frontiers | Frontiers in Marine Science

TYPE Policy and Practice Reviews
PUBLISHED 14 October 2022
DOI 10.3389/fmars.2022.1028388

OPEN ACCESS

EDITED BY
Kum Fai Yuen,
Nanyang Technological University, Singapore

REVIEWED BY
Yen-Chiang Chang,
Dalian Maritime University, China
Juan Moreno-Gutiérrez,
University of Cádiz, Spain

*CORRESPONDENCE
Xiaofei Liu
liuxiaofei1@mail.sdu.edu.cn

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

RECEIVED 26 August 2022
ACCEPTED 21 September 2022
PUBLISHED 14 October 2022

CITATION
Liu X (2022) The supervision and multi-sectoral guarantee mechanism of the global marine sulphur limit—assessment from Chinese shipping industry.
Front. Mar. Sci. 9:1028388.
doi: 10.3389/fmars.2022.1028388

The supervision and multi-sectoral guarantee mechanism of the global marine sulphur limit—assessment from Chinese shipping industry

Xiaofei Liu*

Political Science and Law School of Weifang University, Weifang, China

To significantly reduce sulfur oxides emissions from fossil fuel-powered ships, reduce air pollution in ports and slow ocean acidification, the International Maritime Organization (IMO) has imposed the new 0.50%m/m limit (reduced from 3.50%m/m in the past) on sulphur in ships' fuel oil. This has given rise to a host of issues regarding fuel replenishment operations, safe operation management, maritime regulation, and coordinated governance of air and climate. In response to ocean acidification and climate change, regulations on the use of low-sulfur oil or alternative fuels by ships greatly reduce sulfur oxide emissions, but have no significant impact on reducing greenhouse gas emissions. In fact, the refining process for low-sulfur fuels and the use of the gas cleaning system on ships both increase energy consumption and carbon dioxide emissions. To ensure the decarbonization process of shipping industry, there is an urgent need for a conceptual change in global ocean governance so as to promote the coordinated governance of air pollution and climate change. China's conception of "a maritime community with a shared future" provides a new model for global ocean governance. The Chinese government has formulated regulations at different levels to promote the coordinated management of atmospheric pollutants and greenhouse gas emissions. Regarding supervision of sulfur oxide emissions from ships, this study proposes to build a multi-department collaborative supervision mechanism from marine fuel life cycle to enhance sulfur oxide monitoring and risk control capabilities. Specific measures of the proposed supervision mechanism include: the joint supervision of compliant fuel supply, the compliant fuel information disclosure platform, a joint law enforcement mechanism for atmospheric pollution, the ability of intelligent ship exhaust monitoring, and the construction of port power infrastructure.

KEYWORDS

marine sulphur limit, emission control area, air and climate governance, maritime climate change, exhaust gas cleaning system, maritime supervision

1 Introduction

In 2020, the International Maritime Organization (IMO) imposed a regulation on permitted sulfur content in the fuel oil used on board ships, also known as the IMO Sulphur Limit 2020 for Ships Fuel Oil (IMO, 2020). The new marine sulphur limit has caused considerable controversy, which has been pushed to a new high by the fuel quality problems in Singapore in 2022. As a hub port for global marine fuel bunkering, Singapore has played a crucial role in the implementation of the global marine sulfur limit policy. The Singapore government has been actively implementing the new limit since the (IMO, 2020) came into force. In addition to formulating policy guidance for the (IMO, 2020), the Maritime and Port Authority of Singapore (MPA) has been working closely with the shipping industry to ensure the availability of compliant and clean fuels in Singapore (MPA, 2020a). Nevertheless, since February to April 2022, about 200 ships had reported bunkering high-sulfur marine fuel oil contaminated with Chlorinated Organic Compounds (COC) in Singapore. Of these, about 80 ships have reported various issues with their fuel pumps and engines (MPA, 2022a). In response to so many fuel quality incidents, MPA launched a preliminary investigation and reported that these contaminated fuel was from Glencore Singapore Pte Ltd (MPA, 2022b). Low sulfur fuel has also been reported to have quality problems. From June to July 2022, pollution problems were found in several ultra-low sulfur fuel oil (VLSFO) samples in the US Gulf region and Amsterdam, Rotterdam and Antwerp (MARITEC, 2022). The use of inferior fuel oil on ships will lead to damage to power facilities and even loss of power of the whole ship. In addition, exposure to volatile gases from poor-quality fuel can also endanger the health of the crew (Qiu, 2019). The occurrence of such fuel quality incidents is definitely not accidental. Since the implementation of the (IMO, 2020), there have been disputes over the fuel quality, the safety of using low-sulfur oil, the compliance cost of installing an exhaust gas scrubber, and the environmental impact of washing water (Johannes et al., 2020).

The new limit of sulphur content in ships' fuel oil is an environmental protection policy, emerging within the trend of energy saving and emission reduction in the shipping industry. According to a study submitted by Finland to the IMO, the implementation of the (IMO, 2020) can reduce sulphur dioxide (SOx) emissions, which will improve the health of the population, especially those living near ports and coasts, and help prevent premature deaths (IMO, 2016). IMO has predicted that since (IMO, 2020) came into force on January 1, 2020, total sulphur oxide emissions from ships would have been reduced by 77% (IMO, 2020). So the resulting reduction in SOx emissions from ships is having major health and environmental benefits for the world, particularly for populations living close to ports and coasts. The (IMO, 2020) concerns regulations on the ship use or fuel carriage, thus, from January 1, 2020, the sulphur content of marine fuel globally cannot exceed 0.5% m/m (mass by mass); from March 1, 2020, only ships equipped with an Exhaust Gas Cleaning System (EGCS) can carry non-compliant fuel, which is only for combustion purposes for propulsion or operation on board a ship; when the compliant fuel cannot be obtained, a Fuel Oil Non-Availability Report (FONAR) must be submitted to the flag state and the competent authority of the next port (IMO, 2020). The Exhaust Gas Cleaning System is an equivalent under regulation 4.1 of of Annex VI of *MARPOL Convention*. According to the provision, "the Administration may allow any fitting, material, appliance or apparatus to be fitted in a ship as an alternative to that required by this Annex if such fitting, material, appliance or apparatus is at least as effective as that required by this Annex." There are three compliance methods for shipowners and ship operators: Firstly, use compliant fuel with a sulphur content of not more than 0.5% m/m; Secondly, use alternative fuels such as Liquefied Natural Gas (LNG), Methanol, Hydrogen, Biofuels and so on; Thirdly, install a compliant alternative device, such as the exhaust gas scrubber approved under Article 4 of Annex VI in *the International Convention for the Prevention of Pollution from Ships* (*MARPOL Convention*) as an equivalent method to meet the sulphur limit requirement (Kevin and Rickard, 2014). In the above three schemes, it is noted that choosing the scrubber is a short-term response, while it is a response with long-term investment value to choose the alternative fuels.

The above regulation takes various measures regarding the allowable limit of sulfur content in marine fuel oil, and focuses too much on the reduction of sulfur oxide emissions. But they ignore the synergistic effect of promoting the reduction of atmospheric pollutants and greenhouse gases from the perspective of the whole life cycle of shipping (Haakon et al., 2017). As a matter of fact, emissions from fossil fuels powered ships include greenhouse gases (GHG), sulfur oxides (SOx), nitrogen oxides (NOx), chlorofluorocarbons (HFC), carbon monoxide (CO), volatile organic compounds (VOCs), fine particulate matter (PM) and other air pollutants that are harmful to health (Kopel, 2017). The definition of the synergistic relationship between atmospheric pollutants and greenhouse gases first found in the *Climate Change 2001: Synthesis Report*, the fourth volume of the *Third Assessment Report of the United Nations Intergovernmental Panel on Climate Change (IPCC)* released in 2001. The (IMO, 2020) ignores this correlation and fails to achieve the synergistic effect of addressing ocean acidification and climate change. In the three years before and after the implementation of this policy, there have been constant debates over it, including the quality of mixed low-sulfur oil products, the operational safety of using low-sulfur oil, the compliance cost of installing EGCS, and the environmental impact of washing water. Furthermore, the COVID-19 pandemic has complicated the implementation and supervision of these sulfur restrictions. Since January 2020, the pandemic has led to great changes in the mode of port state supervision and inspection (Tokyo Mou). For example, the Port

State Control (PSC) inspection, which is mainly based on the non-contact intelligent law enforcement, has reduced the inspection rate of boarding ships, covering up the problems inherent in the (IMO, 2020).

Despite a long preparation period before the implementation of the (IMO, 2020), as well as an effective PSC inspection mechanism to guarantee the implementation, the disputes over the new limit are not reduced. The huge number of ships sailing in the waters under China's jurisdiction and the complex routes pose a huge challenge: the supervision policies on ship exhaust emissions, the competent authority's supervision ability of illegal ships, and maritime supervision technology. China is a Class A member of the IMO and a member of the Tokyo Memorandum of Understanding (Tokyo Mou). With the increasingly stringent global environmental restrictions, China has taken a series of measures to create a healthy and sustainable shipping ecology. The aim is to promote the pollution and carbon reduction in the shipping industry as well as the implementation of the IMO, 2020. The emission reduction of NOx and PM, as well as GHG emission reduction and SOx emission reduction have common problems in terms of mechanism. This study reflects and examines the problems existing in the practice of SOx emission reduction and the legal framework. This will not only help to improve the legal mechanism for reducing marine sulfur oxides, but also provide experience for reducing NOx, PM and GHG emissions. In addition, the implementation of the IMO-mandated Shipping Carbon Intensity Index (CII) is still months away, and however industry criticism of the indicator is mounting. This is the most significant green-related legislation introduced by the IMO since the introduction of the (IMO, 2020). The two regulations are equally controversial and lack consideration of emission reductions in the whole life cycle, making the reflection on (IMO, 2020) more meaningful. Based on the regulatory framework of the marine sulfur limit, this study analyzes the difficulties in the implementation of the (IMO, 2020), and investigates the problems in China's maritime supervision policy, law enforcement, and policy guarantee. Based on China's conception of "a maritime community with a shared future", this study proposes a maritime supervision and multi-sectoral guarantee mechanism for the new limit of sulphur content in ships' fuel oil, so as to improve the legal mechanism for marine emission reduction and realize the coordinated governance of air and climate in the marine field.

2 Literature review

In 1997, the Conference of the Contracting Parties of IMO adopted the amendments to Annex VI of *MARPOL Convention*, which shifted the focus of the shipping industry from safe shipping operation to marine pollution prevention and emission reduction. China officially ratified its accession to *MARPOL Convention* Annex VI in August 2006. During this period, domestic scholars began to study the legal system for emission reduction of sulfur oxides by sea transportation (Chen, 2009), and had primary understanding of the coordinated control of air pollutants and greenhouse gases (Chen and Gao, 2019). In December 2015, the Ministry of Transport of China issued the *Implementation Plan for the Ship Emission Control Zones in the Pearl River Delta, Yangtze River Delta and Bohai Rim (Beijing-Tianjin-Hebei) Waters*. This regulation shows that the Chinese government actively promotes the emission reduction of sulfur oxides in shipping and is fully determined to fulfill its obligations under international conventions. The *United Nations Convention on the Law of the Sea* expands the responsibilities of port states. In order to improve the port state control system for ship pollution, it is necessary to translate the implementation and guarantee mechanism of international conventions on ship pollution prevention and control into domestic law (Jiang and Jiang, 2016). There are two different views on the existence of SOx emission control areas (ECA). According to the Regulation 2 (11) of Annex VI of *MARPOL Convention*, "SOx emission control area means an area where the adoption of special mandatory measures for SOx emissions from ships is required to prevent, reduce and control air pollution from SOx and its attendant adverse impacts on land and sea areas." One point of view is that the shipping industry has long been outside the international emission reduction regulatory system in the past and that *MARPOL Convention* and its Annex VI are preliminary explorations on international maritime emission reduction. The ECAs are of great significance for sulfur oxide emission reduction by sea transport, and should be further expanded (Kevin and Rickard, 2014). The other view is that extending the strict regulations on sulfur emission control zones to a global scale will have negligible or negative environmental benefits, which will reduce the incentive to develop clean fuels and improve energy efficiency while increasing the risk of global warming (Haakon and Eskeland, 2016).

Both domestic and international scholars are concerned about the pros and cons of three compliance measures proposed by the IMO for the shipping industry, and put forward some suggestions. The international community is highly concerned about the composition of the washing water used in the EGCS and the quality of the port water. Some scholars believe that the IMO's permission to use open-loop scrubbers for emission reduction will not reduce the impact of emissions from ships on ocean acidification, and that this environmental policy lacks scientific understanding of washing water as a by-product of emission reduction (Johannes et al., 2020). The new sulfur limitation regulation will slow down the transition from traditional fuels to diversified fuels. Both technical and cost factors are uncertainties for emission reduction and pose challenges to the refining industry (Halffa et al, 2019). But the sulfur limit regulation will benefit port air conditions while enabling the refining industry to profit from major regulatory changes, so contracting parties should

implement these regulations as soon as possible, and impose severe penalties if necessary to ensure the effectiveness of the convention (Brown, 2019). Chinese scholars believe that IMO contracting parties should take measures to supervise the use of fuel oil by ships in accordance with the global marine sulfur limit. At the same time, the shipping authorities, shipping companies, oil refiners and crews should prepare for the implementation of the new marine sulfur limit (Gou, 2019), so as to deal with risks such as the compliance cost of scrubbers and the quality stability of low-sulfur oil (Gou, 2019).

Domestic and international scholars have reached a consensus on the conclusion that the reduction measures of marine sulfur oxides emission has partly led to the increase of greenhouse gases. Under the IMO regulatory framework, there is a correlation and conflict between sulfur oxides and nitrogen oxides and greenhouse gas emission reduction. However, the "sulfur limit" regulatory system ignores the contradictory relationship between shipping sulfur oxides and greenhouse gas emissions reduction, resulting in incoordination in emission reduction practices. In the process of implementing the (IMO, 2020), the inconsistency between the various emission reduction targets and mechanisms of IMO has become more and more obvious. For example, the refining process for refining low-sulfur fuel oil and the use of scrubbers on ships increase energy use, which in turn increases carbon dioxide emissions (Xu, 2008). And the three compliance measures for shipping sulfur oxide emissions reductions has little contribution to climate change mitigation (Paul, 2014). Due to the high production cost of low-sulfur fuel, ships will lower the sailings speed to save fuel, which however increases carbon dioxide emissions to a certain extent (Haakon et al., 2017). In view of the correlation between sulfur oxides and greenhouse gases emitted by ships, China should legislate on the basis of the differences between the two, and establish a coordinated control system for atmospheric emissions from ships (Yuan and Tong, 2017). IMO implements the principle of "non-preference and non-discrimination" for ships. With ships as the regulatory object (Hou, 2017), the IMO regulation is likely to violate the principle of "common but differentiated responsibilities" and imposes additional emission reduction burdens on developing countries (Xiao, 2017). There are many legal, economic and policy issues related to the coordination of marine sulfur oxides and greenhouse gas emissions reduction strategies (Bosch, 2019).

The emission reduction of marine sulfur oxides is an emission reduction problem of marine pollutants and also air pollutants, which is related to human health. The marine sulfur oxide emission reduction is less concerned than maritime greenhouse gas emission reduction. The main reason is that the international community recognized the harm of sulfur oxides earlier than greenhouse gases. Rich experience has been accumulated in the century-long emission reduction of sulfur oxides on land, which provides reference for the maritime emission reduction. The reduction of greenhouse gas emissions has not yet achieved the goal of slowing global temperature rise. Therefore, climate change is the most arduous challenge faced by the international community. But the battle against air pollutants is not over, and the problems with implementing the new standards are being tested. The contradiction between regional emission reduction policy and unbalanced maritime supervision leads to the difference of emission reduction effect. The current research on the marine emission reduction mechanism of IMO is fragmented. Although the domestic and international scientific communities have generally recognized the deficiencies in the implementation of the new regulation, there is still a lack of reflection on the implementation mechanism of the regulation. As the implementation of the (IMO, 2020) is about to reach its third year, the study of the new global marine sulfur limit regulation will help to reflect on the marine emission reduction from both the regulatory framework and the implementation mechanism. This paper analyzes the obstructive factors affecting the implementation effect of the regulation, and puts forward suggestions to improve the implementation mechanism, so as to provide reference for the decarbonization of the shipping industry and the promotion of alternative fuels.

3 The background and legal framework of the marine sulphur limit

3.1 Background

In the past few decades, ocean-going vessels mainly used heavy fuel oil (HFO) and its combustion produces a large amount of sulphur oxides (SOx), nitrogen oxides (NOx), particulate matter (PM) and other atmospheric pollutants (UK, 2011). In addition, the large tonnage global shipping, will inevitably involve significant fuel consumption and the resultant exhaust emissions, cause major air pollution (Eyring et al., 2010). With the intensification of air pollution, the international community is paying increasing attention to air environmental protection, energy saving. Emission reduction policies are being formulated by international conventions for the shipping industry. The IMO Marine Environment Protection Committee (MEPC) has long recognized the serious impact of ship exhaust pollution on the atmosphere and human health. The MEPC has worked with member states to formulate relevant treaties on the pollution caused by ships. The emission reduction obligations of the contracting states are clearly stipulated and the future development of shipbuilding is guided in the direction of green policy and energy saving.

The final reduction restriction of the (IMO, 2020) is 0.5% m/m. It took more than 20 years to reduce from the initial 4.5% m/m to 3.5% m/m, then to 1.5% m/m, and finally to 0.50% m/m. In

1997, the *MARPOL Convention* Conference of States Parties passed Annex VI, entitled, *Regulations for the Prevention of Air Pollution from Ships*. It is stipulated in Article 14 of Annex VI which is that, the sulphur content of any fuel used on ships shall not exceed 4.5% m/m, and the sulphur content of any fuel used on ships in the sulphur emission control area, shall not exceed 1.5% m/m. The pollution caused by ship exhaust attracts more and more attention from the international community. At the MEPC 53 conference in July 2005, Annex VI of the *MARPOL Convention* began to be revised, focussing on the revision of sulphur content in ships' fuel oil, aiming to reduce sulphur oxide emissions by reducing the marine sulphur limit. At the same time, MEPC successively established four international ship ECAs, these being the Baltic Sea, North Sea waters (including the English Channel), 200 nautical miles from the coast of the United States and Canada and the waters adjacent to a certain area of the coast of Puerto Rico (the United States) and the Virgin Islands (the United States), in an effort to control and reduce the emissions of ship pollutants within 0.1% m/m limit in the ECAs (IMO, 2013).

At the first meeting of the IMO Air Pollution Working Group held in November 2006, a new fuel sulphur content limit was proposed for the first time. The limitation of 4.5% m/m for ordinary waters and 1.5% m/m for ECAs having been used before. As the different parties insisted on their own interests with quite different opinions, no compromise was reached. At the MEPC 57 held in March 2008, all parties finally reached an agreement on a sulphur content reduction plan which was approved at MEPC 57 (Tian, 2017). According to the MEPC 57, the limitation was to be reduced to 3.5% m/m from January 1, 2012 and to 0.5% m/m from January 1, 2020. Equivalent measures could be used to achieve the emission reduction target in 2020. At the same time, it was stipulated that, the implementation of the 2020 global standards is to be reviewed by IMO experts. If the implementation conditions cannot be met, the application date may be postponed to 2025 (Xiao, 2017). In October 2018, MEPC held its 73rd session (MEPC 73) and introduced amendments to the *MARPOL Convention*, focusing on amendments to the *Regulations for the Prevention of Air Pollution from Ships* (Gou, 2019). It is stipulated that, from January 1, 2020, the sulphur content of marine fuel shall not exceed 0.5% m/m globally. Two types of compliant alternative measures are proposed, namely, the use of LNG or marine diesel, or the adoption of equivalent alternative measures, such as the scrubber, to make ship exhaust emissions reach the same level as that achieved by using low-sulphur fuel. This is the final plan of the global marine sulphur limit. According to Maritime service network (CNSS), on March 16, 2020, a container ship "MSC Joanna" of the Mediterranean Shipping Company (MSC), the world's second largest container shipping company, entered the waters of United Arab Emirates, and its high-sulfur fuel was not properly treated. Therefore, the Transportation Authority issued a penalty order of "no mooring in any port of United Arab Emirates within one year". Meanwhile, the captain of the ship was punished for "not working on any ship visiting the Middle East countries" and was faced lawsuit (CNSS). The "MSC Joanna" was the first ship to be punished since the implementation of the embargo of IMO high-sulfur oil on March 1, 2020. In the following six months, there were many cases in which port state authorities imposed penalties on ships that violated the global sulphur restriction order, which warned the shipowners, cargo owners, and port authorities.

Nowadays, most of the parties to the *MARPOL Convention* attach great importance to the pollution of ship exhaust. Developed countries have formulated very strict technical support measures and have stricter requirements on ship exhaust emissions, than those imposed by the IMO treaties (Table 1). In addition to the IMO regulations, the European Union and the United States have also issued more stringent regulations (Liu et al., 2014). For example, according to the EU Directive 2005/33/EC Article 4b, from January, 2010, the fuel sulphur content of all ships calling to EU ports shall not exceed the maximum limit of 0.1% m/m (EUR-Lex, 2005). This regulation was implemented 5 years earlier than the IMO regulations in the ECA (Li and Li, 2016). The Environment Committee of the European Parliament stipulated that, by 2020, within 12 nautical miles of territorial waters of all EU member states, the sulphur content in fuel oil used by ships must be

TABLE 1 Requirements and implementation date of marine fuel sulfur regulations in EU and USA.

Country (region)		Inside Sulphur ECA	Outside Sulphur ECA
European Union	At berth/anchor	0.1% m/m since January 2015 under Directive 2012/32/EC	0.1% m/m since 2015 (not if <2 hours or shoreside electricity) under Directive 2012/32/EC
	Passenger ships on regular services		1.5% since January 2015 under Directive 2012/32/EC 0.5% m/m since January 2020 Under Directive (EU) 2016/802
	Other ships		3.5% since January 2015 under Directive 2012/32/EC 0.5% m/m since January 2020 Under Directive (EU) 2016/802
United States of America		0.1% m/m (California: since January 2014; other States: since January 2015)	1.5% m/m (California: since January 2009; other States: since January 2012)
			0.5% m/m since January 2020

Source: the website of European Maritime Safety Agency and United States Environmental Protection Agency.

reduced to 0.1% m/m, which means that it will reach the ECAs standard. The United States is no exception. The California Air Resources Board (CARB) issues a maritime notice, requiring ocean-going ships within 24 nautical miles of the California coastline to use fuel with a sulphur content of no more than 0.1% m/m. California also introduced the *Ocean-Going Vessel Clean Fuel Regulation* which stipulate that, from January 1, 2014, container ships and cruise ships calling at California ports must continuously increase the use of shore power during berthing and the ratio should reach more than 80% by 2020 (Wei, 2018).

China is a party to the *MARPOL Convention* and as a result, it attaches great importance to the impact of ship exhaust pollution on the atmospheric environment. The Ministry of Transport began to implement the ship ECA's policy in 2016 and further expanded the scope of application of the ship ECAs in early 2019. The competent authority in China also imposed penalties on multiple violations of ship exhaust sulfur restriction. According to the statistical data from January 1, 2020 to December 31, 2021, the violations mainly include four kinds:the use of substandard fuel by vessels, the failure of vessels and fuel supply companies to keep fuel supply documents and fuel samples as required, the failure of vessel fuel supply companies to provide fuel supply documents and fuel samples to vessels as required, and the failure of fuel supply companies to fill in fuel supply documents. The first situation accounts for the highest proportion, which is the illegal act with the highest number and amount of punishment (Table 2). In addition, the Ministry of Transport also actively pursues policies to promote the construction of shore power facilities and encourage the use of clean energy, to reduce the impact of ship exhaust pollution on the environment.

3. 2 The legal framework of the IMO, 2020

The (IMO, 2020) is a technical regulatory framework composed of international conventions, countries (regions) on special regulations of ECAs and the use of EGCS. The international conventions on sulphur restrictions in the shipping industry are Annex VI of the *MARPOL 73/78 Convention* and a series of resolutions and circulars. The special regulations of various countries (regions) on ECAs and scrubbers are more stringent regulations formulated by various countries (regions) based on the actual shipping conditions, in addition to the IMO's global regulations on the marine sulphur limit.

3.2.1 International legal framework

The 74th session of the IMO Marine Environmental Protection Committee (MEPC 74) and the 101st session of the Maritime Safety Committee (MSC 101) approved a series of implementation resolutions and circulars regarding the fuel sulphur content limit of 0.5% m/m in May and June, 2019 (Sunshine Security Team, 2020). These regulations include: MEPC.1/Circ.864/Rev.1, MEPC.1/881, MEPC.1/Circ.882, (MEPC.1/Circ.883 stipulated by MEPC.259 (68) Resolution, MEPC.1/Circ.884, MEPC.320 (74) Resolution, MEPC.321 (74) Resolution), MSC-MEPC.5/Circ.15, and MSC.465(101).

The above regulations constitute the international legal framework in relation to the (IMO, 2020), covering the sampling guidance of fuel on board, the verification procedure of fuel samples and the emergency measures that the port state can take when the ship is found to be carrying substandard fuel, appropriate action to be taken when the EGCS fails, best practice measures that member states/coastal states should take, to ensure the effective implementation of Annex VI obligations under the *MARPOL Convention* and the relevant regulations for the safe acquisition of compliant fuel. Among them, the MEPC. 321 (74) Resolution stipulates the monitoring content and procedures of ports for the testing of sulphur content in fuel and methods to deal with defects, providing specific guidance for port state inspections. IMO makes detailed regulations on all aspects of compliant fuel oil, alternative measures and port state inspections, that may be involved in the implementation of the (IMO, 2020).

The fulfilment of the international legal obligations is enforced by competent authorities of the port states. At present, there are a total of 10 memoranda on port state control operating effectively in the world. On January 20, 2020, the Memorandum of Understanding on Port State Control in the Asia-Pacific Region (Tokyo mou) and Paris

TABLE 2 China's coastal waters experiencing violation of the sulphur limit penalty cases. (2020/1/1-2021/12/31).

Subject	Number of cases	Amount of penalty (RMB)
The vessel and fuel supply company fail to keep the fuel supply & receipt documents and fuel samples as required	702	3,211,351
The ship's fuel oil supply company fails to provide the ship with fuel oil supply & reception documents and fuel oil samples as required	12	419,000
The ship's fuel supply company fails to truthfully fill in the fuel supply and reception documents	7	28,500
The ship uses fuel oil that does not meet the standards or requirements	1,038	16,174,051
Total	**1759**	**19,459,402**

Source: the website of Maritime Safety Administration of the People's Republic of China.

Memorandum of Understanding on Port State Control (PARIS MOU) jointly issued a press release on the prohibition of carrying non-compliant fuel. It reinforced the new regulations and applicable dates to the shipping industry and pointed out that, from March 1, 2020, the competent authority will inspect to establish whether ships are carrying non-compliant fuel, and the presence of non-compliant fuel on ships without EGCS will be acknowledged as violating the (IMO, 2020) by the law enforcement agency (China Ship Survey, 2020). Although COVID-19 has made the implementation of this regulation technically and mechanically difficult, the memoranda on port state control are determined to implement these legal measures, as soon as possible.

3.2.2 Special regulations of the competent authorities of various countries (regions) on ECAs

The sulphur limit of 0.1% m/m is implemented in the four ECAs mentioned above and it is suitable for ECAs designated by China, the European Union, the United States, South Korea, Australia, Turkey and Iceland. The European Union and the United States take a leading role in the implementation of environmental protection policies. Due to geographical location factors, South Korea's relevant policies have a greater impact on the shipping industry in China. The regulations of the European Union, the United States and South Korea are selected for further assessment, in the following part.

In the European Union, the fuel conversion should be completed by the crew within one hour (EMSA, 2019). When the ship arrives at the berth, the ship should be provided with fuel that meets the requirements. The policy implementation is expressly exempted for ships that stay at a berth for less than two hours and ships that shut down all engines and use shore power while berthed (berthed or at anchor) in the port. From January 1, 2010, ships berthing for more than 2 hours in the ports of member states must use low-sulphur oil of less than 0.1% m/m, from 1 hour after arrival to 1 hour before departure (Cao and Dong, 2017).

Although the waters of California in the United States belong to the North American ECAs designated by Annex VI of the *MARPOL Convention*, the state still implements its own low-sulphur fuel regulations, namely, the *California Air Resources Board Ocean Shipping Fuel Regulations*. Consequently, ships operating within 24 nautical miles of the Californian coastline must comply with two different sets of sulphur emission regulations. Although these two regulations both specify a maximum sulphur content of 0.1% m/m, the *California Air Resources Board Ocean Shipping Fuel Regulations* specifically requires that, the fuel should meet the requirements of grades of distillate fuel oil (Pritchard, 2008). Furthermore, it is not allowed to meet the specified requirements through the use of a scrubber. At the same time, when the open-loop scrubbers are used on ships, the local restrictions on the discharge of washing water during washing should be noted.

In South Korea, in order to reduce sulphur emissions from ships at the South Korean ports and nearby waters, the Ministry of Maritime Affairs and Fisheries launched The Special Act on the Improvement of Air Quality in Port Areas. This law came into effect on January 1, 2020. The main impact on ship operations relates to the 0.1% m/m sulphur limit and the voluntary ship speed restriction order (International Maritime Information, 2020). The sulphur restriction was implemented from September 1, 2020 and continues until December 31, 2021: when ships are berthing (berthing or anchoring) in the ECAs, fuel used should not exceed 0.1% m/m within the following time: 1 hour after berthing until 1 hour before leaving the berth; 1 hour after anchoring and 1 hour before leaving the anchorage. From January 1, 2022, during the entire period of the ship entering the ECAs, fuel used shall not exceed 0.1% m/m or an alternative method is used (China Shipowners Mutual Assurance Association, 2020).

3.2.3 Regional special requirements for scrubbers

The scrubbers are installed on many ships, as a compliant alternative to meeting the requirements of global sulphur limit. The MEPC.259 (68) Resolution, passed by the IMO, has detailed regulations on the use of scrubbers on ships worldwide. In addition to this regulation, some countries have also issue special regional requirements for the use of scrubbers and the discharge of washing water. For example, Germany, Belgium and Oman have prohibited the discharge of washing water and Japan and South Korea have accepted that, scrubber can be used as an alternative, according to the IMO guidelines.

The European Union stipulates that, fuel oil with a sulphur content of more than 3.5% m/m shall not be used, unless a closed-loop scrubber is adopted. There are special approval requirements for scrubbers used by ships of the European Union member states. In addition, for scrubbers, based on research and test purposes, relevant reporting, duration, emission and evaluation requirements, are proposed by the European Union. In terms of wash water discharge, for scrubbers that uses chemical agents, additives, formulations and produces chemical agents in the system, unless the shipping company proves that its washing water discharge has no obvious negative effects and does not threaten human health and the environment, the washing water shall not be discharged into the ocean, including closed piers, ports, and estuaries. There are stricter regulations on the pH value of washing water discharge and scrubbers, that meet the requirements of continuous monitoring (EMSA, 2015).

In the United States, the differences in IMO's requirements for scrubbers are: the discharge of wash water must not contain oil, including oily mixtures; it is forbidden to discharge washing water residues, which must be sent to shore reception facilities. In addition, the United States also has detailed special regulations on the use of scrubbers, including continuous

monitoring equipment for wash water, monitoring equipment for polycyclic aromatic hydrocarbon (PAH) emissions, pH value measurement of washing water discharge, sample acquisition and items that need to be analyzed (California Air Resources Board, 2008).

In Australia, the following requirements must be met, as regards washing water discharge: the equivalent approval from the competent authority of the flag state or its authorized classification society, should be obtained. Notify the Australian Maritime Safety Authority (AMSA) before arriving at the first port in Australia and a report is required. In terms of the monitoring of washing water discharge, there are detailed regulations on the discharge, receiving, processing and recording of wash water residues and wash water testing. If the data or evidence of the washing water sampling analysis is not provided to the AMSA before arriving at the first port in Australia, the ship is not allowed to directly discharge the washing water into Australian waters. If it is found that the exhaust gas cleaning system does not meet the requirements of the IMO guidelines (including but not limited to, wash water discharge standards), the use of scrubbers in Australian waters may be prohibited (Australian Maritime Safety Authority, 2018).

There are two main restrictions in Singapore: Firstly, is the prohibition on the discharge of washing water from open scrubbers in the port of Singapore. It is not suitable for ships that are divided into lanes and do not call at the port of Singapore. Secondly, the emission reduction technology installed on ships with the Singapore flag must be approved by the Maritime and Port Authority of Singapore (MPA) or an authorized classification society (MPA, 2020b).

4 The dilemma of implementing the IMO, 2020

Countries response to the (IMO, 2020) differs, due to their different economic development standards and positions. Some countries support it, while others insist on delaying or opposing its implementation. As mentioned earlier, the United States and the European Union are ahead of other countries in the implementation of environmental protection regulations and some of their regulations are stricter than the IMO regulations. Other countries such as the Marshall Islands, Malaysia, Panama, have strictly implemented the regulations of the (IMO, 2020). The New Zealand government argues it does not need to implement the IMO, 2020 since other shipping countries have already implemented Annex VI of the *MARPOL Convention*, and the registered merchant ships in New Zealand are too small in quantity to emit enough sulfur oxides to harm the port environment (Brevan, 2016). Similar views are held by some countries where the total tonnage of merchant ships is not dominant, such as India, Indonesia, Philippines and Egypt (China Ship Gazette, 2020). They have expressed reservations about implementing the (IMO, 2020) and will stick to their national policies for the time being. The five member states of the Eurasian Economic Union, these being Russia, Kazakhstan, Kyrgyzstan, Belarus and Armenia, have decided to postpone the implementation date of the new sulphur limit, by 4 years.

In response to the provisions of the (IMO, 2020), there are three compliance methods that can be adopted by shipowners. The use of alternative fuels, such as LNG, ethanol and methanol are restricted, due to unsound technical conditions and supporting facilities, which is not a universal compliance method. Its impact on regulatory practice has, thus, not yet appeared. The problems in the practice of the other two compliance methods (the compliant low-sulphur fuel and scrubbers) are analyzed and their impact on regulatory practices will be explored in this study.

4.1 Acquisition and the safety of the low-sulphur fuel

There is a contradiction between supply and demand in the compliant low-sulphur fuel supply market. Affected by low-sulphur crude oil resources and refinery processing techniques, the output of low-sulphur fuel is limited and supply exceeds demand. The applicability of the blended low-sulphur fuel needs to be studied and verified. There are problems with the compatibility of low sulphur fuel mixed with various raw materials (Haakon et al., 2017). The composition of compliant fuels supplied in different regions differs widely, which poses a challenge to the potential tolerance of vessel machinery. Frequent conversion of low-sulphur fuel refined by different processes, may increase the possibility of ship engine failure, as well as influencing inspections and safe operations (Gan, 2020). After the (IMO, 2020) is officially implemented, many worldwide out-of-control accidents of ships are now considered to be related to the conversion of low-sulphur fuel. The potential impact of low-sulphur blended fuel on the environment is not clear. As the (IMO, 2020) has took effect, the problem of low-sulphur blended fuel has gradually become prominent. A research report submitted by Germany and Finland to the IMO lists the negative effects of low-sulphur blended fuel, indicating that, low-sulphur fuel will increase black carbon emissions and cause major environmental risks (Wang, 2020). Frequent oil changes will increase the risk of damage to the main engine of the ship. The potential safety and environmental impacts of low-sulfur oil have not been determined, which is at odds with the IMO's claims. The problem is that the new sulfur limit regulation has not been fully estimated, including the environmental impact of

scrubbers, the cost of repeated construction due to stricter decarburization regulations, and the safety and availability of compliant fuels.

4.2 Safety and environmental risks of alternative measures

The scrubber has been widely adopted by shipowners, as a compliant alternative measure. According to data from the DNV-GL, as of January 1, 2020, there are nearly 4,000 ships (in operation and under construction) installed with scrubbers worldwide, accounting for about 12% of the total tonnage (Xu, 2019). As a technical solution for ship air pollution reduction approved by the IMO, the technology of scrubbers is still evolving. There are problems such as diverse models, inconsistent technical standards and doubts about the effectiveness regarding environmental protection. Moreover, there is no authoritative regulatory standard with strong practicality in terms of supervision, thus causing confusion to all relevant parties, which is not conducive to uniform law enforcement, fair markets and effective implementation of emission reduction targets. The installation cost, safety and environmental protection effect of the scrubber are all to be verified. Therefore, the attitude towards the scrubber is the most controversial in the shipping industry.

4.2.1 Safety risks of scrubber

Since the EGCS is a developing technology, there are many uncertainties in its use. The device of the EGCS is complex, with strict operation and maintenance requirements, and high requirements for the crew's operation ability. When an scrubber is used, fuel conversion will cause problems such as oil separator sludge, filter blockage, fuel pump blockage and fuel spray nozzle inhibition (Johannes et al., 2020). In extreme cases, there will be blockages in fuel pipelines, which increase the risk of ships losing power or electricity (Wang, 2019). In response to nitrogen oxide emission reduction, the scrubber will be upgraded in the future. In addition, the untimely installation of scrubber is likely to cause lock-in effect of equipment, so that the shipping companies will again face the dual pressures of technological development and policy orientation. Both shipping companies nor maritime regulatory authorities lack experience in the use and supervision of scrubber, and the crew's inadequate operation experience will raise the probability of equipment failure. The standing emergency low-sulfur fuel oil kept on board will occupy the oil tank space, and it may be insufficient for long-distance sailing (Li et al., 2019). After the implementation of the (IMO, 2020), the vast majority of ships will use low-sulfur fuel oil, and it is uncertain whether each port can supply enough high-quality low-sulfur fuel oil.

4.2.2 Environmental risks of scrubber

The scrubbers is a system designed to remove sulfide from the exhaust of marine fuel burning devices such as main engine, auxiliary engine and boiler. According to its working process, it can be divided into Open-loop scrubbers, Closed-loop scrubbers and Hybrid scrubbers. The scrubber has been in dispute for its environmental problem, mainly focusing on the composition of the wash water and the discharge of residues (Haakon and Eskeland, 2016). Therefore, different countries have different attitudes towards the use of scrubber (Table 3).

Most countries accept closed-loop scrubbers and Hybrid scrubbers (Figure 1). Open-loop scrubbers directly discharge the wash water into the ocean, transforming air pollutants into marine pollutants and thus polluting the ocean (Chen and Gao, 2019). However, how to dispose of the pollutants such as sodium sulfite generated by closed scrubbers has not yet been determined (Johannes et al., 2020). This sulfur limit measure is an "equivalent alternative measure" stipulated in Article 14 of *MARPOL Convention* Annex 6, which is essentially a business arrangement to pursue compliance targets rather than to achieve pollutant reduction and fuel substitution through technological innovation. It is questionable whether the EGCS can actually achieve the purpose of "equivalent substitution". This fully reflects the short-sightedness of IMO to transfer the policy cost of international supervision to shipping companies, and is not in line with the green and sustainable development of shipping industry.

4.2.3 Lack of effective regulatory mechanism

The port has a strict receiving and processing mechanism for slop oil, domestic garbage, ballast water and domestic sewage generated by ships. Nevertheless, the waste water and residues generated by the scrubber has not been included in the existing pollutant disposal mechanism, which causes uncertainty to the shipping industry compliance and increases the risk of marine pollution. As an attempt to reduce marine emissions, the EGCS will face more requirements for pollutant reduction in the future, and the waste generated by the operation of the system will pose new challenges to the reception of pollutants at ports. Since the implementation of the new marine sulfur limit, the port authorities have not established a definite monitoring mechanism for the "by-products" of pollutants from the operation of the EGCS, which will create a regulatory gap in the implementation of this environmental policy.

4.3 Adaptability of the shipping industry to new regulations

The shipping industry has converted from high-sulphur fuel to low-sulphur fuel, under the requirements of the (IMO,

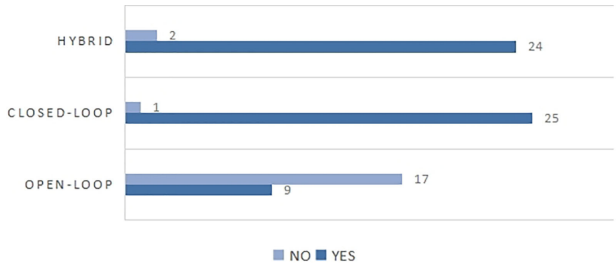

FIGURE 1
Proportion of Scrubbers of three different types for the countries in Table 3.

2020). In addition to the uniform requirement that the sulphur content does not exceed 0.5% m/m, some countries, regions, and ports implemented stricter sulphur emission restrictions. If the crew are not familiar with the sampling procedure or operation, the consequences of violation may also be caused. Shipowner must, therefore, ensure that the crew are familiar with the sulphur emission limits of the relevant port states within their sailing range. It is necessary to train the crew on sampling procedures or operations, otherwise there may be high administrative penalties and operational and legal risks. In addition, the shipping industry lacks a risk assessment procedure as regards personal injury when the fuel tank is cleaned in an enclosed space and also as regards relevant emergency mechanisms. Crew members will, thus, be directly affected in the implementation of the new sulphur limit regulations.

4.4 Different standards for sulphur limit inspections by competent authorities of various countries (regions)

The successful implementation of the marine sulphur limit depends on the implementation by the Port and Coastal State Control in various countries (regions). Various countries have different opinions on the implementation of the (IMO, 2020) and the specific standards operated by competent authorities of various countries (regions) also vary. In addition, the global COVID-19 pandemic has not yet ended and the competent authorities in the various countries and the regional port state supervision memorandum, have also taken appropriate mitigation measures during the epidemic, which makes the implementation and supervision of the global sulphur limit even more complex. The United Kingdom, the TOKYO MOU and the PARIS MOU have made announcements suspending the way that inspectors conduct sulphur restriction inspections supervised by port states and carry out documented examination. The existing regulatory capabilities seriously affect the implementation impact of the sulphur limit policy (Eworldship, 2020). When the global COVID-19 pandemic finally ends, strict supervision will again be performed and imperfections in the supervisory mechanism, limitations in supervisory technology and the imperfections of support mechanisms, will be more apparent.

4.5 Uncertainty in the development of alternative fuel technologies

As a compliance measure to deal with the (IMO, 2020), alternative fuels are also a long-term plan for the maritime industry to deal with climate change. The alternative fuel is a term relative to traditional fossil fuels. The study adopts the definition of the *Federal Energy Policy Act of 1992* (EPACT). It is appropriate to define it by enumerating. According to the EPACT, an alternative fuel is: "Methanol, denatured ethanol, and other alcohols; mixtures containing 85% or more by volume of methanol, denatured ethanol, and other alcohols with gasoline or other fuels; natural gas; liquefied petroleum gas; hydrogen; coal-derived liquid fuels; fuels (other than alcohol) derived from biological material; and electricity." At present, there is no unified international regulatory framework in the field of marine alternative fuels. In addition to the international standards for LNG ships and methanol-powered ships, the international and domestic standards for other alternative fuels are still in progress. This situation reflects not only the uncertainty in the research and development of marine alternative fuel technology, but also the difficulty of building an alternative fuel supply chain. Taking LNG fuel as an example, although the LNG industry has been developing for 40 years, it has only been used as a marine alternative fuel for a few years. The relevant regulations and supply chains are imperfect, and other clean alternative fuels have a long way to go to achieve large-scale commercial applications (Weng, 2019). Due to the long service life of ships, the shipping industry faces both the risk of stranded assets and investing in the wrong technology when they try to transition from traditional fossil fuels to low/zero carbon fuels. Moreover, many clean alternative fuel technologies

have not yet been proven, and the relevant standards are being formulated. Thus, before policy, environment, cost, infrastructure and safety regulations are improved, the blind development of alternative fuels will lead to unpredictable duplication of construction and waste of resources in the shipping industry.

5 Policy and supervision regarding sulphur limit in China's shipping industry

5.1 Policy development of marine sulphur limit in China

With the rapid development of the economy in China, the impact of large-tonnage vessels on the air environment of seaports has attracted increasing concern. Regarding the establishment of a legal system for limiting emissions of ship exhaust, relevant laws and regulations are being formulated, such as the *Law of the People's Republic of China on the Prevention and Control of Atmospheric Pollution* and *Regulations on the Administration of Prevention and Control of Ship Pollution to the Marine Environment*. On September 23, 2020, the *Maritime Traffic Safety Law of the People's Republic of China* (revised draft) was reviewed and approved at the 109th Executive Meeting of the State Council (MSA, 2020). There are systems concerning shipping company safety and pollution prevention, as well as management issues in the law. This law, known as the 'root' of maritime traffic safety management, provides a legal basis for further regulating the discharging of ships and reducing marine pollution.

For the 'sulphur restriction' regulations in the shipping industry, the Ministry of Transport issued the *Plan for Ship Emission Control Areas in the Pearl River Delta, Yangtze River Delta, and Bohai Rim (Beijing-Tianjin-Hebei) Waters* in December 2015. This was the first time of establishing a ship-based air pollutant emission control area. It is required that, from January 1, 2016, qualified ports in the China ECA can implement measures higher than those of the current emission control requirements, including as regards the use of fuel with a sulphur content of not more than 0.5% m/m during berthing. From 2017, when ships berth in a core port area of the China ECA (except for 1 hour after docking and 1 hour before departure), fuel oil with a sulphur content of not more than 0.5% m/m should be used. On June 27, 2018, the State Council issued the *Three-year Action Plan to Fight Air Pollution*, which included considering ships as an important control measure. The plan aims to continuously improve the air quality and raise the prevention and control of air pollution to a more stringent level. In the same year, the Maritime Safety Administration of the Ministry of Transport issued the *Plan for Ship Air Pollutant Emission Control Area* ([2018] No. 168), which extends the sulphur limit to all ships entering the China ECA. Alternative measures, such as connecting shore power, using clean energy and exhaust gas post-treatment, can be chosen by ships for operation (MSA, 2018).

In order to effectively implement the (IMO, 2020), the Maritime Safety Administration of China issued the *2020 Plan of Global Marine Fuel Sulphur Restriction* on October 23, 2019. The amendments, guidelines, and circulars of the *MARPOL Convention* are internalized, being referred to as the Chinese Global Marine Sulphur Limit (MSA, 2020). In addition to the IMO requirements, the Maritime Safety Administration has formulated special requirements for the use of low-sulphur fuel on ships: Firstly, from January 1, 2020, international ships entering the air pollutant discharge control area of inland rivers must use fuel oil with a sulphur content not exceeding 0.1% m/m or adopt equivalent measures. Secondly, from January 1, 2022, international ships entering the air pollutant discharge control area of Hainan, must use fuel oil with a sulphur content not exceeding 0.1% m/m. Thirdly, from January 1, 2020, ships must not discharge washing water of open-typed exhaust gas cleaning systems in a ship air pollutant ECA. The *2020 Global Marine Fuel Sulphur Limitation Regulation Plan* does not change the requirements of the *Ship Air Pollution Emission Control Zone Plan*. These two implementation plans are complementary. The new implementation plan does not change the requirements of the *Plan for Ship Air Pollutant Emission Control Area*, and the two implementation plans are complementary to each other. International voyage ships sailing in China's coastal emission restriction areas must meet the requirements of these two implementation plans at the same time.

In specific law enforcement practice, law enforcement personnels usually carry out on-site supervision and inspection according to the above procedures, and take disciplinary measures against illegal acts. In August 2021, when the law enforcement officials of Quanzhou Maritime Safety Administration carried out daily supervision and inspection, they found a ship that violated the sulphur regulations. The marine fuel oil was sampled, sealed and marked according to the procedures, and one of the samples was sent to a professional testing organization with national qualifications for testing. The professional organization found that the sulfur content in the fuel sample of the ship was 0.559% (m/m), which exceeded the emission standard and violated Article 64 of the Law of the *People's Republic of China on the Prevention and Control of Air Pollution*. In addition, the owner of the ship who has been subject to maritime administrative punishment for this illegal act within one year was investigated. According to the provisions of Article 9, paragraph 1 (2) of the *Regulations of the People's Republic of China on Administrative Penalties for Maritime Affairs*, the owner of the ship shall be punished severely and a fine of RMB 80,000 shall be imposed (QZMSA, 2021).

5.2 Factors influencing the establishment of effective supervisory systems

With the continuous improvement in environmental protection awareness during the process of China's economic transformation, the regulations on the emission limit of ship pollutants will be more stringent in the future. When the global COVID-19 is over, the revived shipping industry will reveal some of the institutional deficiencies temporarily covered up during the epidemic. For example, ship exhaust emission supervision policy, the ability to supervise illegal ships and maritime supervision methods, are far from perfect. In addition to the difficulties in the implementation of the (IMO, 2020) analyzed above, China still has the following problems in marine sulphur limit supervision.

5.2.1 Limitations of maritime supervision technology

Since the official implementation of the (IMO, 2020), the inspections of the sulphur content of the fuel employed by the maritime departments in China include document inspections and brief inspections of fuel samples. The method of document inspection cannot effectively inhibit ship violations. The proportion of brief fuel sample inspections is limited. In addition, the global COVID-19 epidemic has not yet ended. The maritime department has adopted non-board inspection methods for ships on international voyages, so it is difficult to prevent illegal activities. In addition, although China's anti-pollution monitoring mechanism and the technology of the maritime sector are increasingly effective for ships sailing in Chinese waters, such as the use of advanced technology and equipment like sniffers, intelligent monitoring methods have not yet been widely used and their ability to detect violations is limited.

5.2.2 Different supervision standards

There are few studies on the technical performance of scrubbers, the composition of wash water and the air pollutant emission inventory and there is a lack of supervision and uniform legal standards. At present, there are also issues concerning supervision and inspection of scrubbers by the competent authority in China, including insufficient supervision experience, incomplete support systems, lacking in understanding of technical issues such as related equipment operation and malfunctions and a lack of strict control and supervision standards. The low penalty amount is also one of the problems. As stipulated by Article 106 of the *Air Pollution Prevention and Control Law* of China, the penalty amount is between 10,000 and 100,000 CNY, which is lower than the fuel cost of ship operation. In shipping practice, domestic shipping companies also lack an in-depth understanding of the scrubber technology and it is necessary for the competent authority to formulate guidelines for the supervision and inspection of scrubber, in order to standardize safe operation, reduce production and operational risks and hidden dangers to crew safety. The research and compilation of the, 'Air Pollutant Emission Inventory' can reflect China's ability to plan and control air pollution. This basic work is related to the formulation of air pollutant emission limit policies of China for the future.

5.2.3 Insufficient supervision enforcement

At present, the inspection of atmospheric sulphur content by the maritime department of China comprises mainly document examination and random inspection of fuel samples. The existing inspection methods cannot completely eliminate illegal emissions. In practice, there are still some domestic shipping companies and ships that use high-sulphur fuel and forge fuel storage receipts, in order to save costs. There is a gap between the amount of administrative penalties imposed by the maritime department for violations of sulphur restrictions and the cost of companies using high-sulphur fuel in violation of the regulations. The illegal cost is low and the administrative enforcement is insufficient. The number of administrative punishment cases is uneven, with the southern coastal provinces in the majority (Figure 2). In all the Maritime Safety Administrations, the four types of cases are still dominated by the use of fuel oil which does not meet the regulation (Figure 3).

5.2.4 Necessity for coordinated supervision of multiple departments

Regarding the issue of supervision, according to the inland river and marine environmental protection regulations in China, domestic departments with environmental supervision and management roles include environmental protection departments at all levels, marine administrative departments, maritime departments, waterway departments, the Yangtze River Administration of Navigational Affairs and port and shipping departments. Among these, the maritime department mainly performs port state supervision and inspection functions, including verifying whether relevant documents are valid, conducting random inspections of fuel and judging whether there are potential dangers that could endanger the safety of ships and pollute the marine environment. The prevention and control of air pollution is, however, a systematic project. The sulphur content standard of marine fuel involves various operations such as the shipping industry, fuel supply industry and oil refining industry. There are many relevant supervising subjects, therefore, the implementation of the IMO, 2020 requires the maritime supervision authorities to improve the supervision mechanisms and the coordinated guarantee of the competent authorities related to fuel supply guarantees, scrubber manufacturing and the shipbuilding industries.

6 Suggestions for a multi-sectoral guarantee mechanism

With the acceleration of globalization, prevention and control of air pollution, climate change, and destruction of marine ecosystem are becoming global challenges and threats. It is therefore urgent to strengthen international cooperation and promote the reform of the marine governance system. With the increasingly severe global environmental protection situation, China creatively put forward the concept of "a community with a shared future for mankind", which aimed to build a long-term, stable and in-depth cooperation mechanism, providing "China's experience" for international cooperation on maritime emission reduction (Yang, 2021). This theory extends to the ocean field is "a maritime community with a shared future". The guiding significance of the "a maritime community with a shared future" for marine pollutant emission reduction is that it points out the realization path and construction mechanism of emission reduction. It is manifested in three aspects. The first is to realize the sharing of marine scientific and technological achievements based on new development concepts, including resource development technology and pollutant emission reduction technology, and to increase resource utilization efficiency. The second is to promote the coordinated development of marine environmental protection regions and build a mutually beneficial regional cooperation model to ensure the sharing of marine space and resources. The third is to take the sustainable utilization of marine resources as the goal, and address new problems with innovative thinking.

The concept of "a maritime community with a shared future" advocates "common interests", and creates mechanisms by constructing the common interests of mankind. It provides conceptual choices and development paths for solving the unresolved global crises faced by human society (Chen, 2021). Ocean acidification, climate change, and coordinated governance of air and climate are no longer problems that can be solved by a single regulatory authority. The concept of "a marine community with a shared future" provides a new way of joint supervision for the reform in the field of marine governance. Shipping emission reduction involves the reform of a series of supporting mechanisms in the upstream, midstream and downstream industries of the entire shipping industry, with many regulatory authorities involved. The competent authority for technical standards such as the EGCS is the Ministry of Industry and Information Technology of China, the competent authority for fuel quality is the market supervision authority, and the maritime authority mainly performs port state supervision and inspection duties. After the new round of China's state institutional reform in March 2018, all functions of the former Ministry of Environmental Protection, together with the responsibilities for addressing climate change and emission reduction originally belonging to the National Development and Reform Commission, were unified under the Ministry of Ecological Protection, with The Department of Atmospheric Environment and the Department of Climate Change established respectively to be responsible for specific work. This adjustment is a major progress in promoting coordinated emission reduction, which is conducive to realizing the synergistic benefits of emission reduction of conventional atmospheric pollutants and GHG emission control. It is therefore necessary to integrate law enforcement resources of marine departments and build a multi-department joint supervision mechanism from the whole life cycle of marine fuel.

6.1 Establishing an inter-ministerial collaboration platform for compliant fuel supply supervision

In terms of compliant fuel supply, the Ministry of Transport leads and works with the General Administration of Customs,

FIGURE 2
Comparison of administrative punishment cases in various maritime authorities. Source: The website of Maritime Safety Administration of the P. R. C and local Maritime Authorities.

the State Administration for Industry and Commerce, the Ministry of Commerce and the State Administration of Taxation, to promote large-scale production of refining and chemical enterprises, build a bonded fuel supply mechanism, effectively reduce the cost of bonded fuel and create a sound business environment, through taxation and subsidies.It is necessary to build a joint law enforcement and supervision mechanism, for air pollution prevention. The aforementioned should be combined with the General Administration of Quality Supervision, Inspection and Quarantine, Ministry of Ecology and Environment, General Administration of Safety Supervision and Ministry of Public Security, to strengthen the law enforcement linkage and information notification during and after an incident, to inhibit illegal activities. There is a great need to build a coordinating mechanism for pollution emergency response and governance, integrate the different specialized resources, in order to construct an integrated operating mechanism for scientific early warning, intelligent response and environmental management, as well as to improve pollution risk response capabilities.

6.2 Establishing a 'big data' platform for compliant fuel information disclosure

The shipping industry is a capital and technology-intensive industry and default decisions will lead to greater costs, which is also a common problem faced by the global shipping industry. In order to strengthen the predictability of policies, address the problem of information asymmetry in the shipping market and guide the shipping industry to realize the optimal allocation of resources, it is recommended to establish a 'big data' platform for compliant fuel information at the national level. On the one hand, this would publish a 'white list' of compliant fuel oil suppliers and low-sulphur fuel suppliers in various ports around the world, to strengthen the availability of low-sulphur fuel supply market information and avoid operational risks caused by asymmetric information between supply and demand. Furthermore, credit management should be applied. Classified supervision is conducted regarding fuel supply units, as well as agency enterprises, according to their corporate credit rating. Establish a classification system for offshore refuelling ships and enterprises and high-level corporate rating should be offered, with preferential policies, based on enterprise classification, operating safety time, annual filing and for new ships. As soon as possible, try to eliminate old, single-hull ships, and enterprises and ships with poor operating conditions, to promote a positive operation of marine refuelling market.

6.3 Improving the ability of intelligent ship exhaust monitoring

The supervision of ship exhaust gas emission is not only a mechanism problem, but also a technical problem. It helps to control the fuel quality at the end. Due to the fluidity of air, the

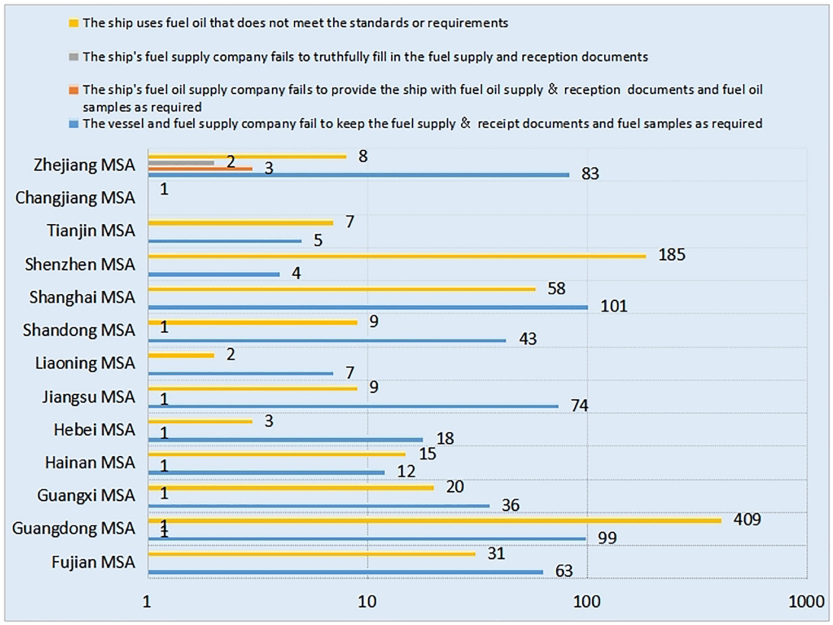

FIGURE 3
Proportion of different case types from local Maritime Authorities. Source: The website of Maritime Safety Administration of the P. R. C and local Maritime Authorities.

TABLE 3 Restrictions on the use of Scrubbers in various countries (○ for Acceptance, × for Non-acceptance).

Country	OPEN-LOOP	CLOSED-LOOP	HYBRID
China	× (Except for Hong Kong and Taiwan)	○	○
South Korea	○	○	○
Japan	○	○	○
Singapore	×	○	○
Indonesia	○	○	○
India	× (in most ports)	○	○
Saudi Arabia	×	○	○
United Arab Emirates	×	○	○
Oman	×	○	○
Denmark	×	○	○
Russia	○	○	○
The European Union	×	○	×
Ireland	×	○	○
Iceland	×	○	○
Norway	×	○	○
Britain	○ (except in the Forth and Tay)	○	○
South Africa	○	○	○
Kenya	×	○	○
Argentina	×	○	○
Bermuda	○	○	○
New Zealand	×	○	○
Australia	○	○	○
Canada	×	×	×
The USA	○	○	○
Panama Canal Authority	×	○	○
Suez Canal Authority	×	○	○

Source: Official websites of port authorities of various countries.

detection of pollutants is technically difficult. At present, the construction of ship emission control zone has been carried out for a short time in China, and the intelligent supervision is being explored. Ship exhaust telemetry is capable of all-round three-dimensional monitoring of land, sea and air emissions through shore-based fixed ship exhaust sniffing systems, etc., and can quickly find and track suspected ships (Cheng, 2018). Tianjin Maritime Safety Administration applied the ship exhaust telemetry system into the monitoring of ship exhaust. With the fuel quick inspection and ship exhaust detectors, Tianjin Maritime Safety Administration built a comprehensive ship exhaust monitoring network, and effectively implemented a new supervision mode of telemetry supervision and onboard collection of evidence (China Water transport, 2021). It is recommended to popularize intelligent maritime monitoring equipment equipped with artificial intelligence and big data technology, and promote intelligent monitoring technologies like sniffing technology. In addition, it is also suggested to increase the coverage scope and elements of the monitoring network, improve the level of informatization and information sharing, the efficiency and accuracy of law enforcement inspections, and the ability of sulfur oxide monitoring and risk control.

6.4 Promoting the construction of port shore power infrastructure

With the increasingly stringent policies on emission reduction of ship pollutants, the requirements for the port's pollution response capacity are also getting higher and higher. In addition to policy and institutional guarantees, the anti-pollution infrastructure at port also plays an essential role. In order to greatly reduce the air pollution caused by ships at port, one successful case in the world is the use of shore power. California promotes the use of shore power through subsidies, various economic incentive plans and emission taxes, and the European Union is also promoting the use of shore power (Winkel et al., 2016). To ensure the normal operation of lighting, ventilation, communications and other critical equipment, ships berthing at ports must use lots of electricity. Replacing ship auxiliary engines with shore power can significantly reduce emissions at ports and

effectively reduce air pollution. The construction of shore power infrastructure requires not only huge economic investment, but also relevant safety operation specifications and inspection standards. China has encountered multiple obstacles in the implementation of shore power in recent years. It is recommended to accelerate the construction of shore power infrastructure and formulate subsidy policies at the national level. The central or coastal governments should formulate subsidy measures for the use of shore power and low-sulfur oil by port ships as soon as possible. In addition, incentive measures should be formulated to encourage the construction of green ports and promote the application of new energy-saving emission reduction technologies for ships, thereby reducing the pollution emissions from ships in ports (Li et al., 2017).

7 Conclusion

Although there are many problems and uncertainties in the implementation of the (IMO, 2020), the environmental protection trend of energy structure transition and emission reduction in the global shipping industry is unlikely to be reversed. Navigation safety and marine pollution prevention will be two major value orientations that must be considered simultaneously at international conventions and in domestic laws. The new sulphur regulation of the shipping industry is not only a severe test for port and coastal state control mechanisms but also a significant challenge to China's maritime regulatory mechanism. Marine sulphur limit supervision can provide useful experience for the future implementation of shipping environmental protection regulations. In order to promote robust development of the shipping industry, implement the deployment of the Party Central Committee and the State Council utterances on accelerating the construction of an ecologically aware society, encourage pollution prevention and control, and combat air pollution, the development of shipping industry in China should encourage not lowering environmental protection standards, while promoting international and domestic cooperation. There should also be development of operable inspection instruction manuals, the promotion intelligent supervision technology, establishment an inter-ministerial collaboration platform for supervision of compliant fuel supply and the introduction of a 'big data' platform for compliant fuel information disclosure. There also needs to be the promotion of the construction of port and shore power infrastructure and the strengthening of the regulation of the safe operating procedures of shipping companies, to improve maritime supervision mechanisms in China. There is also a need to build a comprehensive multi-sectoral coordination guarantee mechanism, to guarantee the effective implementation of the marine sulphur limit regulation in China.

Author contributions

XL participated in conception of the research ideas and study design. XL: original idea and writing up. XL approved the submitted version.

Funding

This work was supported by the Fundamental Research Found of Weifang University (Grant No. 2022BS56).

Acknowledgments

Thanks to all the colleagues in the Compass-Rose Passenger Ship Innovation Studio of the Xiamen Maritime Safety Administration (Lujiang Maritime Department) for their supports.

Conflict of interest

The author declares 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

All claims expressed in this article are solely those of the authors and do not necessarily represent those of their affiliated organizations, or those of the publisher, the editors and the reviewers. Any product that may be evaluated in this article, or claim that may be made by its manufacturer, is not guaranteed or endorsed by the publisher.

References

Australian Maritime Safety Authority (2018) *Limitation of sulphur emissions from cruise vessels while at berth in Sydney harbour*. Available at: https://www.amsa.gov.au/about/regulations-and-standards/62018-limitation-sulphur-emissions-cruise-vessels-while-berth-sydney (Accessed 2022/6/23).

Bosch, D. W. Jr. (2019). Rocking the boat: The legal implications of IMO 2020 for future IMO greenhouse gas reduction strategies and the impacts to Louisiana. *LSU J. Energy Law Resour.* 8 (1), 261–286.

Brevan, M. (2016). Shipping and Air Pollution: New Zealand's Failure to Ratify Marpol Annex VI. *Australian and New Zealand Maritime Law J* 30 (1), 90–98.

Brown, S. E. (2019). IMO 2020: Industry conditions and readiness. *Tulane Maritime Law J.* 44 (1), 276–279.

California Air Resources Board. (2008). *Ocean-going vessel fuel regulation*. Available at: https://ww2.arb.ca.gov/our-work/programs/ocean-going-vessel-fuel-regulation (Accessed 2022/6/23).

Cao, B., and Dong, G. (2017). Supervision measures and reference for the implementation of ship emission control zone in EU. *China Water transport* 17 (5), 43–45.

Chen, B. (2009). The revision of annex VI of MARPOL 73 / 78 convention on the sulfur content standard of fuel oil and its impact on China. *China maritime affairs* 2, 37–39.

Chen, Q. (2021). Global commons governance and building a community with a shared future for mankind. *Int. Forum* 3, 54–55. doi: 10.13549/j.cnki.cn11-3959/d.2021.03.003

Cheng, H. (2018). How to control marine air pollution? *World Environ.* 6, 61–63.

Chen, M., and Gao, S. (2019). Global regulations on open desulfurization of ships - prohibition of dominance and approval of countermeasures. *China Cosco Shipping* 10, 72–73.

China Ship Survey. (2020). In: *The Tokyo memorandum and Paris memorandum ban the carrying of non-compliant fuel*. Available at: https://www.sohu.com/a/368247970_120056227 (Accessed 2022/6/23).

China Shipowners Mutual Assurance Association. (2020). *Notice! south korea's sulfur restricted zone will take effect on September 1*. Available at: https://mp.weixin.qq.com/s/mnUZ3fSziYEkjJu8vxhh2w (Accessed 2022/6/23).

China shipping gazette. *Attention! these areas have stricter sulfur emissions requirements. don't get fined!*. Available at: https://mp.weixin.qq.com/s/3mPlFHZLlp9leLJU17-DzQ (Accessed 2022/6/23).

China Water Transport. (2021). *Use of ship exhaust telemetry system: Tianjin maritime safety administration's investigation into excessive sulfur content in marine fuel*. Available at: http://www.zgsyb.com/news.html?aid=600168 (Accessed 2022/6/23).

CNSS. *After march 1, the first ship that carried high-sulfur fuel in violation of regulations appeared! it was directly rejected by the port for 1 year*. Available at: https://mp.weixin.qq.com/s/GhqvunJPiSCkDgQ1eHeT1Q (Accessed 2022/6/23).

EMSA. (2015). *Air pollutants*. Available at: https://www.emsa.europa.eu/tackling-air-emissions/air-pollutants.html (Accessed 2022/9/16).

EMSA. (2019). *Air emissions*. Available at: http://www.emsa.europa.eu/main/air-pollution/sulphur-directive.html (Accessed 2022/6/23).

EUR-Lex. (2005). Directive 2005/33/EC of the European Parliament and of the Council of 6 July 2005 amending Directive 1999/32/EC. Available at: https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A32005L0033. (Accessed 2022/6/23).

Eworldship. (2020). *Britain Announces suspension of inspection of ship fuel oil "sulfur restriction"*. Available at: http://www.eworldship.com/html/2020/ship_inside_and_outside_0329/158120.html (Accessed 2022/6/23).

Eyring, V., Isaksen, I. S. A., Berntsen, T., Collins, W. J., Corbett, J. J., and Endresen, O. (2010). Transport impacts on atmosphere and climate: Shipping. *Atmospheric Environ.* 44 (37), 4735–4771. doi: 10.1016/j.atmosenv.2009.04.059

Gan, S. (2020). The IMO sulphur limit 2020 is implemented for 100 days. *China Sship Survey* 4, 28–33.

Gou, Y. (2019). The impact and countermeasures of the IMO sulphur limit 2020. *Mar. Equip. Materials Marketing* 8, 79–82. doi: 10.19727/j.cnki.cbwzysc.2019.08.029

Haakon, E. L., and Eskeland, G. S. (2016). Environmental regulations in shipping: Policies leaning towards globalization of scrubbers deserve scrutiny. *Transportation Res. Part D* 47, 6–10. doi: 10.1016/j.trd.2016.05.004

Haakon, E. L., Rehn, C. F., and Eskeland, G. S. (2017). *Sulphur abatement globally in maritime shipping* Vol. 57 (Pergamon-elsever science ltd the boulevard, Langford Lane, Kidlington, Oxford OX5 1GB, England: Social Science Electronic Publishing), 6–21.

Halffa, A., Younesb, L., and Boersma, T. (2019). The likely implications of the new IMO standards on the shipping industry. *Energy Policy* 126, 277–286. doi: 10.1016/j.enpol.2018.11.033

Hou, Y. (2017). Legal regulation of ship air pollution. *J. Shandong Univ. Sci. Technol. (SOCIAL Sci. EDITION)* 19 (5), 9. doi: 10.16452/j.cnki.sdkjsk.2017.05.007

IMO. (2013). *Study on effects of the entry into force of the global 0.5% fuel oil sulphur content limit on human health*. Available at: https://wwwcdn.imo.org/localresources/en/MediaCentre/HotTopics/Documents/Finland%20study%20on%20health%20benefits.pdf (Accessed 2022/9/16).

IMO. (2016) *Special areas under MARPOL*. Available at: https://www.imo.org/en/OurWork/Environment/Pages/Special-Areas-Marpol.aspx (Accessed 2022/6/23).

IMO. (2020) – *cutting sulphur oxide emissions*. Available at: https://www.imo.org/en/MediaCentre/HotTopics/Pages/Sulphur-2020.aspx. (Accessed 2022/6/23)

International Maritime Information. (2020). *South korea's sulfur restricted zone will take effect in September*. Available at: http://www.simic.net.cn/news_show.php?id=238589 (Accessed 2022/6/23).

Jiang, J., and Jiang, W. (2016). The responsibility of port states to deal with ship pollution: implementation and guarantee mechanism. *China ocean Law Rev.* 1), 39.

Johannes, T., Cox, T. J.S., Itterbeeck, K. V., Meysman, F. J. R., and Blust, R. (2020). The impact of scrubber discharge on the water quality in estuaries and ports. *Environ. Sci. Europe* 32 (1), 102–113. doi: 10.1186/s12302-020-00380-z

Kevin, C., and Rickard, B. (2014). Emission control areas and their impact on maritime transport. *Transportation Res. Part D* 28, 1–5. doi: 10.1016/j.trd.2013.12.004

Kopel, S. (2017). Making ships cleaner: Reducing air pollution from international shipping. *Comp. Int. Environ. Law* 26 (3), 234. doi: 10.1111/reel.12220

Li, W., and Li, N. (2016). Introduction on ship emission control area (ECA) and associated PSC inspection countermeasures. *China maritime Saf.* 3, 22–24. doi: 10.16831/j.cnki.issn1673-2278.2016.03.004

Li, L., Li, Y., and Gaojia, (2017). Prevention and control experience of pollution from vessels and ports in united states and suggestions for China. *Environ. Sustain. Dev.* 5, 111–115. doi: 10.19758/j.cnki.issn1673-288x.2017.05.035

Liu, T. K., Sheu, H. Y., and Tsai, J. Y. (2014). Sulfur dioxide emission estimates from merchant vessels in a port area and related control strategies. *Aerosol Air Qual. Res.* 14 (1), 413–421. doi: 10.4209/aaqr.2013.02.0061

Li, H., Zhang, X., and Xu, Z. (2019). How ship owners face the IMO sulphur limit 2020. *China ship survey* 2), 25–27.

MARITEC (2022). *Bunker flash update-chemical contaminants in fuels from ARA region*. Available at: https://www.maritec.com.sg/news-detail/BUNKER_FLASH_Chemical_Contaminants_in_Fuels_from_ARA_Region_BF202207-05 (Accessed 2022/6/23).

MPA. (2022a) *Update on MPA's preliminary findings on reported bunker fuel contamination in Singapore port*. Available at: https://www.mpa.gov.sg/media-centre/details/mpa-completes-its-investigations-into-bunker-fuel-contamination-in-singapore-port (Accessed 2022/6/23).

MPA. (2022b) *Update on MPA's investigation of bunker fuel contamination in Singapore port*. Available at: https://www.mpa.gov.sg/media-centre/details/mpa-completes-its-investigations-into-bunker-fuel-contamination-in-singapore-port (Accessed 2022/6/23).

MPA. (2020a) *MPA publishes second edition of guides on IMO*. Available at: https://www.mpa.gov.sg/media-centre/details/mpa-publishes-second-edition-of-guides-on-imo-2020 (Accessed 2022/9/16).

MPA. (2020b) *The IMO sulphur limit*. Available at: https://www.mpa.gov.sg/web/portal/home/singapore-registry-of-ships/about-srs-and-what-new/IMO-2020-Fuel-Oil-Sulphur-Limit (Accessed 2020/12/23).

MSA. (2018) *Plan for the marine air pollutant emission control area (Chinese and English version)*. Available at: https://www.msa.gov.cn/page/article.do?articleId=552CD0E5-0969-48D6-BF44-78F6720A7528 (Accessed 2022/6/23).

MSA. (2020) *The "Law of the people's republic of China on maritime traffic safety (Revised draft)" is passed at the executive meeting of the state council*. Available at: https://www.msa.gov.cn/html/xxgk/hsyw/20200924/E5B6D2E0-132A-4084-AE95-F68DEFE53F49.html (Accessed 2022/6/23).

MSA. (2020). *Maritime safety administration publishes plan for the IMO sulphur limit*. Available at: https://www.msa.gov.cn/page/article.do?articleId=7917B172-1CB6-421E-881C-25E5D00001B3 (Accessed 2022/6/23).

Paul, G. (2014). From reductionism to systems thinking: How the shipping sector can address sulphur regulation and tackle climate change. *Mar. Policy* 43, 376–378. doi: 10.1016/j.marpol.2013.07.009

Pritchard, B. (2008). California Air resources board approves clean-fuel standards for oceangoing ships. *Int. Environ. Rep.* 31 (16), 750–751.

Qiu, J. (2019). Implementation recommendations for the use of low-sulfur furl in the implementation of the new standard for the sulfur content of ship fuel in 2020. *World Shipping* 12, 28–32. doi: 10.16176/j.cnki.21-1284.2019.12.007

QZMSA. (2021) *The four step method of "building, learning, screening and checking" makes the ship's fuel oil exceed the standard "no place to escape*. Available at: https://mp.weixin.qq.com/s/KyMLU4iKNsKLGQRylTLKCA (Accessed 2022/9/16).

Sunshine Security Team. (2020). In: *Interpretation of the latest port state inspection procedures (IMO Res.A.1138(31))-—APPENDIX 18*. Available at: https://mp.weixin.qq.com/s/lWMcX1RG1qFoJQrVcrL-4A (Accessed 2022/6/23).

Tian, M. (2017). The impact of sulfur emission control policy of international maritime organization. *Int. petroleum economics* 5), 77–82.

Tokyo Mou. (2021). *Tokyo Mou launched guidance on remote psc inspection*. Available at: https://www.tokyo-mou.org/doc/Press%20Release%20on%20remote%20PSC%20inspection-f.pdf (Accessed 2022/6/23).

UK. (2011). *Air pollution from ships-clean shipping coalition*. Available at: https://www.legislation.gov.uk/uksi/2010/895/contents/made (Accessed 2022/6/23).

Wang, C. (2019). What should Chinese ships do to reduce emissions under sulfur restriction. *Transport construction Manage.* 6, 62–65.

Wang, S. (2020). In: *Attention! black carbon emissions from ships are being targeted*. Available at: https://mp.weixin.qq.com/s/nCDd6YMXmizjg9tVL4v0bw (Accessed 2022/6/23).

Wei, M. (2018). Inspiration of American marine ship energy conservation and emission reduction policy. *China Ship Survey* 1, 60–63.

Weng, Y. B. (2019). Application prospect of marine alternative fuels. *China Ship Survey* 8, 46–49.

Winkel, R., Weddige, U., Johnsen, D., Hoen, V., and Papaefthimiou, S. (2016). Shore side electricity in Europe: Potential and environmental benefits. *Energy Policy* 88, 584–593. doi: 10.1016/j.enpol.2015.07.013

Xiao, Y. (2017). The current gaming situation of international marine SOx emission reduction and its impact on China. *Peace Dev.* 3, 92–104.

Xu, H. (2008). The spring and autumn changes of ship gas emission reduction. *China ship inspection* 6, 83–86.

Xu, Y. (2019). 80% is open-loop. In: *The climax of ship scrubber installation*. Available at: http://www.chinaports.com/portlspnews/381 (Accessed 2022/6/23).

Yang, Z. (2021). On the interaction between the concept of maritime community with a shared future and the construction of the 21st century maritime silk road. *J. Ocean Univ. China (Social Sci. Edition)* 5, 1–10. doi: 10.16497/j.cnki.1672-335x.202105001

Yuan, X., and Tong, K. (2017). Analysis on the legal regulation of cooperative control of atmospheric emissions from Chinese ships. *China Maritime Law Res.* 28 (2), 11.