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A study on policy measures to promote ship SOx towards "low zero emission" and recommendations for China's practice

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A STUDY ON POLICY MEASURES TO PROMOTE SHIP SO_X TOWARDS "LOW ZERO EMISSION" AND RECOMMENDATIONS FOR CHINA'S PRACTICE

By

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Declaration

I certify that all the material in this dissertation that is not my own work has been identified, and that no material is included for which a degree has previously been conferred on me.

The contents of this dissertation reflect my own personal views, and are not necessarily endorsed by the University.

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Abstract

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Ship sulphur oxides (SOx) have become one of the most important marine environmental pollutants of worldwide concern due to their high proportion and serious hazards. International Maritime Organization (IMO) has developed and implemented MARPOL Annex VI to control ship SOx emissions worldwide. China, the United States (US), the European Union (EU) and other countries or regions have also introduced corresponding regional emission reduction policies and measures, thus promoting ship SOx towards "low zero emission", that is, reducing emissions or not emitting as much as possible.

Based on a comprehensive collection of literature on SOx emission reduction policies and measures, this paper provides a descriptive overview of the generation and hazards of SOx, technologies and fuels that can help reduce SOx emissions from ships, as well as policy measures and application examples to promote the use of cleaner technologies and fuels. The successful experiences of international countries in the implementation of policy measures are also summarized.

Considering the environmental impacts brought by the rapid development of Chinese shipping in recent years, this paper categorizes the main mandatory regulations and incentive measures for controlling SOx emissions in China through the review, analysis and organization of relevant literature, based on the technologies and fuels used for SOx emission reduction from ships, and focuses on the shortcomings of the regulatory framework and incentives in China's practice with relevant data. Based on the theoretical analysis and experience, this paper proposes suggestions for China to improve the legal effectiveness of Domestic Emission Control Areas (DECAs), improve the legal system, strengthen supervision and enforcement, and improve the effectiveness of incentives.

KEY WORDS: SOx; Policy measures; China's practice; Mandatory regulations； Incentives

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List of Abbreviations

UNCTAD	United Nations Conference on Trade and Development
NO_x	Nitrogen Oxide
SO_x	Sulphur Oxide
PM	Particulate Matter
IMO	International Maritime Organization
MOT	Ministry of Transport of The People's Republic of China
SO_2	Sulphur Dioxide
GHG	Greenhouse Gas
NRDC	Natural Resources Defense Council
SECA	Sulphur Emission Control Area
OECD	Organization for Economic Cooperation and Development
IAPP	International Air Pollution Prevention Certificate
PSC	Port State Control
DECA	Domestic Emission Control Area
SO_3	Sulphur Trioxide
$PM_{2.5}$	Fine Particulate Matter
SO	Sulphur Monoxide
S_2O_3	Sulphur Dioxide Trioxide
WHO	World Health Organization
MGO	Marine Gas Oil
VLSFO	Very Low-Sulphur Fuel Oil
ULSFO	Ultra-Low Sulphur Fuel Oil
EGCS	Exhaust Gas Cleaning Systems
BIMCO	The Baltic And International Maritime Council
ICS	International Chamber Of Shipping
LNG	Liquefied Natural Gas
SP	Shore Power
MARPOL	International Convention For The Prevention Of Pollution From Ships
MEPC	Marine Environment Protection Committee

EU	European Union
US	United States
ITF	International Transport Forum
ESI	Environmental Shipping Index
FWC	Fair Wind Charter
EPA	Environmental Protection Agency
PRD	Pearl River Delta
YRD	Yangtze River Delta
BRA	Bohai Rim Area
MOF	Ministry Of Finance Of The People's Republic Of China
PRC	People's Republic Of China
UNCLOS	United Nations Convention on the Law of the Sea
MSA	Maritime Safety Administration
UAV	Unmanned Aerial Vehicle
IoT	Internet of Things
RPAS	Remotely Piloted Aircraft-Based System
EMSA	European Maritime Safety Agency
CARB	California Air Resources Board
CIC	Concentrated Inspection Campaign

Chapter 1 Background

1.1 Background and significance of the study

International maritime transport carries more than 80% of worldwide trade (United Nations Conference on Trade and Development [UNCTAD], 2019), providing low-cost and environmentally friendly transportation of goods. At the same time, the problem of gas emissions from ships brought about by the fast development of maritime trade is also receiving increasing attention. NO_x, SO_x, PM, etc. emitted from ships are extremely harmful to the environment and human health, and SO_x is the most significant and harmful gas emitted from ships. A new study shows that SO_2 emissions from shipping accounted for 12 percent of worldwide emissions from anthropogenic sources in 2017 (McDuffie et al., 2020).

Environmental policy measures are considered essential to reduce emissions and encourage sustainable growth (Carrilho-Nunes & Catalão-Lopes, 2022). Therefore, the international community has developed a number of emission reduction policy measures to deal with the adverse effects of ship emissions. IMO has developed and implemented international mandatory emission reduction regulations by delineating SECAs, mandating ships to take measures to reduce ship SOx emissions. Member states have also developed their own emission reduction policies and measures to control ship SOx emissions and promote the application of emission reduction technologies and fuels.

China has a long coastline connecting more than 50 coastal ports and the busiest inland waterway system in the world. Inland and coastal shipping as well as port networks play a key role in supporting trade development and promoting economic growth in cities (Fu et al., 2017). From 2010 to 2021, cargo throughput at China's coastal ports increased nearly eight-fold, and cargo throughput at inland ports increased nearly three-fold (Ministry of Transport of the PRC [MOT], 2011; MOT,2022). At present, China is already one of the largest shipping countries in the world and already has seven of the world's top ten container ports, as shown in Figure 1.

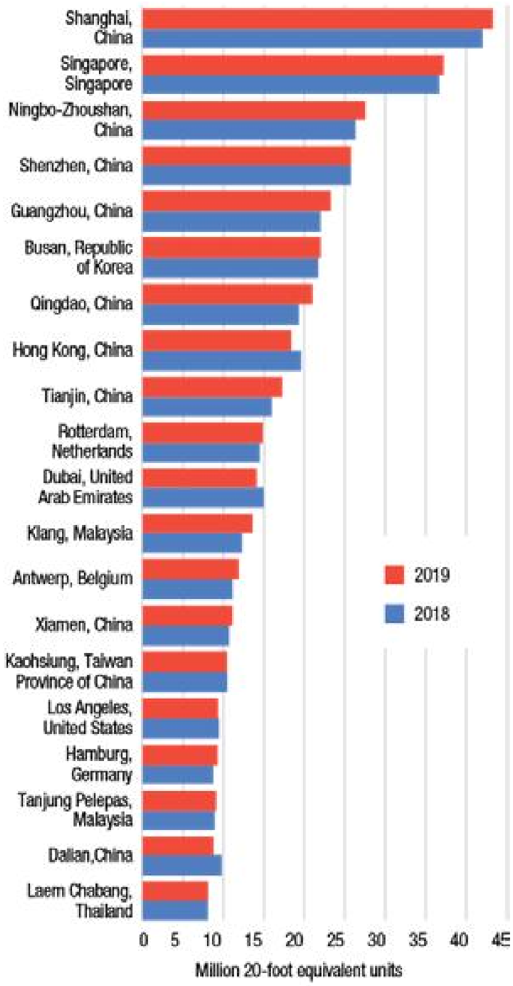


Figure 1: Top 20 leading global container ports, 2018-2019

Source: UNCTAD. (2020). Review of Maritime Transport 2020. United Nations Publications.

However, China's increasingly prosperous maritime trade has also led to an increase in SO_x emissions from ships. In 2017, China accounted for 14.3% of global SO_2 emissions from ocean-going vessels (Wang et al., 2021). At the same time, SOx emissions from shipping have become a significant source of air pollution in Chinese ports (Table 1). Moreover, the scale of China's future shipping trade, port size and ship activities will still grow gradually, which will bring increasingly serious environmental problems if shipping emissions are not controlled.

Table 1: Contribution of shipping to air pollution based on ship emission inventories for major port cities or regions in China

Port city or region	NO_x	SO_2	$PM_{2.5}$	Year
Hong Kong	37%	52%	41%	2017
Shanghai	25%	17%	5%	2015
Shenzhen	16%	59%	5%	2013
Tianjin	9%	10%	3%	2013
Pearl River Delta	12%	14%	4%	2015
Yangtze River Delta	12%	7%	1.3%	2015
Coastal Provinces	9%	10%	NA	2013

Source: Natural Resources Defense Council [NRDC]. (2020). *Leading the development of green shipping.*

In recent years, as environmental awareness has increased, China has taken a series of regional policy measures to control SOx emissions from ships to accelerate the reduction of SOx emissions within China's jurisdiction, in fulfillment of the international convention on SOx emission reduction from ships. China has ensured the reduction of emissions mainly through mandatory regulations including the establishment of DECAs, further restrictions on the sulphur content of marine fuel and the use of SP, and the implementation of economic incentives at the national and local levels to create conditions for ships to adopt further green technologies and fuels. These mandatory emission reduction regulations and incentives have indeed been effective in reducing SO_x emissions from ships, and according to the study, China's ship SO_2 emissions decreased by 29.6% in 2019 compared to 2016 (Wang et al., 2021).

However, these policy measures are not perfect, the regulatory framework is still inadequate, and there are shortcomings in incentives. First, the effectiveness of China's DECAs policy on emission reduction is limited by international law. Second, the coercive power of SP regulations is not sufficient. Third, the authorities' enforcement tools are limited and of varying intensity, and there may be "pollution leakage". Fourth, the cost of non-compliance by enterprises is low, and the policy deterrence is insufficient. Fifth, the regulatory system is not perfect, and the fuel quality management is weak. Sixth, the geographical nature of the incentives somewhat limits the motivation of ship participation. Seventh, the continuity of the policy is not strong, which reduces the initiative of ship retrofitting. Eighth, the mismatch between policy and demand somewhat reduces the motivation of ships to use new technologies and fuels.

The above-mentioned deficiencies and challenges have to some extent affected the implementation effect of mandatory regulations for emission reduction in China as well as the participation of incentive measures. Therefore, an in-depth study of these shortcomings and challenges, based on the summary of international successful experience, and the proposed optimization will undoubtedly have important practical significance for the practice of SOx reduction policies in China. At the same time, some policy measures, which have been proved to be beneficial to reduce NOx and GHG emissions, and therefore put forward optimization suggestions will also be beneficial to China in dealing with other environmental problems of ships.

1.2 Current status of domestic and international research

1.2.1 Research by foreign scholars

Foreign scholars' research on policy measures for SO_x emission reduction from ships is earlier and more comprehensive, and this paper will review four aspects: the necessity, implementation, effectiveness and negative impacts of the policy measures.

The first is a study on the need to control SO_x emissions from ships. Eyring et al. estimated the amount of SO2 emitted at sea before limiting SOx emissions from ships to be about 5-8% of global anthropogenic emissions (Eyring et al, 2005). Zis and Psaraftis provide a new estimation of approximately 3.5% for 2015, based on data from the OECD (Zis & Psaraftis, 2019). IMO reports that the global shipping industry emits an average of 10.6 million tonnes of SO_x, accounting for 12 per cent of global emissions (IMO, 2015). Meanwhile, IMO estimates that the global sulphur cap in 2020 are expected to reduce total SOx emissions from ships by 77%, equal to 8.5 million tonnes of SOx (IMO, 2019).

The second is a study on policy implementation. Sampson et al. were among the first scholars to conduct academic research on the implementation of SECA. They argued that although implementation was difficult, most companies complied, and even if there were some instances of non-compliance, it was probably unintentional (Sampson et al., 2016). Kopela noted that violations in the high seas are difficult to detect. And coordination between national regulations and global regulatory regimes will improve consistency in abatement measures and provide a more effective self-regulatory tool for the shipping industry (Kopela, 2017). Zis and Cullinane argue that a harmonised enforcement regime is needed to ensure fair competition between ship operators (Zis & Cullinane, 2020).

The third area is a study on the effects of policy measures. Bilgili argues that the expected outcome of the IMO's 2020 sulfur cap is not ideal from a life-cycle perspective, noting that alternative fuels would be more favorable in terms of the overall environment and that the IMO should focus more on developing new regulations and policies on alternative fuels (Bilgili, 2021). Lindgren's study, based on differential regression, concluded that the 2020 sulfur cap reduced the annual average ambient concentration of SO_2 in coastal areas by 22% (Lindgren, 2021).

Fourth is the study of the negative impact of response measures. In this regard, the international community is highly concerned about scrubbers, and opinions are most divided. Some scholars believe that scrubbers simply redirect the sulphur released into the air to the ocean or land. A study by the Swedish Institute has shown that scrubber water from untreated open-loop systems contains significant amounts of substances that are harmful to the marine environment. Teuchies et al. suggest that the impact of scrubber emissions on the ocean is a long-term and complex process (Teuchies et al., 2020).

1.2.2 Research by Chinese scholars

From the literature collected by the author, relevant studies in China have focused on the content, effects, and regulation of China's DECA policy.

Chinese scholars are most concerned with the content and effects of China's DECA policy. Some scholars have studied in detail the evolution of the development of China's DECA policy (Zhang & Zheng, 2020). Taking Bohai Rim Area (BRA) as an example, Liu quantitatively analyzed the impact of DECA policy on reducing pollutant emissions and concluded that the policy had a positive effect on reducing emissions (Liu, 2020). Some scholars also believe that the existing DECA policy is not effective and that there is a need to develop an appropriate subsidy scheme to encourage shipping companies to adopt more effective emission reduction technologies (Zhu et al., 2017).

Chinese scholars have also studied many regulatory aspects related to policy measures. Some scholars believe that a performance evaluation index system for DECA enforcement should be established to evaluate the enforcement of the existing DECA. (Yu et al., 2021). Feng summarizes the main problems in the implementation of China's policy measures and points out that China currently lacks a sound regulatory system for the implementation of policy measures and has limited regulatory capacity and level (Feng, 2021). Li discusses the problems in laws and regulations related to sulphur limitation on ships and maritime supervision and enforcement from the current situation of DECA policy regulation, and puts forward suggestions to improve the regulations and improve the supervision work (Li, 2022).

Review: through the study of the literature, it is found that scholars' research on policy measures for controlling SOx emissions from ships, which started earlier abroad, is more comprehensive and in-depth, while domestic scholars focus most on the implementation effects of China's DECAs policies and the difficulties in regulation. In general, there are few comprehensive studies on global emission reduction policy measures, especially incentive measures. Therefore, this paper will comprehensively analyze the global policy measures for SOx emission reduction from ships, summarize the beneficial experiences in their implementation, and propose guiding, targeted, and operable improvement countermeasures for China's emission reduction policies measures.

1.3 Main research content and key problems to be solved

This paper provides a descriptive overview of two types of global emission reduction policy measures and summarizes the successful experiences in international practice, based on the technologies for reducing SOx from ships. At the same time, the paper summarizes China's policy measures to reduce SOx emissions from ships, analyzes the shortcomings of China's regulatory framework and the challenges in the implementation of incentives based on the successful international experience, and puts forward ideas and suggestions for improvement. The study covers the following aspects.

Chapter 1, Clarifies the background and significance of the study, and the current status of domestic and foreign research. The research methods and contents of this paper are introduced.

Chapter 2, An overview of SO_x control in ships. An overview of SO_x generation and hazards, technologies and fuels that can help reduce SO_x emissions from ships, and policy measures to promote the use of cleaner technologies and fuels.

Chapter 3, International policy measures and experiences in promoting SOx towards “low zero emissions”. A general description of different types of international policy measures for SOx emission control from ships and corresponding application examples are presented. It also analyzes and summarizes some experiences in the practice of policy measures in various countries.

Chapter 4, Policy measures to control SOx from ships in China and the shortcomings in implementation. Starting with abatement technologies, this chapter summarizes the major SOx reduction policy measures in China and focuses on the shortcomings of the regulatory framework and incentives.

Chapter 5, Recommendations for China. Suggestions for reducing SO_x emissions from ships in China are presented, taking into account the beneficial experiences of foreign countries.

Chapter 6, Summary and Outlook.

1.4 Research methods

1.4.1 Literature research method

The literature research method is the method of reviewing, analyzing, organizing and searching for the essential properties of things, and forming a scientific understanding of facts through the study of literature. This study adopts the literature research method to sort out and analyze the relevant regulations and theories, and summarize the results that have been achieved and the issues that need further research, so as to lay a solid foundation for the subsequent research of this paper.

1.4.2 Case Study Method

Case study is a kind of empirical investigation, which is a method to reveal or investigate actual phenomena in a realistic context. Case study is a method of empirical inquiry that involves studying phenomena, especially the relationship between phenomena and contexts, in real contexts, guiding multiple data collection through pre-developed theoretical propositions, and discussing conclusions. In order to achieve an in-depth discussion of China's SOx reduction policy measures, international typical policy measures that are very similar to the topic are selected as case subjects in this study.

1.4.3 Comparative research method

The comparative research method is a research method that examines related things together according to certain criteria, observes and understands things from the perspective of interconnections and differences, and then explores the laws of development. Based on the case study, this paper analyzes the shortcomings and challenges of similar policy measures in China, and proposes suggestions for optimization.

Chapter 2 Overview of SO_x emission control for ships

2.1 The source and hazard of SO_x in ships

SO_x is a collective term for different chemical compounds containing sulphur and oxygen, including sulphur monoxide (SO), sulphur dioxide (SO_2), sulphur trioxide (SO_3) and sulphur dioxide trioxide (S_2O_3), which are mainly produced by the combustion of fossil and fossil fuels.

Ships obtain propulsion, heat and electricity mainly through marine fuels. When marine fuels are burned in engines, the sulphur in them is mainly converted to SO_2, and a small portion is oxidized to SO_3, resulting in sulphuric acid and sulfate aerosols, and is emitted directly as Particulate Matter (PM). At the same time, SO_x, together with NO_x, contributes to the secondary formation of $PM_{2.5}$, and these contribute to climate change and air pollution (NRDC, 2014). In addition to this, there are also risks to human health. Epidemiological studies have consistently linked sulphur to a range of diseases, including lung disease and premature death (Eyring et al., 2005). The World Health Organization (WHO) claims that chronic exposure to SO_2 leads to increased mortality and morbidity, and can negatively affect lung function (WHO, 2005).

Moreover, SO_x migrates long distances in the atmosphere and may cause damage far from its initial source. Thus, even though SO_x may be emitted by ships on the high seas, they can still travel long distances from their original point of emission.

2.2 Technologies and fuels that help reduce SO_x emissions from ships

There are three main options for SO_x reduction during voyages: the use of compliant fuel oil , the use of approved exhaust gas cleaning systems (EGCS), and the use of liquefied natural gas (LNG). While at berth, shore power (SP) is the more widely used abatement technology (Zhong et al., 2021).

2.2.1 Compliant Fuel Oil

SO_x is a pollutant produced during combustion, and since it is proportional to the sulphur content of the fuel, the main way to reduce SO_x emissions is to reduce the sulphur content of the fuel (European Commission, 2010), and the easiest way to do this is to switch to fuels with low sulphur content, such as marine gas oil (MGO), very low-sulphur fuel oil (VLSFO), and ultra-low sulphur fuel oil (ULSFO).

Even in the absence of any emission control equipment, switching to low sulphur fuel will directly result in a reduction of sulphur oxide emissions. In fact, switching to low-sulphur fuels is now a common preference of shipowners to reduce emissions. In the case of container ships, for example, Alphaliner statistics show that 87.5% of the world's container ships currently choose to use fuel oil with low sulphur content (Zhong et al., 2021).

2.2.2 EGCS

In addition to reducing the sulphur content of the fuel, the installation of post-treatment equipment, such as EGCS, also known as scrubbers, which are generally classified as open-loop, closed-loop or hybrid systems, is also an option that meets international requirements for emission reduction. EGCS can remove the SO_x effect and well implement, thus becoming a short-term solution for many shipowners to choose. According to the BIMCO statistics, As of January 2021, there are 4,006 scrubber-equipped vessels worldwide (Sand, 2021).

However, many countries and regions are restricting or banning scrubbers in consideration of the potential secondary pollution caused by the discharge of washing water. Figure 2 briefly lists some of the countries (regions) that have banned open-type scrubbers. Table 2 details some of the regions that have restricted or banned washing water discharge as of September 2020.

Figure 2: Some countries (regions) where open-type scrubbers are banned

Source：Cheng, M., & Gao, S. (2019). Global regulatory requirements for open scrubbers on ships - banned dominant, permitted countermeasures.

Table 2. Locations where washing water discharges are restricted or prohibited as

of September 2020

Country	Details
Argentina	Prohibits open-loop (OL) discharge water in internal waters, territorial seas, and EEZs
Australia	Ships using scrubbers must notify Australian Maritime Safety Authority before port arrival
Bahrain	Prohibits OL discharges in territorial seas and EEZs unless they can be proven to comply with the 2015 IMO guidelines
Belgium	Discharges prohibited in ports, internal waters, and within 3 nautical miles (nm) of shore
Bermuda	Prohibits OL discharges in territorial seas; closed-loop (CL) discharges allowed with prior approval
Brazil	Discharges prohibited at Vale bulk terminals/ports; discharges discouraged within 24 nm of shore
China	Prohibits OL discharges in internal rivers and Domestic Emission Control Areas
Egypt	Discharges prohibited in territorial seas, ports, and the Suez Canal
Estonia	Discharges prohibited in ports and estuaries unless the ship owner can demonstrate that the discharge does not cause significant adverse effects
Finland	Discharges prohibited in the port of Porvoo
France	Prohibits OL discharges in some ports and rivers, including Bordeaux, Port Jérôme-sur-Seine, River Seine, and Le Havre
Germany	Discharges prohibited in internal waterways
Gibraltar	Prohibits OL discharges in waters of Gibraltar
Hong Kong	Use of scrubbers requires an exemption
Ireland	Discharges prohibited in ports of Dublin, Waterford, and Cork
Latvia	Discharges prohibited in territorial seas and ports
Lithuania	Discharges prohibited in ports
Malaysia	Prohibits OL discharges in territorial seas except for ships transiting the Malacca Strait that are not bound for a Malaysian port
Norway	Prohibits OL discharges in World Heritage Fjords sea areas of Geirangerfjord and Nærøyfjord
Oman	Discharges prohibited in territorial seas
Pakistan	Prohibits OL discharges in the ports of Karachi and Bin Qasim
Panama	Prohibits OL discharges in the Panama Canal
Portugal	Prohibits OL discharges in port
Qatar	Discharges prohibited in territorial seas
Saudi Arabia	Prohibits OL discharges in port
Singapore	Prohibits OL discharges in port
Spain	Prohibits OL discharges in the ports of Algeciras, Cartagena, and Huelva
Sweden	Discharges prohibited in the ports of Brofjorden, Gävle, Norrköping, Umeå, Sundsvall, Skellefteå, and Stockholm
United Arab Emirates	Prohibits OL discharges in the port of Fujairah
USA	California: Prohibits the use of scrubbers to comply with fuel sulfur limits within 24 nm Connecticut: Discharges prohibited in ports and waters of the state Hawaii: Discharges allowed, but special reporting required

Sources: Comer, B., Georgeff, E., & Liudmila. (2020). Air emissions and water pollution discharges from ships with scrubbers.

Furthermore, the lack of regulations or standards for uniform classification and transportation requirements for residues makes practical acceptance difficult. It can be seen from the GISIS system that the current receiving capacity of many port states is still not sufficient to meet the demand. Figure 2 shows that only four ports in China can receive residues.

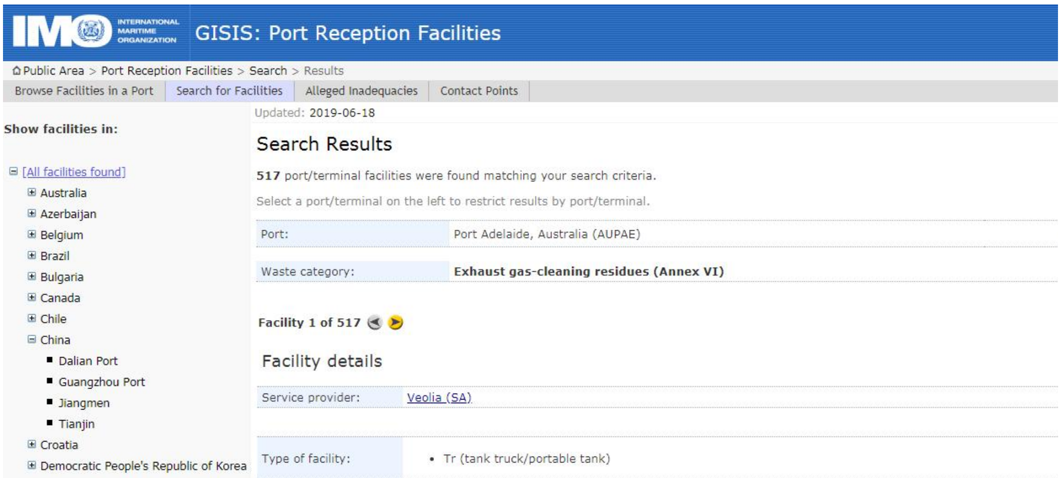


Figure 2 - Port reception facilities of China.

Source: IMO. (n.d.) GISIS: Port Reception Facilities.

2.2.3 LNG

LNG is widely considered a promising energy source for short and medium term shipping because it is an eco-friendly fuel that contains almost no sulphur and can reduce NO_x, SO_x and PM emissions by 85-100% compared to conventional ship fuels (Kim & Seo, 2019). LNG is becoming an option for more new ships.

While the price of LNG is advantageous, the cost of transporting LNG to ports and ships is very high. This may change if the LNG fuel network expands and more ports are able to provide LNG fuel. Moreover, the investment costs for new building are large and hardly cost competitive.

2.2.4 SP

SP is another reliable and effective solution. SP system consists of a shore-side power supply system, a shore-ship connection system and a shipboard power receiving system (Qi et al., 2020). SP allows a ship to shut down its engine and connect to the grid while at berth, replacing the ship's own fuel auxiliary engine to power the overall equipment used by the ship while in port, in order to meet the ship's power needs, thus significantly reducing SO_x emissions while the ship is in port emissions while the ship is in port.

According to the study, if all ships at berth use SP, SO_2 emissions can be reduced by 3-60%. In addition to this, when ships use SP while at berth, air pollution emissions in the port area can be eliminated, and the climate impact (if the grid is clean), noise and vibration can be reduced (Zhen et al., 2022).

2.3 Policy measures to promote the use of clean technologies and fuels for ships

Currently, global policy measures to promote the use of cleaner technologies and fuels to reduce SOx emissions from ships can be broadly divided into two categories: international mandatory emission reduction regulations and local emission reduction policy measures.

2.3.1 The International Mandatory Emission Reduction Regulation

The international mandatory emission reduction regulation, which is a policy proposed by the signatories of MARPOL, assessed and implemented by IMO, mandates ships to take measures to reduce SO_x emissions from ships. All ships entering the designated area must unconditionally accept the corresponding constraints, and the constraints are uniformly stipulated by IMO, and the policy is applied globally with significant effect.

2.3.2 Regional emission reduction policy measures

In addition to the international mandatory emission reduction regulation, national and local governments also adopt regional emission reduction policy measures to achieve better control effect, which are generally divided into two kinds of regional mandatory regulations and incentive measures.

Regional mandatory regulations are issued and implemented by the national or local governments to compel ships entering the designated areas to take measures to reduce SO_x emissions from ships or to meet more stringent SO_x emission control requirements. All ships entering the designated area must unconditionally accept the corresponding constraints, and the policy effect is closely related to the policy severity.

Incentive measures, refers to the state or port economic benefits in exchange for shipping enterprises in the designated area to reduce the effect of ship air pollutant emissions means, shipping enterprises can accept the constraints to obtain financial compensation, but also can refuse the constraints and give up the financial compensation, the policy effect depends on the incentive intensity.

Chapter 3 International policy measures and experiences in promoting SOx towards “low zero emissions”

Shipping is largely an international industry. As such, IMO, as the appropriate forum for countries to develop global and regional rules, standards, recommended practices and procedures applicable to ships, has attempted to reach global agreement on controlling SO_x emissions from ships through an international mandatory emission reduction regulation, known as MARPOL, to reduce global SO_x emissions from shipping.

At the same time, some countries have taken a proactive approach by proposing regional emission reduction policy measures and striving to make these policy measures achieve practical results in order to reduce the air pollution problems caused by ship SO_x emissions in their waters and ports. This chapter describes in general terms the international policy measures related to the control of SO_x emissions from ships, and at the same time analyzes and summarizes some experiences in the formulation and implementation of policy measures in various countries.

3.1 The international mandatory emission reduction regulation

3.1.1 MARPOL's sulphur limit requirements

In 1988, Marine Environment Protection Committee (MEPC) began discussing and considering research issues on air pollution. In 1990, Norway submitted a report to IMO on air pollution from ships, explaining the pollution of the air environment, such as SO_x and NO_x emitted from ships worldwide (IMO, n.d.a). In November 1991, the

IMO adopted resolution A.719(17) on "Prevention of Air Pollution from Ships", deciding that the best way to reduce air pollution from ships through the cooperative efforts of member states was to establish a new annex to MARPOL that would provide rules for the limitation and control of emissions of harmful substances from ships into the atmosphere (Hughes et al., 2017). So, Annex VI to MARPOL was adopted in 1997, to deal with air pollution caused by ships, including ship SO_x, while expanding the scope of IMO work to the marine atmospheric field.

MARPOL Annex VI sets limits on the sulphur content of marine fuels from the applicable geographical areas, applicable standards, respectively. In the applicable geographical area, the provisions of the ship sulphur emission control area (SECA), and as the boundary, divided into SECA and SECA outside (Table 3: Global ship sulphur emission control areas). Currently, the MARPOL Convention delineates four SECAs for ships, which are the Baltic Sea, the North Sea, North America and the Caribbean Sea, as shown in Figure 3.

Table 3: Global ship sulphur emission control areas

Emission control area	Adopted	In effect from
Baltic Sea	26/09/1997	19/05/2006
North Sea	22/07/2005	22/11/2007
North American	26/03/2010	01/08/2012
US Caribbean Sea	26/07/2011	01/01/2014

Source:Author's compilation based on information from “www.imo.org”.

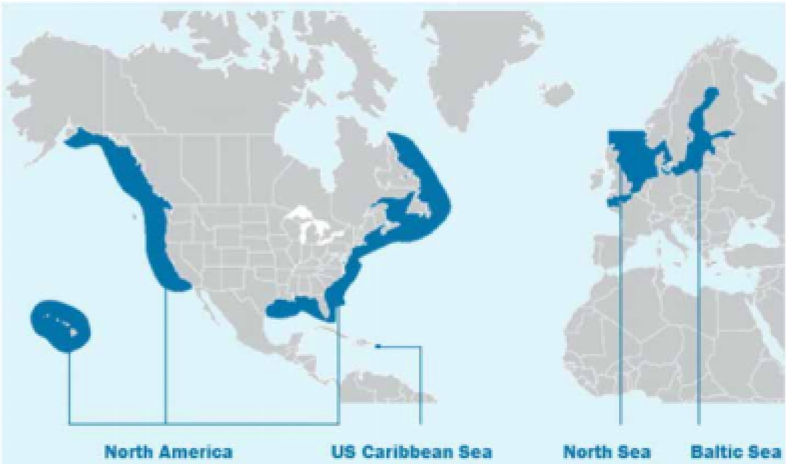


Figure 3: Global ship sulphur emission control areas

Source: NRDC. (2014). Prevention and Control of Shipping and Port Air Emissions in China.

In terms of applicable standards, the regulation has undergone a series of step changes over the years with different control standards for the sulphur content of marine fuel (expressed as % m/m, i.e., by mass) globally and within SECA, as shown in Figure 4.

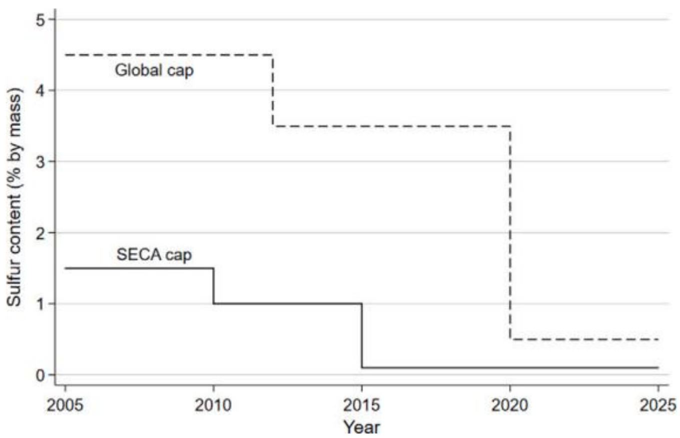


Figure 4. Sulphur cap applied globally and in the SECA.

Source: Lindgren, S. (2021). The coast is clear: Shipping emission standards, air quality and infant health.

Under the latest developments in the Annex, more stringent controls on SO_x emissions have been adopted. Within SECA, the sulphur content limit for fuels used on board ships has been set at 0.1% m/m since 2015. Outside SECA, the sulphur content of ship fuel should not exceed 0.5% m/m as of January 1, 2020, according to the latest MEPC amendment to Annex VI in 2008, which is also known as the 2020 global cap.

For ships entering or leaving SECA, Regulation 14.6 requires that before entering SECA, the ship must be fully converted to SECA-compliant fuel oil. Likewise, conversion to fuel oil cannot begin until after leaving SECA. There should be a written description of the fuel oil conversion procedure on board the ship and a record of the situation. At the same time, considering the correlation between the sulphur content of the ship's fuel oil and the quality of the fuel oil, the provision and quality of the fuel oil are clearly defined in Regulation 18.

Meanwhile, the MEPC 78, which ends in June 2022, approved the draft amendments to MARPOL Annex VI designating the entire Mediterranean Sea as SECA. The specific date of entry into force will be decided at MEPC 79 (IMO, 2022). This means that stricter limits on SOx emissions will be imposed under the IMO framework.

3.1.2 The implementation and enforcement of the sulphur limit

The effectiveness of MARPOL's sulphur limitation requirements in reducing SOx emissions from ships will depend on the effectiveness of their implementation, i.e., compliance by shipowners and ship operators, and enforcement of non-compliance, which is important to ensure a level playing field.

With regard to the implementation of the sulphur limitation requirements, although MARPOL makes it mandatory for ships to take measures to reduce SOx emissions from ships by limiting the sulphur content of marine fuel, Regulation 4 of the Convention provides that alternative measures, such as scrubbers, may be taken to meet the total SOx emission control requirements where permitted by the competent authority of a Contracting Party.

Ships can comply with MARPOL sulphur limits by using compliant fuels (including alternative fuels) or using emission reduction technologies with a degree of flexibility, taking full account of cost effectiveness, technological developments and port capacity, for example, the availability of port fuel and LNG and the accessibility of onshore power facilities. This flexible approach to compliance is consistent with the "goal-based" regulatory approach adopted by the IMO since the 21st century (International Chamber of Shipping [ICS], 2020).

Because of this flexibility, choosing the best sulphur reduction option for compliance has become the biggest challenge for shipowners and ship operators. It is also evident that ports play a very important role in ensuring that ships calling at ports receive quality fuel that meets IMO requirements and provides alternative energy sources, such as onshore power.

Enforcement of MARPOL sulphur limits is the responsibility of the competent authorities of the Contracting Parties. MARPOL Annex VI sets out the procedures for investigation, certification and inspection, including sampling, but IMO is not responsible for setting fines or sanctions, depending on individual member states. Flag States have jurisdiction over ships and issue International Air Pollution Prevention Certificates (IAPPs) to ships of 400 gross tons and above. Port States are able to apply Port State Control (PSC) to the sulfur emission limits set by MARPOL. When the inspection by the port authority of a Contracting State finds that the ship's sulphur limitation measures do not comply with the international sulphur limitation requirements, the corresponding action can be taken in accordance with the regulations. At the same time, according to the IMO Instruments Implementation Code, IMO to review the compliance of member states, so as to urge member states to actively fulfill their compliance obligations.

3.2 Regional emission reduction policy measures

In order to promote the use of cleaner fuels and technologies for ships, in addition to the universal provisions of MARPOL, some regional organizations, countries and industries have taken a proactive approach to control SOx emissions from ships by developing and implementing regional emission reduction policy measures, as shown in Table 4.

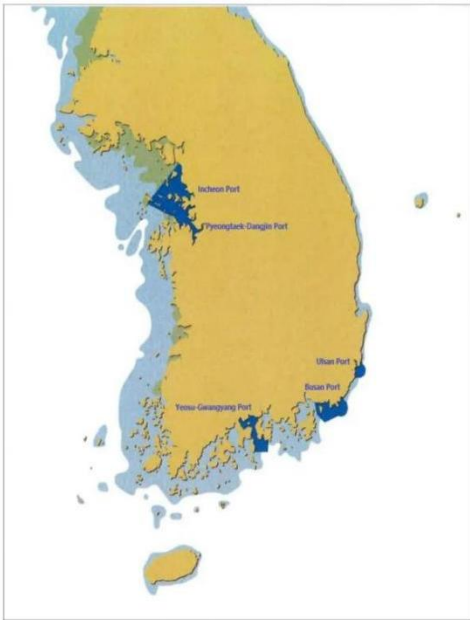
Table 4: Regional emission reduction policy measures and application examples

Nature	Policy measure makers	Application examples
Regional mandatory	States or local governments establish ship SO_X emission control requirements.	1. The EU requires ships berthing in EU ports for more than 2 hours to use fuel oil or shore power with a sulfur content of no more than 0.1% m/m from January 1, 2010. 2. California, US from January 1, 2014, mandates the use of marine fuel oil with a sulphur content of no more than 0.10% m/m for ships in 24 nautical miles of coastal waters, ports, and some islands (as shown in Figure 5). 3. California, US, mandated the use of shore power in a phased manner for ships calling at ports from January 1, 2014. 4. Korea mandates the use of 0.1% m/m sulphur fuel for ships in phases and waters (as shown in Figure 6) from September 1, 2020.
Incentive-based	States, local governments, or industry organizations establish incentive requirements for relevant ship SO_X emission reductions.	1. Singapore started to reward ships using low sulphur oil in the port area since January 1, 2011. 2. The Port of Antwerp, Belgium has been rewarding vessels using LNG power in the port area with closed scrubbers since June 1, 2015. 3. The Port of Vancouver, Canada has been rewarding vessels using cleaner fuels, such as LNG, and using emission reduction technologies, such as shore power, since 2007.

Source: Compiled by the author based on information from various government websites

Figure 5: Sulfur-restricted areas in California, US

Source: Wang, H. C. (2017). Brief introduction on ship emission control area of foreign countries.



SOX Emission Control Area

Figure 6: Sulfur-restricted areas in Korea

Source: Korea Register. (2020). Designation of SO_x Emission Control Area in Republic of Korea.

These regional emission reduction policy measures are complementary to the international mandatory emission reduction regulation, in comparison, they are more flexible and operable, and can be adjusted according to the actual implementation. As can be seen from Table 4, the regional mandatory emission reduction policies are mainly more stringent sulphur content limits and mandatory use of SP at ports of call. Incentive emission reduction measures, on the other hand, provide higher and sustained rewards for those ships considering the adoption of green shipping fuels and technologies to go beyond the existing mandatory requirements, which can accelerate the emission reduction process. At the same time, states or regions that pursue incentive-based emission reduction measures will also provide greater environmental and health benefits to port cities. These policy measures have not only promoted the wide use of low sulphur fuels, but also the development of SOx control technologies in the maritime industry.

3.3 Experiences in the development and implementation of policy measures

3.3.1 Implementing high frequency of inspections and high fines to improve the deterrent effect of the policy

The strength of penalties and the probability of violations being detected and penalized are two important factors that determine the deterrent effect of the policy. A ship owner or ship operator will be more inclined to violate if the probability of being detected is low or the penalties are not strong enough.

The EU implemented high-frequency sampling and inspection of the sulphur content of marine fuel. The European Commission adopted Implementing Decision (EU) 2015/253 on February 16, 2015, which sets out procedures for onboard sampling, fuel supplier controls, and the number of binding ship inspections and annual fuel sampling that Member States must conduct to verify the sulphur content of marine fuel used by ships operating in waters under their jurisdiction. EU 2015/253 requires that Member States annually At least 10% of the total number of individual ships calling on the Member State concerned should be inspected by ship logbooks and bunker delivery notes. From 1 January 2016, the 10% of ships inspected will be subject to further testing of the sulphur content of bunker fuel by sampling, analysis, or a combination of sampling and analysis, depending on the location of the Member State's shoreline. Unless a member state uses telemetry or rapid screening analysis to identify non-compliant ships, or inspects more than 40% of the ships' instruments arriving in port each year, the sampling rate may not be less than 30% or 40% of the inspected ships from January 1, 2020 (European Commission, 2015).

EU countries and the US have also set high fines for violations, such as Belgium's penalty of up to 6 million euros (about $6.38 million) for violations of excessive sulphur levels in marine fuels. In addition to the maximum statutory fine of US$70,117/day for a single vessel violation of MARPOL, the US Coast Guard can also consider a vessel as "criminally negligent" if it is suspected of intentional violations, such as falsifying documentary information, and initiate a direct investigation (NRDC, 2016). The basic purpose is to ensure that companies cannot benefit financially from violations.

3.3.2 Use digital technology to improve the capacity and efficiency of supervision and enforcement

In recent years, the European Maritime Safety Agency (EMSA) through the continuous application of digital technology to enhance the ability and efficiency of law enforcement in EU member states.

First, it is equipped with a large number of highly digital law enforcement devices. For example, EMSA has developed a remotely piloted aircraft-based system (RPAS) to achieve real-time automatic detection of SOx emission levels from ships through the combination of Unmanned Aerial Vehicle (UAV) and Internet of Things (IoT) technologies, improve visualization and expand data collection (EMSA, 2022).

Second, EMSA integrated and correlated data from internal and external sources to create a comprehensive database, THETIS-EU, which became operational on January 1, 2015, to record and exchange compliance inspection results and information from EU member state authorities in accordance with EU legislation, such as the sulphur Content Directive (EU) 2016/802 (EMSA, n.d.). All Member State authorities are able to share these inspection results through this system in order to promote consistency in the implementation of legislation by Member States.

At the same time, THETIS-EU can also identify targets and alerts based on the intended requirements of EU legislation, prioritize ship inspections based on risk, and thus improve the overall effectiveness of member state inspections. For example, THETIS-EU receives in real time the level of sulphur content of a ship's combustion as observed by EMSA through the sniffer remote aircraft system, and when the required standard is exceeded, the competent authority where the ship is located is alerted and can request an inspection of the ship at the next port of call, which helps member states to identify non-compliant ships (EMSA, 2022).

The use of digital technology applications in the EU allows almost real-time monitoring of sulphur compliance, minimizing the number of inspections by those operators with good records while minimizing the number of sub-standard vessels in EU waters and supporting the uniform implementation of EU legislation.

3.3.3 Increasing the enforceability of SP regulations through a comprehensive system of regulations

California is the first place in the world to mandate the use of SP to increase air quality benefits, and it is leading the way in SP technology in the United States with the most comprehensive SP regulations.

California made SP use mandatory for different types of vessels through the "Ships At-Berth Regulation" as of January 1, 2014 (Haniuk, 2020). The law also requires each shipping company to use SP for ships calling at each California port as a percentage of their total calls at that port, reaching 50 percent during 2014-2016; 70 percent during 2017-2019; and 80 percent after 2020. Penalties for non-compliant vessels range from $1,000 to $75,000 per vessel. In 2020, enforcement authorities fined Del Monte Fresh Produce N.A., Inc. up to $1,990,650 after finding that it had violated the Ships At-Berth Regulation at the Port of Hueneme for five consecutive years (California Air Resources Board [CARB], 2021).

In order to be able to meet these requirements, ports and terminals must install the necessary shoreside infrastructure, and shipowners are responsible for ensuring that their vessels are equipped with the appropriate modifications. Shipowners must provide CARB with vessels capable of using shore power by the 2014 deadline. The fleet is also required to submit an annual compliance statement demonstrating compliance with regulatory requirements for the applicable compliance period. The record-keeping and reporting requirements will help monitor the implementation of the regulations and provide greater insight into the fleet's emissions performance and operations, which will facilitate the development of future standards.

The scope of the relevant requirements will be gradually expanded as the new regulation now replaces the existing "Ships At-Berth Regulation" from January 1, 2021. In fact, after the regulations were mandated, each year the SP utilization rate of vessels calling at the Port of Los Angeles exceeded the SP utilization rate requirement of vessels calling at the port for that year as stipulated in the "Ships At-Berth Regulation" (Peng, 2021), and the SP utilization was effective.

3.3.4 Full application of the Environmental Ship Index (ESI) to improve the motivation and initiative of ship emission reduction

The ESI is an emissions reduction index developed and introduced in 2010. Ports offer discounts based on a ship's total ESI score, which includes SO_x, NO_x and CO_2 emissions, with additional points for ships using SP. The ESI score ranges from 0 to 100, with a score of 0 for ships that exactly meet the current standard and 100 for ships with zero SO_x and NO_x emissions and declared (or monitored) energy efficiency. As of October 1, 2021, the total number of ports participating in the program is 60 (ESI, 2021), as shown in Figure 7.

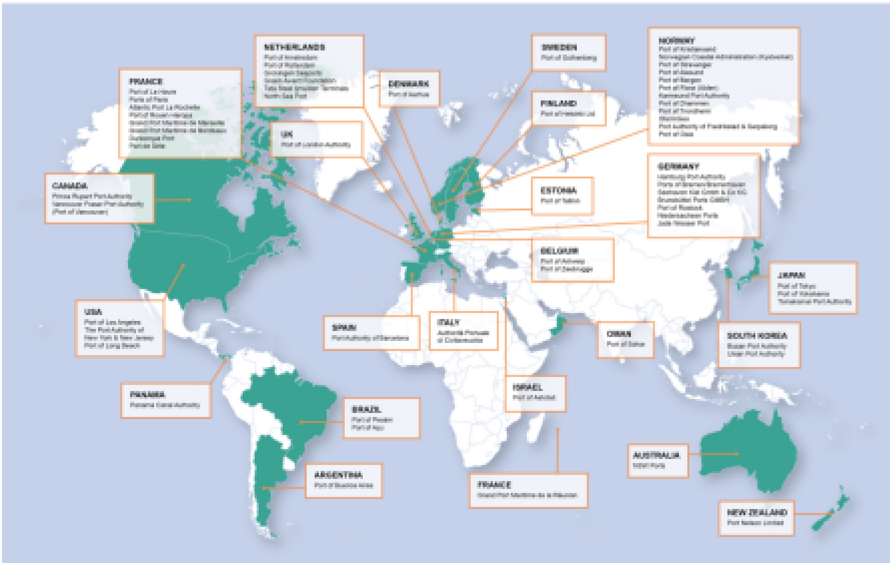


Figure 7： Incentive ports for participation in ESI projects

Source: ESI. (2021). Participating Incentive Providers.

Participating ports can determine the minimum qualifying score for which a ship can receive a discount, the strength of the discount, and the score for different air pollutant emissions in the ESI rating. For example, the Port of Antwerp in Belgium has set a minimum qualifying score of 31, above which a discount on tonnage charges can be obtained, and in 2017 has set an additional discount of 10% and 5% for vessels using closed-loop scrubbers or LNG, respectively, due to the greater emphasis on SO_x-related emissions.

Ports use the ESI to reward ships that exceed regulatory requirements for environmental performance, and ships pass a single assessment to receive rewards from all participating ports. Even with the increase in the number of ports participating in the ESI, ships do not require additional assessment, but instead can achieve higher and sustained returns. For example, a COSCO Shipping 100,000-ton ocean-going vessel with an ESI score of 50 is eligible for subsidies at four ports of call on a typical route from China to North America, including two Canadian ports, and receives approximately $3,000 per call (equivalent to a 50% reduction in port taxes). With considerable economic incentives, ships are also much more motivated to use emission reduction technologies and fuels.

Chapter 4 Policy measures to control SO_x from ships in China and the shortcomings in implementation

In recent years, China has been actively developing and implementing its own emission control policy measures, as well as some incentive measures, while fulfilling MARPOL emission reduction regulations. However, if these policy measures have dilemmas in enforcement and other aspects, it will lead to inefficient implementation of policy measures and make it difficult to obtain the expected emission reduction effects. This chapter summarizes the major SOx control policy measures in China, and focuses on the shortcomings of the regulatory framework and incentives at this stage.

4.1 Major SO_x control policy measures in China

From the perspective of SO_x reduction technologies and fuels, China's emission control policy measures can be divided into three main categories, one is to enforce stricter regulations on the sulphur content of marine fuels to achieve emission reduction; the second category is to use a combination of economic incentives and administrative compulsion to promote the use of SP for ships in port, thereby reducing port emissions; the third category is to use incentives to promote the application of low- and zero-emission fuels.

4.1.1 Set up DECAs and limit the sulphur content of marine fuel

Setting up sulphur emission control areas and mandating the use of fuel with low sulphur content is one of the more prominent measures to control SO_x emissions from ships at the source. Based on the experience of the international SECA policy and the actual development of China's port and shipping industry, China established and implemented the China DECA policy, and imposed mandatory requirements on the sulphur content of ship fuel both inside and outside the DECA (MOT, 2015; MOT,2018). This is also the most central policy for SO_x reduction from ships in China.

China's DECA policy has gone through two phases. The first phase provided the basic legal basis for setting DECA and limiting the sulphur content of ship fuel through Articles 63 and 64 of the *Atmospheric Pollution Prevention and Control Law of the PRC*, which was amended in 2015. Meanwhile, through the *"Implementation Plan on Domestic Emission Control Areas in Waters of the Pearl River Delta, the Yangtze River Delta and Bohai Rim (Beijing, Tianjin, Hebei)"*, commonly known as DECA1.0, the requirements were refined.

DECA1.0 establishes the Pearl River Delta (PRD), the Yangtze River Delta (YRD) and the Bohai Rim Area (BRA), the three regions with the most developed shipping economies in China, as DECA. DECA 1.0 aims to progressively require ships to use fuel with a sulphur content of 0.5% m/m through ship regulation in core ports.

In 2018, China's DECA policy entered its second phase. This year, as the global rate of SO_x reduction from ships accelerated, MOT issued the *"Implementation Scheme of the Domestic Emission Control Areas for Atmospheric Pollution from Vessels"*, commonly known as DECA 2.0, in accordance with the "2020 sulphur Cap". In DECA 2.0, the DECA control area is further increased and divided into inland DECA and coastal DECA, covering the area as shown in Figure 8. The coastal control area includes all sea areas and ports within 12 nautical miles of China's territorial waters, as well as Hainan at the southernmost tip of China. The inland river control area includes parts of the Yangtze River Main Line and the Xijiang River Main Line. At the same time, the sulphur content control standards for marine fuel oil inside and outside DECA have been further improved (MOT, 2018).

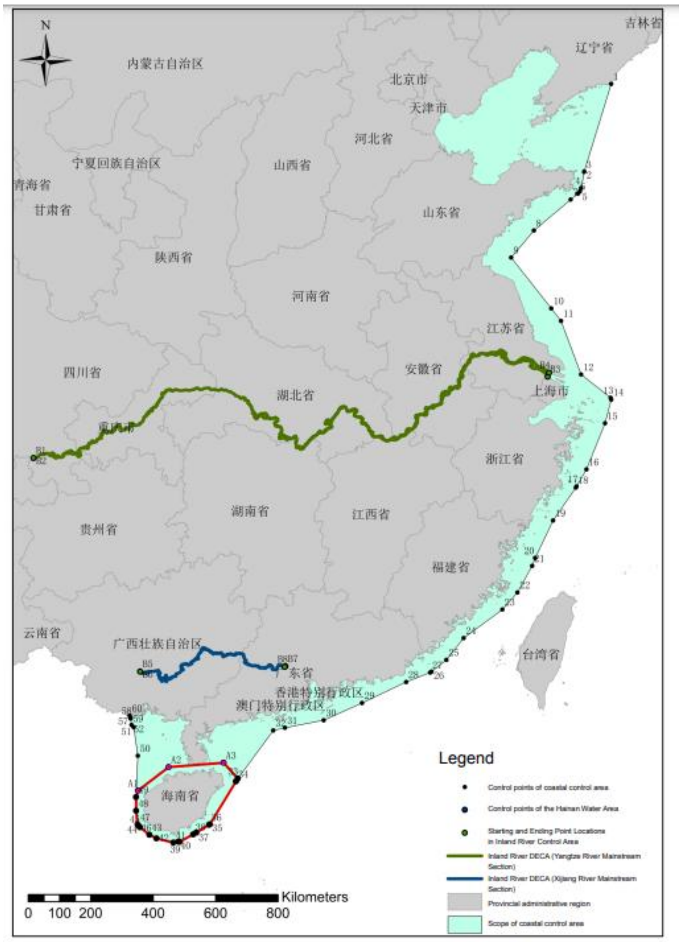


Figure 8: Geographic Scope of the DECA 2.0

Source: MOT. (2018). Implementation Scheme of the Domestic Emission Control Areas for Atmospheric Pollution from Vessels.

According to the latest mandatory requirements, within the coastal DECA, vessels in the sea and directly between river and sea use fuel oil with sulphur content no greater than 0.5% m/m from January 1, 2019, which is equivalent to meeting the standard required by the IMO's 2020 sulphur cap one year earlier. Within the scope of inland waterway DECA, sea-going vessels shall use fuel oil with sulphur content no more than 0.1% m/m from Jan. 1, 2020. Inland river vessels and vessels engaged in direct voyages between the sea and the river shall use fuel oil with sulphur content conforming to the newly revised "*Marine Fuel Oil standard"* since January 1, 2019, which means the control is below 10 PPM, much lower than the IMO's requirement. Meanwhile, based on the strategic positioning of the development of Hainan National Ecological Civilization Pilot Zone, sea-going vessels entering Hainan waters in the coastal control area shall use marine fuel oil with sulphur content no greater than 0.1% m/m from January 1, 2022.

Figure 9 summarizes the evolution of DECA and fuel oil sulphur content control standards and how they compare with the international SECA. It is also clear from the figure that after 2020, the requirements for the sulphur content limit of fuel oil for marine vessels within the DECA in China are comparable to the international SECA standards, and the requirements for inland waterway vessels are higher than the international SECA.

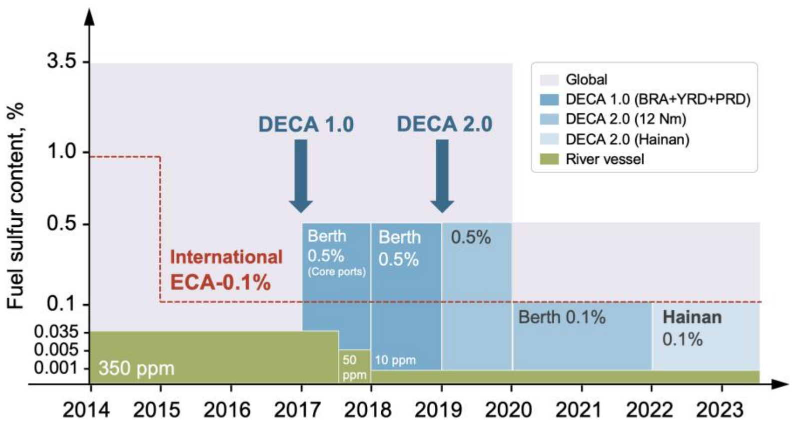


Figure 9: Evolution of fuel sulphur content requirements under DECA in China

Source: Wang, X., Yi, W., Lv, Z., Deng, F., Zheng, S., Xu, H., Zhao, J., Liu, H., & He, K. (2021). Ship emissions around China under gradually promoted control policies from 2016 to 2019.

Within the non-emission control area, sea-going vessels should use fuel oil with no more than 0.5% m/m from January 1, 2020. Inland river vessels and vessels engaged in direct voyages between the sea and the river should control the sulphur content of marine fuel in inland waters to less than 10 PPM from January 1, 2019. Vessels engaged in direct voyages between the sea and the river can use fuel oil with no more than 0.5% m/m in ordinary coastal coastal waters. Table 5 is a summary of the sulphur content control requirements for ship fuel oil in Chinese waters.

Table 5 Vessel fuel sulphur content control requirements in Chinese waters

Ship Type	Domestic Emission Control Area			Non-domestic Emission Control Area	
	Coastal Control Area		Inland River Control Area	Coastal Waters	Inland Waters
	Hainan Waters	Other Waters			
Seagoing Vessel	From 2019.1.1, ≤0.50% From 2022.1.1, ≤0.10%	From 2019.1.1, ≤0.50%	From 2019.1.1, ≤0.50% From 2020.1.1, ≤0.10%	From 2012.1.1, ≤3.50% From 2020.1.1, ≤0.50%	From 2012.1.1, ≤3.50% From 2020.1.1, ≤0.50%
Inland Waterway Vessel	—	—	From 2019.1.1, ≤10ppm	—	From 2019.1.1, ≤10ppm
Vessels engaged in direct voyages between the sea and the river	From 2019.1.1, ≤0.50%	From 2019.1.1, ≤0.50%	From 2019.1.1, ≤10ppm	From 2012.1.1, ≤3.50% From 2020.1.1, ≤0.50%	From 2019.1.1, ≤10ppm

Source: China MSA. (2018). Notice on the standard implementation of the supervision and management of ship air pollutant emission control area.

4.1.2 A variety of policy measures to promote the use of SP at the port

Since 2010, China has promoted the use of SP for ships in port through mandatory regulations and incentives to reduce SO_x emissions during port calls. *Atmospheric Pollution Prevention and Control Law of the PRC (2015 Revision)* , which was implemented on January 1, 2016, makes general provisions for the construction and use of SP. Article 63 of the Law stipulates that new terminals shall plan, design and construct shore-based power supply facilities; completed terminals shall gradually implement shore-based power supply facilities transformation. Ships calling at port should be given priority to use SP. *The Yangtze River Protection Law of the PRC,* implemented on March 1, 2021, further clarifies the requirements for the use of SP on vessels in the Yangtze River basin, and the penalty provisions for vessels that fail to use SP as required. At the same time, the "*Implementation Scheme of the Domestic Emission Control Areas for Atmospheric Pollution from Vessels*" released in 2018 and the "*Measures for Administration of Port and Ship Shore Power*" released in 2019 have refined the requirements for the construction and use of SP.

First of all, the *"Implementation Scheme of the Domestic Emission Control Areas for Atmospheric Pollution from Vessels"* specifies the five types of ships listed in Table 6 that should use SP (the table "meet IMO Tier II" refers to the ship NO_x emissions meet MARPOL's ship NO_x emission phase II control requirements). If the ship does not use clean energy, new energy, on-board power storage device or shut down the equivalent alternative measures of auxiliary engine during the port call, and the time of inland port call exceeds 2 hours or the time of coastal port call exceeds 3 hours, SP should be used.

Table 6: Ships that should use SP

Implementation time	Vessel Nationality	Sailing waters	Vessel type	Ship single engine power	Meet IMO Tier II
2019.7.1	No limit	Coastal or inland waters	Existing ships (except liquid cargo ships)	No limit	Not limited
2021.1.1	No limit	Coastal or inland waters	Cruise ships	No limit	Not limited
2022.1.1	China	Coastal or inland waters	Official Vessels	More than 130kW	Not satisfied
2022.1.1	China	Inland waters	Inland river vessels (except liquid cargo ships)	More than 130kW	Not satisfied
2022.1.1	China	Coastal waters	Container ships, ro-ro passenger ships, passenger ships of 3,000 gross tons and above, and dry bulk carriers of 50,000 tons and above	More than 130kW	Not satisfied

Source: Compiled by the author based on the "Implementation Scheme of the Domestic Emission Control Areas for Atmospheric Pollution from Vessels".

Secondly, the *"Measures for Administration of Port and Ship Shore Power"* further sort out and clarify the power supply facilities of the terminal SP, the receiving facilities of the ship SP and the relevant requirements for the use of SP by ships calling at port, including construction, use, service, safety and supervision and inspection, etc., which create conditions for promoting the use of SP electricity by ships calling at port.

While imposing mandatory requirements for the construction and use of SP for some ships, the Chinese government also uses incentives to ensure that ports and shipping companies are motivated and proactive, considering that the facilities for SP require significant investments from ports and ship owners.

The first is in the construction of facilities. The proportion of berths visited by ships where electricity is provided is a key factor influencing shipowners' decisions to retrofit their fleets. the *"Guidelines for the Application of Incentive Funds for the Use of Shore Power for Ships Calling at Ports 2016-2018 Project"*, issued in 2016, established specific incentive funds to support the retrofitting of SP facilities at ports and ships. According to the content of the program, ports and vessels that complete SP projects in 2016, 2017 and 2018 can receive subsidies covering up to 60%, 50% and 40% of the purchase cost of the equipment, respectively (MOT, 2017). By the end of June 2020, China has completed more than 5,800 sets of SP facilities in ports, covering more than 7,200 berths, realizing that more than 50% of berths in major ports and ports within DECA have SP supply capacity (Chen et al., 2021). The planned targets for SP layout in Chinese ports shown in Figure 10 have been achieved ahead of schedule.

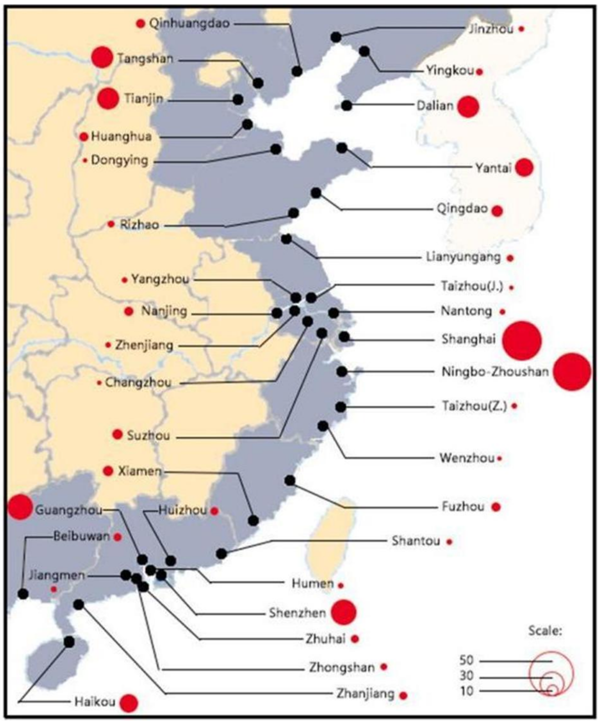


Figure 10: China's port SP layout planning targets for 2020

Source: Yin, M., Wang, Y., & Zhang, Q. (2020). Policy implementation barriers and economic analysis of shore power promotion in China.

Secondly, in the use of SP, each port has introduced a detailed implementation plan of SP use incentive policy to promote the use of SP by ships. The incentives for shore power usage in some Chinese ports are shown in Table 7.

Table 7: Incentives for Shore Power Use in Selected Chinese Ports

Port	Related Policy Documents	Main Contents
Shenzhen Port	**Rules for the Implementation of Funding for the Port and Maritime Part of the Shenzhen Transportation Special Fund in the Field of Green Transportation Construction**	**The costs associated with the use of SP are subsidized**
Shanghai Port	**Shanghai Port Green Pact**	**Encourage priority navigation and berthing rights for contracted vessels**
Tianjin Port	**Notice of Tianjin Port and Maritime Administration on Several Measures to Further Promote the Use of Shore Power by Ships Calling at Tianjin Port**	**Take "four priority" measures such as priority berthing, priority crossing, priority passage, priority loading and unloading operations, etc., and reduce or waive shore power service fees and preferential port loading and unloading fees for vessels that meet the requirements**
Rizhao Port	**Measures for the Management of Shore Power for Ships of Rizhao Port Group**	**Implement incentive measures such as priority berthing for ships using shore power**
Qinhuangdao Port	**Work Plan for Comprehensive Management of Air Pollution in Ports in 2021**	**Encourage ships to use shore power, and give priority loading and unloading and berthing policy to ships using shore power by port enterprises**
Suzhou Port	**Notice on Further Promoting the Use of Shore Power by Ships Calling at Ports in Jiangsu Province**	**Priority berthing, priority loading and unloading**
Jiujiang Port	**Implementation Plan for the Renovation and Promotion of Shore Power Facilities for Ports and Ships (2020)**	**Priority berthing and unberthing, priority operation**

Source: Compiled by the author from various port government documents

4.1.3 Adopting incentives to drive LNG fuel adoption

In terms of SO_x reduction from ships, LNG fuel is currently recognized as a more effective option in the short to medium term. Therefore, China is encouraging the new construction and conversion of LNG vessels through incentives on the one hand, and strongly encouraging ports to deploy the necessary infrastructure to ensure the supply of LNG on the other.

At the national level, China actively encourages new construction and conversion of LNG vessels. According to the *"Standardization of inland waterway vessels subsidy funds management methods"* issued in 2014, newly built LNG-fueled vessels with a deadweight tonnage of not less than 400 tons will receive a subsidy of 630,000-1,400,000 CNY (approximately US$95,000-210,000) (MOT, 2014). At the same time, *"Ship scrapping and dismantling and ship standardization subsidy funds management measures"* was issued in 2016 to subsidize ship owners who use the overall renewal of power systems to convert into LNG-powered demonstration vessels (Ministry of Finance of the PRC [MOF], 2015).

At the same time, LNG refueling stations are being actively built. MOT has issued the *"LNG Refueling Terminal Layout Plan for the Yangtze River Main Line, Beijing-Hangzhou Canal and Xijiang River Shipping Main Line (2017-2025)"*, which plans to basically build an LNG refueling terminal system in the Yangtze River Main Line, Beijing-Hangzhou Canal and Xijiang River Shipping Main Line by 2025 with government funding. According to the information the authors learned from MOT, 23 LNG refueling stations have been built in China's inland waters as of June 2022.

At the local level, in June 2021, Guangdong Province funded the construction of 50 LNG mono-fuel bulk carriers and will renovate 300 existing vessels within two years. In addition, Jiangsu, Anhui, Hubei and other provinces have started the research work of LNG (Zhu & Zhu, 2022).

4.2 Shortcomings of the regulatory framework

4.2.1 DECA policy effectiveness limited by international law

China tries to further improve emission control standards through the establishment of DECA, so as to reduce the emission of SO_x from ships and promote the continuous improvement of air quality in port cities. However, China's DECA is different from the SECA identified in MARPOL Annex VI, which is a regional mandatory emission reduction regulation. Because of the constraints of international law, the geographical scope of the emission control areas delineated in accordance with Chinese domestic law is strictly limited.

According to the United Nations Convention on the Law of the Sea (UNCLOS), each country has the right to adopt its own laws and measures to reduce and control pollution of the marine environment by ships in its ports, internal waters and territorial sea, but the legal effect of domestic laws is limited to the territorial sea, and the right of innocent passage of foreign ships (mainly merchant ships) in the territorial sea should be guaranteed. In China's 1958 declaration on the territorial sea, it is clearly stated that the width of China's territorial sea is 12 nautical miles. Since China is a party to the UNCLOS, the outer boundary control of China's DECAs, which is delineated in accordance with domestic law, should be 12 nautical miles beyond the baseline of the territorial sea, which is much smaller than the limit of 200 nautical miles for SECAs.

According to the study, within 12 nautical miles outside the baseline of China's territorial sea (equivalent to DECA 2.0), SO_2 emissions decreased by 78.8% in 2019 compared to 2016, but increased by 41.5% in the area between 12 and 50 nautical miles from the baseline, especially along the 12 nautical mile boundary.The proportion of SO_2 emissions from ships between 12 and 50 nautical miles increased from 17.5% in 2016 to 35.3% in 2019, making it the main spatial contributor in 2019 (Wang et al., 2021). Figure 10 shows the change of spatial distribution of ship SO_2 emissions in China from 2016 to 2019. This phenomenon suggests that China's DECA policy is generally effective in reducing SO_2 emissions from ships, but the control effect is somewhat constrained compared to the international conventionally recognized SECA, and ships still generate a fairly high emission intensity around China DECA.

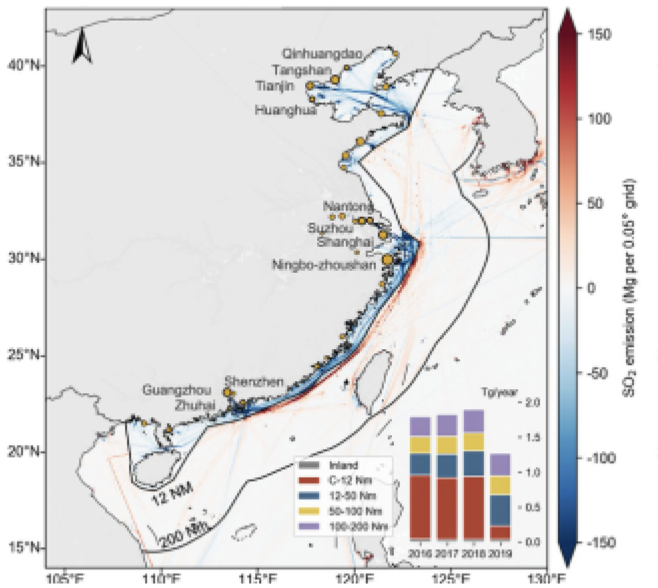


Figure 10: Changes in the spatial distribution of ship SO_2 emissions in China, 2016-2019

Source: Wang, X., Yi, W., Lv, Z., Deng, F., Zheng, S., Xu, H., Zhao, J., Liu, H., & He, K. (2021). Ship emissions around China under gradually promoted control policies from 2016 to 2019.

4.2.2 The coercive power of SP regulations is not sufficient

Although the current *Atmospheric Pollution Prevention and Control Law of the PRC* sets general requirements for the construction and use of SP, it does not specify the time when existing terminals and ships should have SP equipment. Therefore, the "Legal Liability" section of the Law cannot set up penalty clauses for "violation of the provisions of this Law". *The Yangtze River Protection Law of the PRC*, which has be implemented on March 1, 2021, further specifies the requirements for the use of SP for vessels in the Yangtze River basin and also has penalty provisions, but there are also no clear requirements and penalty provisions for the renovation of SP facilities for terminals and vessels.

This also means that, in the Chinese regulations and normative documents based on the requirements of the *Atmospheric Pollution Prevention and Control Law of the PRC*, although various detailed regulations are made for the construction of SP power supply systems in ports and the use of SP by vessels calling at ports, it is not possible to set effective punitive measures with legal effect for the violation of the regulations. In the actual "supervision and inspection" process, for non-implementation of the relevant provisions of the situation, only "notify the competent transport authorities of the registered waterway transport operators" "report to the MOT " or "ordered to rectify". The enforceability of SP regulations is generally weak, making it difficult to enforce the use of SP by ships calling at ports.

4.2.3 Limited and varying intensity of enforcement tools

Currently the main means of enforcing regulation of SO_x emissions from ships in

China is to check bunker delivery notes and ship logbooks, as well as to carry out testing of the sulphur content of marine fuel if any non-compliance is suspected. However, the information in the logbooks may be falsified because the fuel usage on board, the time of changeover and the amount of fuel remaining in each tank at the time of each changeover are usually handwritten (Zis & Cullinane, 2020). Sulphur content testing by sampling fuel is the most reliable way to check fuel compliance, but the results of rapid sampling tests are not a legal basis, and qualified laboratories are unable to produce results in a short period of time, and requiring ships to wait for laboratory test results before leaving port is likely to cause undue delays to the ship.

In addition, there are no clear regulations on the number of ship inspections and fuel sampling in China. The total number is relatively small and the intensity of enforcement varies from region to region due to time, manpower and financial constraints. In 2017, for example, China Maritime Safety Administration (MSA) took a total of 6,494 fuel oil samples, which is only 0.06% compared to the annual berthing volume of about 10 million ships in Chinese ports (Peng, 2020). In 2019, the number of fuel oil samples taken at Taicang port in Jiangsu was 589, which is also less than 1% compared to the number of nearly 120,000 ships entering and leaving the port (Zhang, 2020).

Of course, there are individual regions in China, such as Jiangsu and Shanghai, that have started to use sensing technology to monitor ship emissions. By adding sensing equipment to drones, bridges, and sea patrol boats in these regions, real-time monitoring of ship SO_x emissions, including ships in transit, can effectively screen out ships with higher fuel sulphur content, making regulation more efficient. However, in most other areas of China, these regulatory devices are not widely available (Liu, 2020). This regionalized disparity will likely force shipping companies to schedule high-quality ships to operate in these regions, while ships with poorer compliance and enforcement of emission reduction measures move to ports with less stringent regulations in order to avoid them as much as possible. This "leakage" will only transfer pollution from one port to another and seriously undermine the overall effectiveness of the measures already taken by ports and shipping (NRDC, 2014).

4.2.4 Low cost of corporate violations and insufficient deterrence

For ships that use fuel that does not meet the standards or requirements, according to Article 106 of the *Atmospheric Pollution Prevention and Control Law of the PRC*, the competent authorities shall impose a fine of 10,000 RMB or more than 100,000 RMB (about US$1,500-15,000) in accordance with their duties. However, the penalties for using non-compliant fuel in China are not even as high as the cost of one day's fuel saved by the ship operator for violating the regulations.

Take for example a large container sea vessel with a capacity of 10,000 TEU. At a speed of 20 knots, the ship can consume 170 tons of fuel per day (Zis & Cullinane, 2020). Using the May 2021 bunker price at the Shanghai port as an example (Figure 11), the average of the spread between VLSFO and HSFO/IFO380 in May is about $130/ton, as calculated from Table 8. If a ship uses high sulfur fuel oil for one day in China, the fuel cost saving is about US$22,100 based on the average price difference between VLSFO and HSFO/IFO380 in May. The benefits are even greater when navigating in inland river emission control areas (where sulphur content is required to be less than 0.1% m/m). It is easy to see that the cost of ship violations is low.

Figure 11：Shanghai Port Bunker Price Curve for May 2022

Source: Ocean Freight Online App

Table 8: Price difference between high and low fuel oil in Shanghai port in May, 2022 (Unit: USD/ton)

Date	Price of LSMGO	Price of VLSFO	Price of HSFO/IFO380	Price difference between VLSFO and HSFO/IFO380
May 1	1295.00	873.25	779.50	93.75
May 2	1261.00	911.00	810.00	101.00
May 3	1270.00	890.75	814.50	76.25
May 4	1312.00	919.75	884.50	35.25
May 5	1299.00	906.00	860.00	46.00
May 6	1306.00	914.75	871.00	43.75
May 7	1306.00	914.75	865.75	49.00
May 8	1305.25	919.25	870.00	49.25

May 9	1264.00	902.25	858.25	44.00
May 10	1239.25	882.50	841.50	41.00
May 11	1298.25	898.00	814.50	83.50
May 12	1288.50	898.00	827.00	71.00
May 13	1307.25	957.50	828.00	129.50
May 14	1307.25	929.25	828.00	101.25
May 15	1307.25	929.25	828.00	101.25
May 16	1340.25	984.25	850.50	133.75
May 17	1251.25	962.75	846.00	116.75
May 18	1229.50	970.50	796.50	174.00
May 19	1278.25	953.50	805.00	148.50
May 20	1273.00	968.00	806.00	162.00
May 21	1253.75	976.00	803.50	172.50
May 22	1253.75	976.00	803.50	172.50
May 23	1258.75	999.50	806.00	193.50
May 24	1262.00	974.25	808.00	166.25
May 25	1266.25	1005.00	811.50	193.50
May 26	1270.50	1006.75	826.75	180.00
May 27	1345.00	1031.25	825.25	206.00
May 28	1313.00	1028.50	830.50	198.00
May 29	1311.75	1026.50	830.50	196.00
May 30	1312.25	1090.00	798.00	292.00
May 31	1275.25	1056.00	790.75	265.25

Source: Compiled by the author based on data from Shipping Online APP

Due to the low cost of non-compliance, China's mandatory regulations do not have a strong deterrent effect. And as mentioned earlier, there are limitations to the means of regulating SO_x emissions control from ships, meaning that there is no guarantee that ships will even really be inspected.

4.2.5 Inadequate regulatory system

In, China, the *Atmospheric Pollution Prevention and Control Law of the PRC* stipulates that the competent ecological and environmental departments and their environmental enforcement agencies and other departments with supervisory and administrative responsibilities for atmospheric environmental protection have the right to supervise and inspect those who emit air pollutants through on-site inspection and monitoring, automatic monitoring, remote sensing monitoring, and far-infrared camera. For the regulation of marine fuel, the *Atmospheric Pollution Prevention and Control Law of the PRC* clearly stipulates that the use of marine fuel that does not meet the standards or requirements shall be punished by the maritime administration for ships, while companies that produce or sell illegal marine fuel shall be punished by the market supervision and management departments of local people's governments at or above the county level. However, how the departments do a good job of coordination in ensuring the quality of fuel is not clear, and no regulatory synergy can be formed.

It is because the departments have not formed a regulatory synergy, the MSA in the discovery of ships carrying bunkering documents and fuel samples are qualified, but the sampling and testing results are unqualified, the punishment is often only the ship, fuel supply enterprises but no impact. However, both the fuel delivery documents and fuel samples are provided by the fuel suppliers, and the responsibility for the failed sampling and testing results may lie in the false documents provided by the ships or in the poor quality of fuel provided by the fuel suppliers (Topali & Psaraftis, 2019). If it is due to the fuel supplier providing non-compliant fuel to the ship in order to gain more profit, then just relying on punishing the ship does not solve the root cause of the problem, and the quality of oil can hardly be guaranteed.

4.3 Shortcomings of incentive measures

4.3.1 The geographical nature of the incentives reduces the rate of ship participation.

The *Atmospheric Pollution Prevention and Control Law of the PRC* stipulates that local people's governments at all levels shall take measures to control or gradually reduce the emissions of air pollutants, which emphasizes the responsibility of local governments in environmental protection and improving air quality. As a result, Chinese port cities have initiated many incentive programs. But, most of these emission reduction measures impose an additional time and administrative burden on ship owners and operators, as each port has different criteria and rules for demonstrating compliance and subsequently receiving incentives, and ships need to prepare different compliance materials (Alamoush et al., 2022).

On top of that, in practice, there is little dedicated funding for ports to control SO_x pollution from ships, and even if such funding were available, it would be difficult to see substantial action given the relatively complex approval process for using financial resources to reward ships (Peng, 2020). Ships often receive limited incentives at a port.

As a result, ships that visit the port infrequently are less interested in that port-led program because the process can be laborious and may not even result in substantial incentives at all. This is why there are many incentives in Chinese ports, but the motivation of ships to use them remains low. Even the port of Shenzhen, which has the highest number of ships using SP in China, has a shore power usage rate of only 6.2% in 2019 (Tao et al., 2022).

4.3.2 The lack of policy continuity reduces the initiative of ship retrofitting

China has an incentive policy for the retrofitting of ships' SP facilities only valid for the period of 2016-2018. Due to the lack of sustainability of the retrofitting subsidy policy, the economic cost of ship retrofitting SP is high, which affects the motivation of ships to retrofit SP systems.

In this paper, a 5,000 TEU container ship is taken as an example. Currently, the cost of SP retrofit in China is about 3 million RMB (about 450,000 USD), the annual berthing time of the ship is about 1,340 h, and the power of the auxiliary engine is about 1,666.7 kW. Referring to IMO's practice, the auxiliary fuel consumption rate of 210 g/kW▪h is taken for power generation diesel engines at rated operating conditions (IMO, 2018), and the actual consumption is considered to be almost the same as rated. If the price of VLSFO at Shanghai port from January to May 2022 is US$648.5-1090/ton as shown in Figure 12, the cost of using VLSFO during the ship's port call is about US$0.13-0.22/kW▪h. According to the survey, the average electricity price charge range at Chinese coastal ports is US$0.09-0.19/kW▪h (Mao et al., 2021). For calculation purposes, taking the average of the highest and lowest prices, the cost savings for a ship using SP in China's coastal ports would be about $0.035/kW▪h. The cost recovery period for a 5,000 TEU container ship in China would then be about 5.7 years for a SP retrofit. This does not include other costs such as personnel training, equipment maintenance, and time costs during the retrofit.

Figure 12: Bunker Oil Prices in Shanghai Port, China, January-May 2022

Source: Shipping Online App

Because of the long payback period of ship SP retrofitting, it is difficult for shipping companies to gain significant revenue from SP technology in a short period of time. Therefore, for ship owners or ship operators, it is difficult for them to take the initiative to retrofit SP facilities on board even if ports provide incentives for SP usage when the incentive policy for retrofitting ship receiving facilities is no longer continued.

4.3.3 The mismatch between policy and demand reduces the incentive for ship use

Although China has introduced some considerable economic incentives for the retrofitting of ship facilities and equipment and the application of new technologies. However, in practice, shipowners are sensitive not only to the cost of facility construction and retrofitting, but also to the operating cost (Wang et al., 2021), and most importantly, the price of SP and LNG. If the price of using SP and LNG is not advantageous, ships do not use them even if they have the appropriate facilities and equipment. At present, China does not have a unified incentive policy for use at the national level, and the relevant policies are set by the ports themselves.

In terms of SP usage, although some ports subsidize the price of SP to varying degrees, as mentioned above, there are few substantial incentives due to financial constraints, except for a few ports such as Shenzhen and Shanghai. In practice, once the price of SP is higher than the price of fuel oil, ships tend to use fuel oil.

As for the use of LNG, there are no incentives and the motivation for LNG use is generally low. As of August 2021, the holdings of LNG-powered vessels in China are about 300 vessels, mainly diesel/LNG blends, mainly in inland rivers (Zhu & Zhu, 2022). However, according to information obtained by the authors from the MOT, only one of the 23 LNG bunkering stations in the inland river areas where Chinese LNG-powered vessels mainly operate was bunkered with a single vessel in the first quarter of 2022. In fact, as of August 2021, only five of all LNG refueling stations in China were also operating, refueling a very limited number of vessels. Mixed-fuel vessels still use diesel as the main fuel in practice (Zhu & Zhu, 2022).

Chapter 5 Recommendations for China

5.1 Accelerate applications for internationally recognized emission control areas

Although the current DECA policy in China has achieved significant control effects on SO_x emissions, however, due to the constraints of international law, China's domestic laws set up emission control areas, compared with the internationally recognized emission control areas, the actual scope of restrictions is very limited, and the air pollution emissions from ships outside the region still seriously affect the port atmosphere.

At the same time, considering the application for the establishment of an internationally recognized emission control area needs to be carried out in accordance with the requirements of MARPOL, the procedure is complex and takes a long time. Taking the North American Emission Control Area as an example, it took 40 months from March 2009 when the proposal was submitted to take effect officially. Therefore, China should accelerate the pace of applying for the establishment of an internationally recognized Emission Control Area in order to improve the effectiveness of emission reduction.

5.2 Improve the legal system

In China, for the problem of air pollution caused by SO_x from ships, although the requirements of sulphur content of ship fuel, the use of SP and the delineation of ship air pollutant emission control areas have been written into the relevant laws, but the relevant standard requirements, penalty provisions are not complete, which to a certain extent reduces the compulsory power of supervision. Therefore, it is necessary to learn from the EU's sulphur limitation policy and the experience of the US California SP use to further improve the relevant laws and regulations.

5.2.1 Raising the Penalty Standards for Vessel Non-Compliance

Considering the huge illegal profits of ships using non-compliant fuel, the existing penalty standards in China have limited deterrent effect on ships. Drawing on the experience of the United States and the European Union, the penalty standard for non-compliant sulphur oxide emissions from ships should be appropriately raised. First, when setting the amount of administrative fines, fully consider the illegal profits of non-compliant ships as well as the cost of air pollution control, and raise the upper limit of fines currently stipulated. Second, increase the provisions of measures such as detention and restriction of departure of vessels, and introduce supporting guidelines to clarify the conditions for the use of detention and restriction of departure measures, so as to increase the deterrent effect of administrative penalties through the impact on the sailing schedule of non-compliant vessels.

5.2.2 Improve SP regulations

In terms of SP use regulations, on the one hand, drawing on California's experience, promote the revision of national level legislation, and on the basis of fully assessing the characteristics of the types of vessels calling at ports in China, supplement the roadmap and timetable for mandatory SP facility renovation and SP use for various types of vessels calling at ports, and clarify the corresponding legal responsibilities, so as to lay the foundation for effectively promoting SP use by vessels calling at ports.

On the other hand, it should further clarify the basis of penalties for violations by all parties, improve the compulsory power of the regulations, and effectively promote the use of shore power by ships calling at port.

5.3 Strengthened supervision and enforcement

5.3.1 Strengthen cooperation between government departments

Due to the close connection between ships and shore and the mobility of ships, the pollution behavior of ships may cross multiple administrative regions or involve multiple industry regulatory departments, such as fuel quality non-compliance. Therefore, in order to avoid the lack of cooperation in enforcement and possible "pollution leakage" mentioned above, it is necessary to break the restrictions of administrative divisions and industries and improve the overall effectiveness of regulatory enforcement through cooperation between government departments.

Due to the complexity of the relationship and interest factors between government entities in different industries, special coordination agencies for ship air emission reduction can be set up at the national, provincial and municipal levels respectively, with members sent by various government departments to form the agency members, hold regular meetings to formulate national, provincial and municipal overall strategies, medium and long-term development goals as well as short-term work plans, and develop corresponding communication and collaboration mechanisms to guide and evaluate the functions of various government departments performance, so as to change the fragmented regulatory system of ship SOx emission control and form a regulatory synergy.

For authorities between different administrative regions of the same industry, it is recommended that a joint enforcement mechanism be established between neighboring cities. By sharing testing information and penalty results, joint enforcement actions will be carried out from time to time, so as to better maintain the fairness of the shipping market, promote the maximum utilization of enforcement resources and guarantee the overall effect of supervision.

5.3.2 Accelerating the digitalization of enforcement

Many countries are studying the use of advanced digital technology to monitor and analyze the compliance of ships, such as the drone sensing detection technology vigorously promoted in EU countries, which greatly improves the targeting and effectiveness of enforcement and can effectively alleviate the problem of insufficient on-site enforcement force. Individual regions in China have also made corresponding attempts, but the application is not widespread due to the limitation of funding and other problems. Therefore, it is recommended to equip enforcement units with a certain amount of advanced digital enforcement equipment from the national level, and other equipment in each region in combination with their own needs, so as to improve China's overall enforcement capability.

Meanwhile, China should establish a comprehensive enforcement information system similar to THETIS-EU at the national level, through which a channel is provided for information interaction between government departments to achieve effective use of information. At the same time, through the collection of internal and external information, the completeness of information will be improved, and more scientific analysis and decision-making suggestions will be provided to the state and various government departments.

5.3.3 Actively carry out the exchange and cooperation of international law enforcement

Air pollutants are transboundary. Carrying out international exchange and cooperation in law enforcement will not only help improve China's regulatory capacity, but also achieve a win-win situation for both or more parties in cooperation. On the one hand, we should strengthen cooperation with the EU, the US and other countries in the field of energy saving, emission reduction and environmental protection, and introduce advanced technology and management concepts to improve China's ability to reduce sulphur oxides from ships. Meanwhile, rely on IMO and regional cooperation such as Tokyo Memorandum to improve the enforcement level in activities such as CIC.

On the other hand, international and inter-regional communication and dialogue should be strengthened to reach cooperation agreements and negotiate to deal with problems. For example, China can cooperate with major fuel exporting countries such as Singapore to jointly combat irregularities and fraud by sharing information on fuel supply and receipt.

5.3.4 Increasing enforcement efforts

Shipping enterprises have to make their ships comply with emission control requirements, which will increase their operating costs, so they lack initiative and enthusiasm in this regard. For China's ship SO_x emission reduction policy to be effective, effective supervision of compliance and adequacy of enforcement by ships, such as through monitoring, inspection and penalties, is indispensable.

At present, China does not have clear enforcement requirements, and enforcement efforts vary from place to place, which may cause "pollution leakage" to a certain extent. Therefore, it is necessary to learn from the EU experience, further refine the enforcement standards and requirements, and increase the intensity of detection and inspection, so as to improve the enforcement of mandatory regulations.

5.4 Improving the effectiveness of incentives

5.4.1 Increase funding subsidies

It is recommended that China increase subsidies for two areas of funding. The first is the subsidy for the construction and renovation of SP facilities and LNG vessels. The subsidies should focus on the old ships without SP facilities, establish a standing SP construction subsidy fund, and increase the subsidy ratio of construction funds so as to promote the transformation of ships' shore power facilities and equipment.

Secondly, shipowners are also very sensitive to operating costs. Therefore, increasing the subsidies for SP and LNG use can also increase the shipowners' enthusiasm to adopt low-zero emission. For example, within a certain period of time, with reference to the change of fuel oil price, a floating preferential pricing not higher than fuel oil price can be implemented, and the loss of suppliers will be subsidized by the state and local authorities proportionally, so as to increase the active use of SP and LNG fuel by ships.

5.4.2 Encourage cooperation between ports on major routes

China should encourage extensive cooperation among ports on major routes, such as the Yangtze River Main Line, by assessing the key characteristics of ships calling at their ports. This would not only enable ports to develop a more consistent and effective approach to incentivizing vessel emissions, but would also give ports the opportunity to share insights and experiences and work together to improve that incentive. More importantly, it makes the incentive more attractive to vessels calling at multiple participating ports, since the additional cost of implementing the emission reduction measures can be covered by the incentives offered by each participating port.

For example, the percentage of berths visited by ships that provide electricity is a key factor influencing shipowners' decisions to retrofit their fleets. When two ports cooperate and install compatible SP systems, this provides a significant incentive for ships visiting both ports to invest in SP facilities. Therefore, ports can increase the use of shore power by cooperating on port SP projects.

5.4.3 Promote some ports to join the industry incentive program on a priority basis

Most major international ports around the world, including the Port of Rotterdam, Port of Antwerp, Port of Hamburg, Port of Los Angeles, Port of Vancouver, Port of Tokyo, Port of Busan, etc., have joined international industry incentive programs, such as ESI. Ports participating in industry incentive programs send signals to ship operators that they value lower emissions. Because of the monetary rewards, vessels that regularly call at participating ports are more likely to use cleaner fuels or retrofit their vessels to reduce emissions. Over the past few years, the number of eligible ship calls to ports participating in the industry incentive program has increased significantly, demonstrating a clear interest from ship operators.

Due to the large number of ports in China and the differences in port size and development level due to geographical location, degree of economic development of the hinterland, consolidation and distribution conditions, etc., most of these international industry incentive programs require a certain amount of investment by ports, so there are differences in the ease of joining international industry incentive programs among ports. In this regard, we can give priority to encourage "core ports with conditions" to join, such as Shanghai Port and Shenzhen Port. At the same time, China should promptly evaluate the effectiveness and problems of these ports on an early and pilot basis, and formulate the next promotion policy.

Chapter 6 Conclusion

6.1 Research Summary

Ships use marine fuels to obtain propulsion, heat and electricity, while at the same time emitting large amounts of SO_x, which can cause both climate change and air pollution, as well as harm to human health. In order to reduce SO_x emissions from ships, the world actively promotes the use of clean technologies and fuels for ships. Through the study of relevant policy measures, this paper categorizes these policy measures into two categories: international mandatory emission reduction regulations and regional emission reduction policy measures, studies their application examples, and summarizes the useful experiences.

This paper also summarizes the three most important policy measures to reduce SO_x emissions from ships in China, starting from the clean technologies and fuel types used for emission reduction, the first one is to limit the sulphur content of marine fuel by setting EDCA in a sub-region, the second one is to use a combination of incentives and compulsory means to promote the use of SP in ships calling at ports, and the third one is to use incentives to promote the application of LNG. At the same time, the shortcomings and reasons for the implementation of these policy measures are analyzed in depth.

Finally, based on the successful international experience and the actual situation in China, the authors make suggestions for China's policy practice from four aspects. Firstly, the paper suggests to improve the effectiveness of emission reduction in China by accelerating the application for the establishment of MARPOL-recognized emission control areas. Secondly, this paper suggests that the legal system should be started by raising the penalty standard for vessels' violation of emission regulations and improving shore power regulations, so as to improve the mandatory power of regulations. Thirdly, this paper recommends strengthening supervision and enforcement cooperation among governmental parts, accelerating the digitalization process of enforcement, actively carrying out international exchanges and cooperation in enforcement, as well as increasing enforcement efforts to promote the effectiveness of the policy. Fourthly, this paper proposes to increase the effectiveness of incentives by increasing financial support for incentives, encouraging cooperation among ports on major routes, and promoting some ports to join the industry incentive program on a priority basis.

6.2 Shortcomings and Prospects

This paper systematically summarizes the global policy measures for SOx emission reduction from ships, objectively analyzes the shortcomings in China's practice, and makes some suggestions for China based on the successful international experience. However, due to information and personal capacity limitations, the study of global emission reduction experiences has included detailed analysis of only selected regional and national policy measures, which to some extent limits the completeness of the recommendations. In view of the above shortcomings, the author will continue to make efforts in the next study and strive to achieve more research results.

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