargo throughput of Tianjin Port increased by 12%, container throughput increased by 64%, and carbon emission intensity decreased by 16%. In addition, the Asia Clean Air Center, an international environmental protection organization, released the report "2020 Blue Port Pioneer: Evaluation of Air and Climate Synergy of Typical Ports in China" in April 2022. The report tracked and evaluated decarbonization actions of 11 typical Chinese coastal ports such as Ningbo Zhoushan Port, Shanghai Port, and Qingdao Port, and four typical inland ports, including Yueyang Port, Suzhou Port, Wuhu Port, and Jiujiang Port, for two consecutive years. The report shows that 14 of the 15 typical Chinese ports surveyed have reached the goal of 50% shore power coverage of specialized berths by the end of 2020, and the shore power coverage of four inland ports has reached 100%, double the abovementioned target. The use of shore power for port ships is evidently better than that for freight ships. Except for the missing data of Yingkou, Jiujiang, and Wuhu Ports, the use of shore power for port ships in the remaining 12 ports has essentially achieved 100%, exceeding the 90% target set forth in the Implementation Plan for Special Action on Ship and Port Pollution Prevention (2015–2020). See Table 3 for shore power construction and use of shore power for port ships of typical ports in China.

3.2 Challenges of China's legislation and policies on shipping decarbonization

While China's shipping carbon reduction legislation and policies have made the above achievements, the following shortcomings still exist, which affect the implementation of rules.

TABLE 2 Incentive Policies on Shore Power Construction and Use of Typical Ports in China.

Port	Relevant Legislation and Policies	Content regarding Encouraging Shore Power Construction and Shore Power Use
Shenzhen	Detailed Rules for the Implementation of Shenzhen Transport Special Funds for Port and Shipping in the Field of Green Transport Construction	Financial subsidies
Shanghai	Shanghai Port Green Convention	Priority of navigation
Tianjin	Notice of Tianjin Port and Waterway Administration on Measures to Further Promote the Use of Shore Power for Ships Arriving in Tianjin	Priority of navigation
Xiamen	Interim Measures of Xiamen Municipality on the Administration of the Use of Shore Power for Ships Berthing at Ports	Financial subsidies Economic rewards
Rizhao	Rizhao Port Group Ship Shore Power Management Measures	Priority of navigation
Suzhou	Jiangsu Province Notice on Further Promoting the Use of Shore Power for Ship Berthing	Priority of navigation Service fee exemptions
Jiujiang	Implementation Plan for Port and Ship Shore Power Facility Reconstruction and Promotion (2020)	Priority of navigation
	Guiding Opinions on Port Shore Power Charging	Electricity charge reductions

TABLE 3 Construction and Use of Shore Power in Typical Ports of China.

Port		Shore Power Coverage of Specialized Berths	Utilization Rate of Shore Power for Port Ships
Coastal port	Qingdao	100%	100%
	Yingkou	91%	——
	Ningbo Zhoushan	84%	100%
	Shenzhen	80%	100%
	Shanghai	79%	100%
	Rizhao	54.4%	100%
	Xiamen	50%	100%
	Tianjin	50%	100%
	Lianyungang	36.5%	100%
Inland port	Jiujiang	100%	——
	Yueyang	100%	100%
	Wuhu	100%	——
	Suzhou	100%	100%

(The utilization rate of shore power is primarily sourced from government information disclosure, and the calculation method is the ratio of the number of times that cargo ships use shore power to the number of berths that park in shore power. "——"means relevant data is missing.)

3.2.1 The strong "soft law" characteristic of the current normative system on shipping decarbonization

First, at the level of national legislation, since Article 2 of China's Air Pollution Prevention and Control Law clearly stipulates the implementation of synergistic control of particulate matter, sulfur dioxide, and other air pollutants and greenhouse gases, China's environmental law does not treat CO2 as an air pollutant; hence, it is not feasible to rely on the Air Pollution Prevention and Control Law to implement carbon reduction in shipping in China. At the same time, China has not yet issued the "Climate Change Response Law," which would specifically regulate greenhouse gases. Therefore, at the legal level, there are few regulatory bases for carbon reduction in shipping, which are mainly scattered across environmental laws related to watershed and wetland protection. This also indirectly leads to the limited scope of application of relevant provisions and regulatory subjects and incomplete coverage on shipping decarbonization; for example, the relevant provisions in the Yangtze River Protection Law are only applicable to ships and local governments passing in the Yangtze River basin.

At the same time, it is difficult to locate relevant provisions on carbon reduction in shipping in administrative regulations and local regulations. For example, from the aspect of administrative regulations, the Regulations on Prevention and Control of Marine Environment Pollution from Ships make general provisions on how to prevent and control marine pollution from ships and their related operation activities, including the discharge and reception of pollutants from ships, the prevention and control of pollution from ships' operation activities, and the emergency disposal of ship pollution accidents, but there are no provisions on how to deal with carbon dioxide emissions from ships and carbon leakage caused by oil leakages. In general, the regulation of carbon reduction in shipping in China is mainly concentrated in the low-level departmental normative documents and other policies, which has strong characteristics of "soft law."

As for local legislation, the regulation of carbon reduction in shipping mainly includes the implementation plan, development plan, and guidance issued by provinces and municipalities, and the binding force of the law is also weak. Carbon emissions from shipping are mobile, borderless, and cross-regional. The local legislation on carbon reduction of shipping is not unified because the legislative concept and content of each place are closely related to its economic development level and geographical location, which also limits the final realization of the carbon reduction effect of shipping.

Second, except for Article 84 of the Yangtze River Protection Law, which provides for warning and fines for "ships not using shore power according to regulations," most of the norms regulating carbon reduction in shipping are advocacy provisions and lack of supporting legal responsibilities. For example, in Chapter 3 of the Wetland Protection Law, "Wetland Protection and Utilization," Article 25 provides that shipping activities within the wetland should avoid changing the natural condition of the wetland and take measures to mitigate the adverse impact on the ecological function of the wetland. However, Chapter 6, "Legal Liability," does not see the corresponding administrative legal responsibilities such as fines and orders to suspend production and business. Once there is a situation of acidification of wetland waters and damage to ecological functions due to carbon leakage from ships, it is impossible to impose administrative sanctions on the relevant shipping entities, and the responsible person will only be liable for civil liability at most. Another example is that the Measures for the Management of Energy Consumption Data and Carbon Intensity of Ships, which stipulates in Article 5 of Chapter 2, "Data Reporting and Collection," that Chinese domestic marine vessels and inland river vessels shall record the energy consumption data of ships on a daily basis or on each voyage, and the energy consumption data recorded by ships shall

be kept for at least two years, but the measures do not set up a chapter of "Legal Liability.". According to Article 21 of Chapter 4, "Supervision and Administration,", if the maritime administration finds that a ship fails to report the ship's energy consumption data as required, it shall, in accordance with the Regulations of the PRC on the Prevention and Control of Pollution of the Marine Environment by Ships and Their Related Operating Activities and the requirements of these measures, be dealt with. Such a liability provision is too general and lacks operability and legal deterrence.

3.2.2 The normative content of established rules needs to be improved

Shipping decarbonization is a systematic project that involves shipping infrastructure, shipping technology and equipment, shipping organization systems, shipping governance mechanisms, and more aspects.

First, carbon emission trading mechanisms are out of place. At present, the institutional measures for carbon reduction in China's shipping industry are mainly the regulatory measures led by administrative organs and lack the participation of market-based mechanisms. Market-based mechanisms are designed to internalize the external costs of GHG emissions based on the polluter-pays principle (Wang et al., 2021)and provide economic incentives related to GHG emission reduction (Harilaos, 2012; Daniel, 2018). It has been manifest that the market transaction policy can enhance the economic and emission reduction potential more than the command control policy can (Wang et al., 2016).The adoption of carbon reduction measures based on market mechanisms is the current choice of instruments for regulating GHG emissions in many countries and the International Maritime Organization (Kirval and ÇaliŞkan, 2022). For example, the European Commission voted in July 2021 to adopt the "fit for 55" action plan package. The plan proposes to achieve at least a 55% reduction in GHG emissions by 2030 compared to 1990 emission levels and to achieve carbon neutrality by 2050 (Jeong et al., 2022). As part of the proposed legislation, the European Commission proposes to include shipping in the EU Emissions Trading System (EU ETS), which operates using the "allowances and trading" principle to cap the total amount of greenhouse gas emissions that can be emitted by factories, power plants, ships, and other entities. Over time, the cap is lowered, thereby gradually reducing the total amount of carbon emissions (Harilaos, 2021). In November 2022, the European Parliament, European Commission, and European Council reached a basic agreement on the inclusion of shipping in the EU ETS, with a preliminary agreement covering the timing, applicable ship tonnage, coverage of emissions from navigation, coverage of emissions, use of funds, and other specifics.

China has carried out carbon emissions trading pilot projects in seven provinces and cities, including Beijing, Tianjin, and Shanghai, since 2011 (Zhang et al., 2020), and in 2020, the Ministry of Ecology and Environment officially announced the Carbon Emissions Trading Management Measures (for Trial Implementation), which opened the construction of the national carbon emissions trading market. In 2021, the Carbon Emissions Registration Management Rules (for Trial Implementation), Carbon Emissions Trading Management Rules (for Trial Implementation), and Carbon Emissions Settlement Management Rules (for Trial Implementation) were issued one after another, providing strong rules to support the construction of China's carbon emission trading market.

However, according to the Notice on the Key Work Related to the Management of Enterprise Greenhouse Gas Emissions Reporting in 2022 issued by the Ministry of Ecology and Environment of China in March 2022, the industries covered by carbon emissions trading in China currently include power generation, petrochemicals, chemicals, building materials, iron and steel, non-ferrous, paper making, and civil aviation, and the shipping industry has not yet been included. Nonetheless, Shanghai has taken the lead in trying to include shipping in the carbon emission trading mechanism since 2015 and has made useful exploration of carbon emission accounting, carbon quota allocation, and trading rules for shipping enterprises. Unfortunately, China's carbon emissions trading has not yet covered most domestic shipping enterprises and international operating ships. In the future, China needs to introduce a carbon emission trading mechanism to reduce carbon emissions from shipping and construct detailed legal rules on the scope of participation of shipping enterprises, carbon emission accounting systems, and quota allocation scheme, among others, by combining the characteristics of carbon emissions from shipping.

Second, incentives for shipping decarbonization are fragmented and have not been fully promoted nationwide. Well-designed incentives can guarantee the independent choice of market players on the one hand, and help achieve the expected environmental goals of society on the other. Shipping carbon reduction incentives mainly include energy saving and emission reduction tax incentives, subsidies, rewards, navigation facilitation, and other contents. At the national legislation level, both Article 73 of the Yangtze River Protection Law and Article 101 of the Yellow River Protection Law are only advocacy provisions to encourage the development of incentives, which are more general and lack detailed implementation rules.

For local legislation, only some provinces and municipalities in China have introduced incentives owing to the different degrees of importance attached to carbon reduction in shipping. For example, Shenzhen issued the Interim Measures for the Management of Green Low-carbon Port Construction Subsidy Funds in Shenzhen in 2017 and 2018, and the Rules for the Implementation of the Interim Measures for the Management of Green Low-carbon Port Construction Subsidy Funds in Shenzhen to refine the management of shore power subsidy, clean energy-powered ship subsidy, ship exhaust gas purification facility subsidy, and ship online monitoring equipment subsidy. Shanghai issued the Shanghai Port Shore Power Construction Program in 2019, which formulated supporting policies for shore power construction subsidies, operation subsidies, preferential shore power service fees for ships calling at ports, and preferential shore power tariffs for port construction.

Meanwhile, Zhejiang Province issued in 2022 the Zhejiang Port Shore Power Incentive Scheme, which refines the scope and requirements of port shore power construction subsidies and specifies specific subsidy standards according to the type, frequency, capacity, and transformation completion time of shore power. From this, it can be seen that the implementation of China's shipping carbon reduction incentives is still stuck in pilot exploration at the local level and lacks the guidance of national unified implementation rules. This is not conducive to the formation of stable legislation or policy expectations for carbon reduction in shipping by relevant

enterprises and may reduce the enthusiasm of shipping enterprises for the construction of port shore power facilities and the use of ship shore power.

Finally, there is a lack of a financial support mechanism for carbon reduction in shipping industries. As a typical capital-intensive industry, the development of the shipping industry depends on the financial support provided by the financial system. One of the biggest obstacles to carbon reduction in shipping is the huge capital costs required for cleaner, energy-efficient technologies (Rebelo, 2020). The dual-carbon context requires strong financial support for alternative fuel use, new energy technology research and development, and port shore power retrofitting. As the green and low-carbon transformation of the shipping industry continues to advance, the demand for capital in the shipping industry is increasing daily. Providing strong financial support for carbon reduction in shipping can effectively guide enterprises to upgrade their technology and equipment, thus realizing industrial upgrading and green low-carbon transformation.

At present, China's shipping carbon reduction financial support mechanism is relatively scarce, which is not conducive to the research and development of energy-saving and emission-reduction technology and innovation. Both national and local legislation are in principle lacking operability. For example, according to the Guidance on Building Green Financial System jointly issued by seven ministries and commissions, including the People's Bank of China, the Ministry of Finance, and the Development and Reform Commission, green finance clearly includes "financial services provided for investment and financing, project operation, and risk management of green transportation projects," but the specific operation, financial support mechanism for shipping industry regarding management, approval process, and other contents have not been formulated and formed uniformity rules.

Article 22 of the Huzhou City Green Finance Promotion Regulations stipulates that financial institutions can provide medium- and long-term financial support for the construction of green roads, railroads, waterways, ports, and other green low-carbon transportation infrastructure. However, this article is a principle provision, and the specific rules of the way, type, standard, and application scope of financial support for shipping carbon reduction in practice are not yet clear. At the international level, 28 large banks in the world, including Citibank, Societe Generale, and Credit Suisse, have signed the Poseidon Principles, which aim to incorporate climate change factors into shipping financing decisions and have great normative value in promoting carbon neutrality in shipping (Rebelo, 2020; Kavussanos and Tsouknidis, 2021). The principles now cover more than 50% of total global shipping loans. The Poseidon Principles are a global industry framework, and under the trend of the globalization of green finance, China's legislation and policies on carbon reduction in shipping should respond to it.

4 Normative perfection: Recommendations for the improvement of China's legislation and policies on shipping decarbonization

Under the background of actively promoting carbon peaking and carbon neutrality, China has initially established a regulatory system for carbon reduction in shipping, but the relevant legislation and policies are still inadequate and face real challenges. Based on China's national conditions, this paper proposes the following suggestions for the improvement of shipping carbon reduction legislation and policies.

4.1 Strengthening mandatory force of legislation and policies on shipping decarbonization

On the one hand, the mandatory force of legislation and policies on shipping decarbonization should be enhanced. First, the legal rank of shipping carbon reduction legislation should be improved, and it is suggested that the State Council or the Ministry of Ecology and Environment and the Ministry of Transport should take the lead in formulating special administrative regulations or departmental regulations on shipping carbon reduction, coordinating the scattered policy norms and local legislation, strengthening the connection between institutional norms such as the construction of shore power in ports, the transformation of ships receiving electricity, the promotion of low-carbon powered ships and the verification of carbon emission data in shipping, and improving the carbon reduction norms of shipping.

More importantly, the legal responsibilities corresponding to the relevant systems should be clarified. A law without responsibility is a "tiger without teeth." Since the illegal behavior of shipping carbon reduction mainly violates the environmental management order and infringes on the public interest of the ecological environment, the legal responsibility of shipping carbon reduction is mainly public law responsibility, mainly administrative responsibility, and criminal responsibility should be investigated according to Chapter 6, Section 6, of the Criminal Law ("Crime of damaging environmental resources protection"). According to Article 9 of the Administrative Punishment Law, the legal responsibilities for carbon reduction in shipping include warning, notification and criticism, fine, confiscation of illegal income, confiscation of illegal property, suspension of license, reduction of qualification level, revocation of license, restriction of production and operation activities, order to stop production and business, order to close, restriction of practice, and administrative detention. In addition, since shipping carbon reduction violations may also cause ecological damage such as acidification of water bodies and reduction of biodiversity (Cooley and Mathis, 2013; Shi and Gullett, 2018), ecological restoration can be considered a legal responsibility for shipping carbon reduction.

At the same time, since shipping decarbonization not only refers to reducing carbon emissions of shipping but also includes "increasing carbon sink," therefore, "subscribing carbon sink" can be considered as one of the ways to fulfill the legal responsibility of carbon reduction in shipping. At present, in judicial practice, the courts in Xiamen, Zhangzhou, Ningde, and other places in China have explored attempts to make alternative restoration through the defendant's purchase of marine carbon sinks to compensate for the ecological damage caused by illegal fishing or sea sand mining. Xiamen also set up the first marine carbon sink trading platform and the first ecological judicial public-interest carbon account in the country. This method of responsibility fulfillment is not only helpful to solve the problems of insufficient restoration capacity of

responsible persons and limited actual restoration conditions, but it also contributes to the early realization of the double carbon goal.

4.2 Expanding normative content of legislation and policies on shipping decarbonization

On the other hand, the normative content of regulations should be expanded so as to provide an all-round and whole process legal basis for shipping decarbonization.

4.2.1 Providing normative support for shipping carbon emissions trading

First, China should provide regulatory support for carbon emission trading in shipping. At present, the legal mechanism of carbon reduction in China's shipping industry is dominated by control measures led by administrative organs and lacks the participation of market-oriented mechanisms. Carbon emissions trading in the shipping industry is an important means of market-based carbon reduction measures, which is a "cap-and-trade" system and a quantity-control approach. There are advantages in terms of certainty about mitigation outcomes and cost-effectiveness (Xing et al., 2020), while improving the total industrial output value (Zhang et al., 2020). Research also shows that emissions trading could reduce China's carbon intensity by 20.06% under the unconstrained situation by keeping the total GDP of the country unchanged (Zhang et al., 2017).

In the Chinese context, since the promulgation of the Measures for the Administration of Carbon Emission Trading (for Trial Implementation) in 2021, carbon emission trading has flourished nationwide. In this case, legislators should further improve the existing rules of China's carbon emission trading. In the primary market of carbon emissions trading, China should gradually expand the scope of carbon emissions trading, including the types of greenhouse gases and the industry sectors included in the carbon emissions trading system, and include the shipping industry in the national carbon emissions trading system. In the secondary market of carbon emissions trading, legislators should introduce incentives to promote the diversification of shipping enterprises' participation, and the competent authorities should formulate and improve the rules for trading baseline carbon emissions and certified voluntary emission reductions of shipping enterprises as soon as possible, determining the appropriate level of cap, carbon pricing (Aldy and Stavins, 2012; Hermeling et al., 2015; Rahim et al., 2016)and regulating the monopoly of emission allowances.

Moreover, legislators should improve the carbon emissions trading regulatory mechanism by combining the characteristics of shipping emission reduction. Among them, the collection of ship fuel consumption data and carbon emission data is particularly important for the development of regulations, and it is also a prerequisite for the smooth development of shipping carbon emission trading (Ibna et al., 2017; George et al., 2019). legislators should further improve China's shipping monitoring, reporting, and verification mechanism (MRV) based on the existing Measures for the Management of Energy Consumption Data and Carbon Intensity of Ships, clarify the content and format of the ship energy efficiency management plan and the annual energy consumption report of ships, refine the standards for the assessment of carbon intensity of ships, and also pay attention to the alignment of the relevant standards with the Paris Agreement and the dual carbon targets when designing specific rules.

4.2.2 Concretizing the "incentive and regulation" rules regarding shipping decarbonization

Second, based on local experience, the Ministry of Transport should take the lead in issuing national regulations on carbon reduction incentives for shipping, setting subsidies and rewards for all aspects of carbon reduction in shipping. Up to now, "incentive and regulation" rules, which have been promulgated on shipping decarbonization, are mainly focused on the promotion of low-carbon ports and low-sulfur fuel oil. In the future, types of subsidies/rewards should be expanded, including but not limited to subsidies/rewards for the construction of port shore power facilities, transformation of ship shore power receiving facilities, shore electricity price, shore power use, clean energy powered ships, facilities for purifying ship exhaust gas, online monitoring equipment of ship emissions, and so on. At the same time, the regulations should also specify and detail the standards, calculation methods, application procedures, approval and distribution, supervision, and management of subsidies/rewards by category, aiming at increasing the certainty, operability, and predictability of "incentive and regulation" rules regarding shipping decarbonization, guiding and promoting carbon reduction in shipping with positive incentives. In addition, under the existing framework of the Vehicle and Vessel Tax Law, legislators should conduct research on fuel consumption standards, product technical standards, and special inspection standards for energy-saving ships and new energy ships in line with energy-saving cars and new energy cars, formulate a "catalogue of energy saving and new energy ships exempted from vehicle and vessel taxes," exploring the extension of new energy tax reduction and exemption provisions to the use of low-sulfur oil, shore power, and clean energy ships other than LNG, so as to reduce the technical research and development and infrastructure operation costs of shipping enterprises in an all-round and whole process manner.

4.2.3 Constructing green financial rules that help shipping decarbonization

Finally, China should construct green financial rules to help shipping decarbonization. The China Banking Regulatory Commission (CBRC) and the China Insurance Regulatory Commission (CIRC) should formulate normative documents to (1) clearly stipulate the ways, types, standards, and scope of application of financial support for shipping carbon reduction; (2) establish the financial institutions' shipping carbon reduction investment assessment system and environmental information disclosure system, stipulate the project conditions for financial institutions to carry out assessment, the content of assessment and the subject, content, form, and period of information disclosure; (3) guide financial institutions to innovate green financial products specifically for carbon reduction behaviors, such as shipping infrastructure renovation and technology and equipment upgrading—for example, insurance for new energy ships can be introduced, certain premium preferences can be provided in combination with the carbon reduction of ships, and exclusive rates can be set for new energy ships; and (4) encourage banks, insurance companies, and other financial institutions to use carbon emission assessment as their decision-making basis for loans or underwriting. With reference to the Poseidon Principles, a standard can be established for quantitative assessment and disclosure of whether financial business conforms to the

dual carbon goals from four aspects: assessment, accountability, law enforcement, and transparency.

5 Conclusions

As an important response to climate change, China is continuing to promote the green and low-carbon transformation of the shipping industry under the framework of the rule of law to help achieve the goals of carbon peak and carbon neutrality. Previous research on shipping carbon reduction lacks investigation of Chinese context. This paper first gives a comprehensive literature review on measures for shipping decarbonization in terms of China's legal frameworks, with comments and suggestions for improvement. Specifically speaking, focusing on shipping decarbonization, we reviews relevant legislation and policies both at the national and local levels in China. To date, China has preliminarily established a multi-level shipping carbon reduction regulatory system guided by dual carbon goals and governed by its constitution. The normative content of the existing regulatory system covers shipping infrastructure, shipping technology and equipment, shipping organization system, shipping governance mechanism, and other sectors, including port shore power construction, transformation of ship power receiving facilities, promotion of green low-carbon ships (especially LNG-powered ships), shipping carbon emissions data verification, carbon emissions trading, and other specific institutional norms. Under the joint adoptions of a "command and control" system and "incentive and regulation" system, China's legislation and policies on shipping decarbonization has achieved initial positive results. However, China's' legislation and policies on shipping decarbonization are still insufficient in two aspects, affecting the effectiveness of regulations. On the one hand, the normative system of shipping decarbonization has a strong "soft law" feature, and its mandatory force is insufficient. On the other hand, the normative content of legislation and policies on shipping decarbonization is limited and requires improvement. For example, China urgently needs to introduce a market mechanism of carbon emission trading into shipping decarbonization, its incentive measures for shipping decarbonization are fragmented and have not been uniformly promoted nationwide, and there is also a lack of a financial support mechanism for shipping decarbonization. Correspondingly, when China improves its legislation and policies on shipping decarbonization in the future, on the one hand, it is necessary to strengthen the mandatory force of that normative system by improving the legal hierarchy of relative legislation and clarifying the specific legal responsibilities of different legal systems. On the other hand, China should expand the normative content of its legislation and policies on shipping decarbonization to provide comprehensive and full process legal support for shipping decarbonization by providing a legal basis for shipping carbon emissions trading, concretizing the "incentive and regulation" rules regarding shipping decarbonization, and constructing green financial rules that help shipping decarbonization.

Author contributions

WY and XC completed the literature collection and wrote the main part of the article, contributing equally to this paper, and are therefore listed as the co-first author. YL provided the framework for the article and supervised the work, and is therefore listed as the second and corresponding author. All authors contributed to the article and approved the submitted version.

Funding

This research was funded by National Social Science Fund of China (22CFX041).

Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Publisher's note

References

Aldy, J. E., and Stavins, R. N. (2012). The promise and problems of pricing carbon: Theory and experience. *J. Environ. Dev.* 21, 152–180. doi: 10.1177/1070496512442508

Asia Clean Air Center *2020 blue harbor pioneer*. Available at: http://allaboutair.cn/uploads/soft/220520/2020蓝港先锋.pdf.

Black, J. (2008). Constructing and contesting legitimacy and accountability in polycentric regulatory regimes. *Regul. governance* 2, 137–164. doi: 10.1111/j.1748-5991.2008.00034.x

Bloor, M., Baker, S., Sampson, H., and Dahlgren, K. (2015). Enforcement issues in the governance of ships' carbon emissions. *Laws* 4, 335–351. doi: 10.3390/laws4030335

Bouchery, Y., and Fransoo, J. (2015). Cost, carbon emissions and modal shift in intermodal network design decisions. *Int. J. Production Economics* 164, 388–399. doi: 10.1016/j.ijpe.2014.11.017

Chen, Y. (2020) *The green transformation road of tianjin port, where the throughput has innovated repeatedly and the emission intensity has declined year by year, China discipline inspection and supervision report*. Available at: https://www.tjjw.gov.cn/news/2022/07/07/detail_2022070768675.html.

Chen, J., Zhang, W., Song, L., and Wang, Y. (2022a). The coupling effect between economic development and the urban ecological environment in shanghai port. *Sci. Total Environ.* 841, 156734. doi: 10.1016/j.scitotenv.2022.156734

Chen, J., Zhuang, C., Xu, H., Xu, L., Ye, S., and Nelson, R. (2022b). Collaborative management evaluation of container shipping alliance in maritime logistics industry: CKYHE case analysis. *Ocean Coast. Manage.* 225, 106176. doi: 10.1016/j.ocecoaman.2022.106176

Cooley, S. R., and Mathis, J. T. (2013). Addressing ocean acidification as part of sustainable ocean development. *Ocean Yearbook Online* 27, 29–47. doi: 10.1163/22116001-90000153

Daniel, B. (2018). "Regulating greenhouse gas emissions from ships: The role of the international maritime organization," in *The 50 year legacy and emerging issues for the years ahead*. Eds. H. Scheiber, N. Oral and M. Kwon (Brill/Nijhoff). doi: 10.1163/9789004343146_019

Eide, M. S., Chryssakis, C., and Endresen, Ø. (2013). CO2abatement potential towards 2050 for shipping, including alternative fuels. *Carbon Manage.* 4, 275–289. doi: 10.4155/cmt.13.27

George, P., de Sousa Pessôa, T., Dessypris, N., Barfod, M. B., and Harilaos, N. P. (2019). Monitoring the carbon footprint of dry bulk shipping in the EU: An early assessment of the MRV regulation. *Sustainability* 11, 5133. doi: 10.3390/su11185133

Halim, R., Kirstein, L., Merk, O., and Martinez, L. (2018). Decarbonization pathways for international maritime transport: A model-based policy impact assessment. *Sustainability* 10, 2243. doi: 10.3390/su10072243

Harilaos, N. (2012). Market-based measures for greenhouse gas emissions from ships: a review. *WMU J. Maritime Affairs* 11, 211–232. doi: 10.1007/s13437-012-0030-5

Harilaos, N. (2021). Shipping decarbonization in the aftermath of MEPC 76. *Cleaner Logistics Supply Chain* 1, 100008. doi: 10.1016/j.clscn.2021.100008

Hedley, A., Rock, N., and Zaman, P. (2016) *Maritime GHG emissions: The Paris agreement, an IMO MRV and 'market-based measures' – looking forward to MEPC 69*. Available at: https://www.reedsmith.com/en/perspectives/2016/03/maritime-ghg-emissions-the-paris-agreement-an-imo.

Hermeling, C., Klement, J. H., Koesler, S., K¨ohler, J., and Klement, D. (2015). Sailing into a dilemma: an economic and legal analysis of an EU trading scheme for maritime emissions. *Transport Res. Pol. Pract.* 78, 34–53. doi: 10.1016/j.tra.2015.04.021

Hughes, E., Flagg, S., Deggim, H., and Micallef, S. (2017). Control of emissions to air from international shipping. *Ocean Yearbook Online* 31, 452–471. doi: 10.1163/22116001-03101017

Ibna, Z., Kayvan, P., Rose, N., Shervin, Y., and Shirley, C. (2017). Challenges and opportunities of big data analytics for upcoming regulations and future transformation of the shipping industry. *Proc. Eng.* 194, 537–544. doi: 10.1016/j.proeng.2017.08.182

IMO (2020) *Fourth IMO GHG study 2020–final report*. Available at: https://www.imo.org/en/ourwork/Environment/Pages/Fourth-IMO-Greenhouse-Gas-Study-2020.aspx.

Jeong, B., Kim, M., and Park, C. (2022). Decarbonization trend in international shipping sector. *J. Int. Maritime Safety Environ. Affairs Shipping* 6, 236–243. doi: 10.1080/25725084.2022.2156155

Kavussanos, M. G., and Tsouknidis, D. A. (2021). "Green shipping finance: Existing initiatives and the road ahead," in *New maritime business. WMU studies in maritime affair*. Eds. B. W. Ko and D. W. Song (Berlin, Germany: Springer). doi: 10.1007/978-3-030-78957-2_6

Kirval, L., and ÇaliŞkan, U. Y. (2022). Influence of the European union (EU) on international maritime organization (IMO) about the market-based measures on emissions. *Int. J. Environ. Geoinformatics* 9, 146–153. doi: 10.30897/ijegeo.1047467

Kujanpää, L., and Teir, S. (2017). Implications of the new EU maritime emission monitoring regulation on ship transportation of CO 2. *Energy Proc.* 114, 7415–7421. doi: 10.1016/j.egypro.2017.03.1871

Lee, J. G. (2019). International regulations of greenhouse gas emissions from international shipping. *Asia-Pacific J. Ocean Law Policy* 4, 53–78. doi: 10.1163/24519391-00401003

Lindstad, H., and Eskeland, G. S. (2015). Low carbon maritime transport: How speed, size and slenderness amounts to substantial capital energy substitution. *Transportation Res. Part D: Transport Environ.* 41, 244–256. doi: 10.1016/j.trd.2015.10.006

Liu, Z. (2022). On the legalization path of carbon emission management in China under the background of "dual carbon". *Sci. Law* 3, 94–104. doi: 10.16290/j.cnki.1674-5205.2022.03.005

Nast, T. (2013). The response of the international shipping industry to global climate change. *J. Maritime Law Commerce* 44, 30.

Rahim, M. M., Islam, M. T., and Kuruppu, S. (2016). Regulating global shipping corporations' accountability for reducing greenhouse gas emissions in the seas. *Mar. Policy* 69, 159–170. doi: 10.1016/j.marpol.2016.04.018

Rebelo, P. (2020). *Poseidon principles: Legal directions for implementation & enforcement* (City Law School Research Paper).

Savaresi, A. (2016). The Paris agreement: a new beginning? *J. Energy Natural Resour. Law* 34, 16–26. doi: 10.1080/02646811.2016.1133983

Shi, Y., and Gullett, W. (2018). International regulation on low-carbon shipping for climate change mitigation: Development, challenges, and prospects. *Ocean Dev. Int. La* 49, 134–156. doi: 10.1080/00908320.2018.1442178

Shu, Y., Zhu, Y., Xu, F., Gan, L., Lee, P. T., Yin, J., et al. (2022). Path planning for ships assisted by the icebreaker in ice-covered waters in the northern Sea route based on optimal control. *Ocean Eng.* 267, 113182. doi: 10.1016/j.oceaneng.2022.113182

Sun, L., Ding, P., Xiong, Y., Liu, W., and Hu, Z. (2022). Carbon emission reduction of shore power from power energy structure in China. *Front. Mar. Sci.* 9. doi: 10.3389/fmars.2022.1077289

Wan, Z., Makhloufi, A., Chen, Y., and Tang, J. (2018). Decarbonizing the international shipping industry: Solutions and policy recommendations. *Mar. pollut. Bull.* 126, 428–435. doi: 10.1016/j.marpolbul.2017.11.064

Wang, K., Xian, Y., Zhang, J., Li, Y., and Che, L. (2016). Potential carbon emission abatement cost recovery from carbon emission trading in China. *J. Model. Manage.* 11, 842–854. doi: 10.1108/jm2-03-2016-0027

Wang, S., Zhen, L., Psaraftis, H. N., and Yan, R. (2021). Implications of the EU's inclusion of maritime transport in the emissions trading system for shipping companies. *Engineering* 7, 554–557. doi: 10.1016/j.eng.2021.01.007

Xiao, G., Wang, T., Chen, X., and Zhou, L. (2022). Evaluation of ship pollutant emissions in the ports of Los Angeles and long beach. *J. Mar. Sci. Eng. 10* 9, 1206. doi: 10.3390/jmse10091206

Xing, H., Spence, S., and Chen, H. (2020). A comprehensive review on countermeasures for CO2 emissions from ships. *Renewable Sustain. Energy Rev.* 134, 110222. doi: 10.1016/j.rser.2020.110222

Xu, L., Shi, J., and Chen, J. (2022a). Agency encroachment and information sharing: cooperation and competition in freight forwarding market. *Maritime Policy Manage.* 1, 1–14. doi: 10.1080/03088839.2021.1990428

Xu, L., Xie, F., and Wang, C. (2021a). Passive or proactive capacity sharing? a perspective of cooperation and competition between two regional ports. *Maritime Policy Manage.* 1, 1–18. doi: 10.1080/03088839.2021.1876938

Xu, L., Di, Z., and Chen, J. (2021b). Evolutionary game of inland shipping pollution control under government co-supervision. *Mar. pollut. Bull.* 171, 112730. doi: 10.1016/j.marpolbul.2021.112730

Xu, L., Zou, Z., and Zhou, S. (2022b). The influence of COVID-19 epidemic on BDI volatility: An evidence from GARCH-MIDAS model. *Ocean Coast. Manage.* 229, 106330. doi: 10.1016/j.ocecoaman.2022.106330

Zhang, H. (2017). The 21st century maritime silk road and the leading function of the shipping industry. *Rethinking Silk Road*, 43–55. doi: 10.1007/978-981-10-5915-5_2

Zhang, W., Li, J., Li, G., and Guo, S. (2020). Emission reduction effect and carbon market efficiency of carbon emissions trading policy in China. *Energy* 196, 117117. doi: 10.1016/j.energy.2020.117117

Zhang, C., Shi, D., and Li, P. (2017). The potential effect of china's implementation of inter-provincial carbonemissions trading. *Finance Trade Econ.* 38 (1), 43–55.