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Study on the choice of emission reduction measures for coastal and offshore routes under the background of emission control zone

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Abstract: How to deal with the increasingly stringent regulations on ship emission reduction has become a hot issue in the industry. Aiming at the three emission reduction measures of low-sulfur oil, scrubber and liquefied natural gas (LNG), this study constructed the ship emission and cost calculation model under different emission reduction scenarios, and analyzed the impact of ship sailing conditions, fuel price fluctuation and ship life cycle on emission reduction measures. This paper takes a container ship on a coastal route as an example and calculates it's environmental and emission reduction benefits under various emission reduction scenarios. The results show that low age ships are suitable for installing scrubbers while high age ships are suitable for using low sulfur oil. When the price difference between low sulfur oil and heavy oil is less than us $125/ton, low sulfur oil will be more competitive. LNG is the most environmentally effective solution, but the cost is high.

Keywords: IMO; AIS; Ship emission reduction cost; Sensitivity.

1. Introduction

Controlling the discharge of air pollutants from ships has become the focus of the shipping industry at home and abroad. Internationally, the INTERNATIONAL Maritime Organization (IMO) Convention on The Prevention of Air Pollution from Ships, IMO Marpol, sets limits on sulphur content in Marine fuels and establishes emission control zones (ECA) in designated waters. The emission control area covers the northern United States, the U.S. Caribbean and Europe's Baltic and North Seas, including the English Channel.IMO regulations limiting the sulfur content of Marine fuels to no more than 0.5% will come into effect on January 1, 2020.At the same time, China is also committed to ship emission control. China's recently released Implementation Plan for the Marine Air Pollutant Discharge Control Area (MPAC) imposes stricter limits on Marine pollutant discharge than previous schemes. The emission control area will be expanded to cover 12 nautical miles off China's coast and hainan's waters. Starting from January 1, 2019, ships should use Marine fuel with a sulfur content of not more than 0.5 percent when sailing in the coastal control areas and berthing at ports. Starting from January 1, 2020, ships should use Marine fuel with a sulfur content of not more than 0.5% when sailing in the coastal control zone, and use Marine fuel with a sulfur content of not more than 0.1% during berthing. Ships entering hainan waters shall use Marine fuel with sulphur content of no more than 0.1% for navigation and berthing. And the requirements for the shipborne shore power device are put forward. Faced with strict emission regulations, shipping companies need to make corresponding adjustments. Currently, shipping companies can choose to reduce emissions by switching to compliant, low-sulphur oil, using scrubbers or using liquefied natural gas (LNG) as fuel for their ships.Switching to low-sulphur oil would require little modification to existing ships, but would entail significant fuel costs.Using scrubbers and LNG can effectively reduce ship emissions, and the fuel cost is lower than that of low-sulfur oil, but the initial investment cost of both is higher.The choice of reasonable emission reduction measures for ship compliance, economic and environmental benefits is of great significance. However, the choice of emission reduction measures is a very complex task, which requires consideration of ship characteristics, operating conditions, technology maturity, installation costs, future policy changes and so on. Blind choice of emission reduction scheme will make shipping companies face huge risks. However, domestic research on this aspect is still relatively few.

This study is based on the calculation of ship emission inventory of air pollutants. Atmospheric emission source inventory is a list of the emission sizes of one or several pollutants discharged into the atmosphere by various sources in a geographical area in a certain period based on pollutant classification. The ship will produce a large amount of gas emissions during the voyage, which has a huge impact on the environment. Emission inventory plays an important role in understanding pollutant emission and change during ship navigation. Appropriate emission inventories can be developed for specific voyages and regions to study the environmental benefits of voyages. Automatic Ship Identification system (AIS), which can record the navigation status of ships, has been widely used in energy consumption and emission estimation of ships in recent years. Therefore, based on the AIS data of a certain voyage, this paper USES the bottom-up method to estimate the sulfur and carbon dioxide emissions of ships to establish the emission inventory, sets up different emission reduction scenarios to analyze the environmental benefits of each scheme, and USES the net cash flow method to calculate the emission reduction cost of each scheme in the whole life cycle. In this paper, based on the existing domestic and foreign emission reduction measures, combined with the latest emission standards and China's actual situation, to explore the best cost of emission reduction measures. There are three main contributions. First, this paper considers the impact of the decision model life cycle on costs. Secondly, environmental impact is taken into account while cost is taken into account. Finally, this paper considers the influence of fuel price change, emission control zone expansion and ship life.

2. Materials and Methods

In order to explore the choice of ship emission reduction measures, this paper sets up four groups of emission reduction schemes. Option 1: Diesel with sulphur content of 0.5% for the whole journey; In option 2, diesel with sulphur content of 0.5% is used outside the emission control zone and diesel with sulphur content of 0.1 in the emission control zone; Option 3: Use heavy oil after refitting the scrubber tower; Plan 4: Refit the ship and use LNG.

Based on ASI data, this paper lists the ship's emission inventory during the voyage and obtains fuel consumption data based on the CARBON dioxide emission. Combined with the literature and data of previous studies, the net present value method is used to compare and analyze the costs of the above four groups of emission reduction schemes. According to the grouping, the emissions of carbon and sulfur pollutants in four groups were calculated. And combined with economic benefits analysis of the environmental benefits of four groups of emission reduction schemes. We also examine the maturity and suitability of the technology for each group to ensure its feasibility. Finally, the sensitivity analysis of oil price change, emission control area increase and ship life is carried out to try to cope with changes in different situations in the future.

2.1 Model description

The total cost of vessel includes fuel cost and refit cost, which are calculated separately.

$$Cost = Cost_{fuel} + Cost_{refit}$$

Where, $Cost_{fuel}$ and $Cost_{refit}$ represent the fuel and refit cost.

2.2 Pollutant emission model

According to the different voyage conditions of the vessel, the pollutant discharge is calculated. In view of the large data information of the vessel, we write a code program based on R language to calculate. In order to obtain the fuel consumption of vessels, we mainly focus on CO2 emissions. The pollutant emission formula is shown in formula (2).

$$E^i = E_m^i + E_a^i + E_b^i$$

Where, i represents a certain pollutant, E^i refers to the total emissions of this pollutant. E_m^i, E_a^i and E_b^i equals the main engine, auxiliary engine and boiler emissions of this pollutant.

The emission of the main engine is shown in formula (3).

$$E_m^i = P_m \times (AS / MS)^3 \times LF \times Act \times EF^i \times FCF$$

Where, P_m is the main engine rated power, kW. The cube of the ratio of the actual speed to the service speed represents the engine load under the vessel's operating state. When engine load is less than 20%, the fuel combustion rate decreases, and the load needs to be adjusted, LF is the low load adjustment factor. Act is the navigation time, h. EF^i is the pollutant emission factor, $g / kW \cdot h$. FCF is the fuel correction factor.

The formula of the auxiliary engine and boiler is similar to the main engine. As shown in (4), (5).

$$E_a^i = P_a^j \times LF \times Act \times EF^i \times FCF$$

$$E_b^i = P_b \times LF \times Act \times EF^i \times FCF$$

2.3 Fuel cost model

Based on the CO2 emissions from the above pollutants, the carbon balance method is used to calculate the actual fuel consumption.

$$R = E_{co_2} / C_{\mathrm{f}}$$

Where, R is fuel consumption, E_{co_2} refers to carbon dioxide emissions. C_{f} is the carbon coefficient, representing the amount of carbon dioxide produced per unit of fuel, which is 3.114.

Divide the navigation area into the emission control area and the emission control area. The type of fuel used in different areas may be different, and the fuel consumption of the two must be calculated separately.

$$C_{\mathrm{fuel}} = \sum_{t=0}^{T} \frac{R^{ECA} \cdot C^{ECA} + R^O \cdot C^O}{(1+\mathrm{d})^t}$$

Where, R^{ECA} and R^O are the fuel consumption in the control area and outside the control area, C^{ECA} and C^O represent the fuel price in the control area and outside the control area. We calculate the cost of the vessel's entire life cycle, so we must consider its discount rate, t is the remaining service life of the vessel, and the discount rate d is 10%.

2.4 Refit cost model

The use of scrubbers and LNG requires refit of the vessel. The conversion costs of both can be roughly divided into initial capital investment, opportunity cost caused by the time taken during refit, cargo capacity loss and annual maintenance cost. Among them, the Chinese government may prohibit the use of open-loop scrubbers, it chose to install closed-loop scrubbers. The initial investment cost is calculated based on the engine power, and the initial investment cost of LNG is higher than that of scrubber. Scrubbing towers cost $135 per kilowatt and LNG $340 per kilowatt. The formula is shown in () ().

$$Cost_{scrubber} = Cost_{scrubber}^{fixed} + Cost_{scrubber}^{off-hire} + \sum_{t=0}^{T} \frac{Cost_{scrubber}^{capacity}}{(1+d)^t} + \sum_{t=0}^{T} \frac{Cost_{scrubber}^{maintain}}{(1+d)^t}$$

$$Cost_{LNG} = Cost_{LNG}^{fixed} + C_{LNG}^{off-hire} + \sum_{t=0}^{T} \frac{Cost_{LNG}^{capacity}}{(1+d)^t} + \sum_{t=0}^{T} \frac{Cost_{LNG}^{maintain}}{(1+d)^t}$$

3. Results

3.1 Scheme settings

This paper takes a container ship sailing in China's coastal route as an example. The navigation time is selected as December 14 of this year on October 1, 2017 solstice, and the navigation track is shown in the Figure 1.

The ship in the case is a container ship with a specification of 4400TEU. It was built in 2009. The engine type is a two-stroke diesel engine with a main engine power of 36560kW and a service speed of 24.3 knots. Suppose the ship is not fitted with emission reduction devices. The life cycle of the container ship is assumed to be 33 years according to the Regulations on The Management of Old Transport Ships.

The AIS data of the ship was collected, represented on the map, and the emission control area was added, as shown in the figure. Make a list of the ship's emissions, calculate the cost of each emission reduction scheme according to the process, and analyze the economic and environmental benefits. Finally, the sensitivity analysis of the results was made by changing the fuel price, emission control area and ship life.

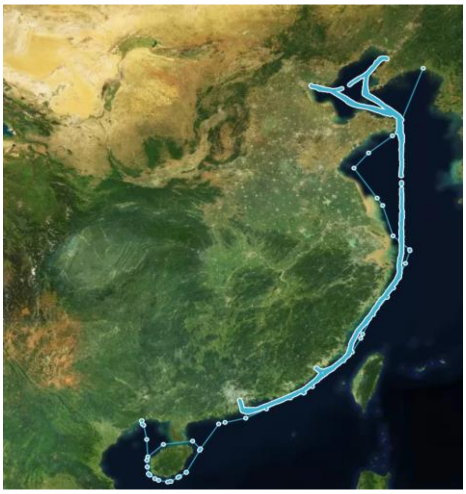

Figure 1. Ship's track

3.2 Cost calculation

HFO is $318/ton; MDO is $518/ton; MGO is $611/ton; LNG is $430 a ton. According to the carbon balance method, it is calculated that the main engine, the auxiliary engine and the boiler will consume 1846.3 tons of fuel oil, 717.5 tons and 176.8 tons respectively. The annual sailing time of ships is about 5,600 hours. It can be estimated that the ship's annual heavy oil consumption is 5821.7 tons and Marine diesel fuel consumption is 2,820.2 tons. The operation and maintenance cost of LNG refitting is 0. LNG refitting involves loss of cargo capacity, but the loss is small. Although only the AIS data of the ship in three months were collected, we used the net present value method to calculate the total cost within the remaining life of the ship, so as to better determine the feasibility of each scheme. The emission reduction costs of each scheme are shown in Table 1.

Table 1. Total cost calculation within the remaining life of the ship (Unit: MMUSD)

Scheme	Modification cost	Total fuel cost	Total fuel cost
MDO	0	40.63	40.63
MDO+MGO	0	46.1	46.1
Scrubber	9.84	24.95	34.79
LNG	12.57	31.94	44.51

Compared with the emission reduction schemes of each group, MGO is the most expensive scheme in the emission control zone, which is related to the high price of MGO and the fact that the voyage is mostly within the emission control zone. It also suggests that switching to fuel may not be a competitive advantage under tougher emissions regulations in the future. Under the current circumstances, the modification of scrubbers is the best emission reduction scheme.

3.3 Environmental benefit analysis

According to the above formula and AIS data, the pollutant discharge inventory of the ship during the period of December 14 of this year in October 1, 2017 is calculated, as shown in table 2.According to the data of this period, the pollutant emission and emission reduction cost of this year are analyzed, as shown in Table 3.

Table 2. Pollutant Discharge Inventory during voyage (Unit: t)

Engine	SOX	NOX	PM2.5	PM10	CO2
Host	96.81	116.13	11.19	13.99	5749.40
Auxiliary	8.15	43.24	1.24	1.35	2300.40
Boiler	1.91	1.23	0.11	0.12	567.04

Taking sulfide as an example, main engine emissions during navigation are the largest, accounting for 90.59% of the total emissions, while auxiliary engines and boilers account for 7.63% and 1.78% of the total emissions respectively.

The control group was set to use HFO for the whole voyage, and its sulfur emissions were 337 tons and carbon dioxide emissions were 27,170 tons, with a total cost of us $1 million. Take sulphide and carbon dioxide as examples to analyze the mitigation costs (increased investment/reduced emissions) of four sets of mitigation options.

Table 3. The cost of each emission reduction scheme in one year

Scheme	SO_X	CO_2	Cost	Cost reduction of sulfur	Cost reduction of carbon
MDO	267.88	27170.23	1.63	0.91	/
MDO+MGO	71.32	27170.23	1.84	0.32	/
Scrubber	267.88	27170.23	1.39	0.56	/
LNG	0	20649.37	1.78	0.23	0.01

Among the 4 groups of emission reduction schemes, scrubber is the scheme with the lowest total cost, but its emission reduction cost is relatively large. MDO+MGO and LNG are the two projects with high total cost, but the two projects with the lowest emission reduction cost.

3.4 Sensitivity analysis

The price of LNG and MGO will remain unchanged, while the price difference between HFO and MDO will be changed.

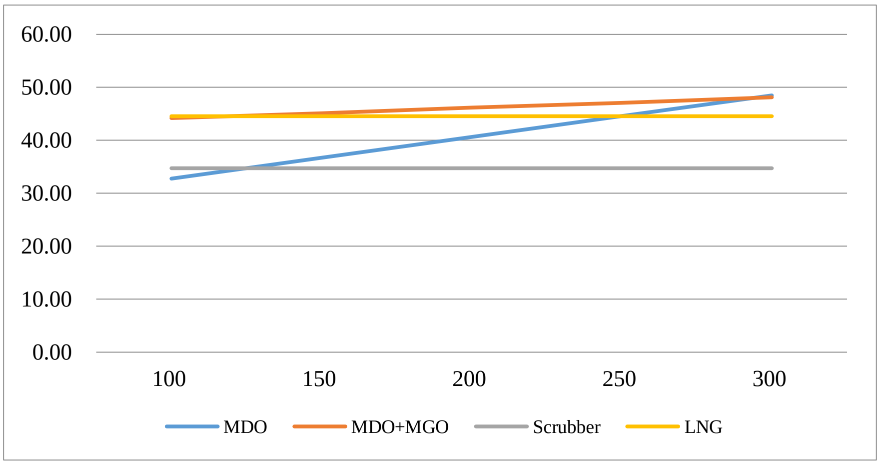

Figure 2. Impact of Fuel price difference between HFO and MDO on total cost

Under the price difference of about 125, the cost of scheme 1 is the lowest, while the cost of scheme 3 is the lowest after the price difference is higher than 125, that is, the scheme of refit scrubber is the best.

The influence of price change on scheme selection was studied with the fuel price predicted by Maersk. Fuel prices are shown in Table 4.

Table 4. 2020-2024 Fuel price (unit: USD/t)

Fuel	2020	2021	2022	2023	2024
HFO	318	323	326	340	341
MDO	518	501	495	405	406
MGO	611	590	580	580	585

LNG	430	415	407	405	406

Substitute the above fuel price into each emission reduction plan.

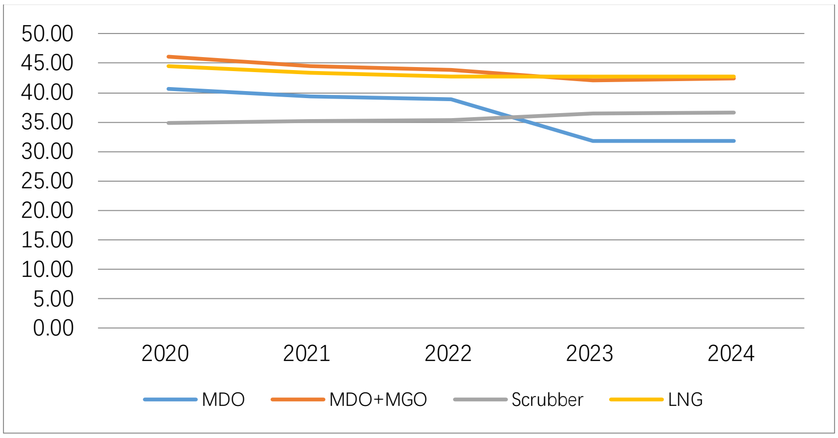

Figure 3. Estimate the impact of future oil prices on costs

Future oil prices are crucial to the choice. According to the table, it is estimated that the PRICE of HFO will rise slightly in the future, while the price of MDO, MGO and LNG will decline, among which, THE PRICE of MDO will decline greatly from 2022 to 2023.The change in oil prices between 2022 and 2023 also changes the cost of mitigation options, with MDO becoming the least costly option. At the same time, the costs of option 2 and option 4 have become similar or even slightly lower than option 4, which means that even with stricter emission regulations, switching to fuel with lower sulfur content will be cheaper than using LNG. The figure also confirms the impact of the price difference between HFO and MDO on scheme selection.

Analyze the impact of changing the emission control area on the total cost of each scheme, as shown in Figure 4.

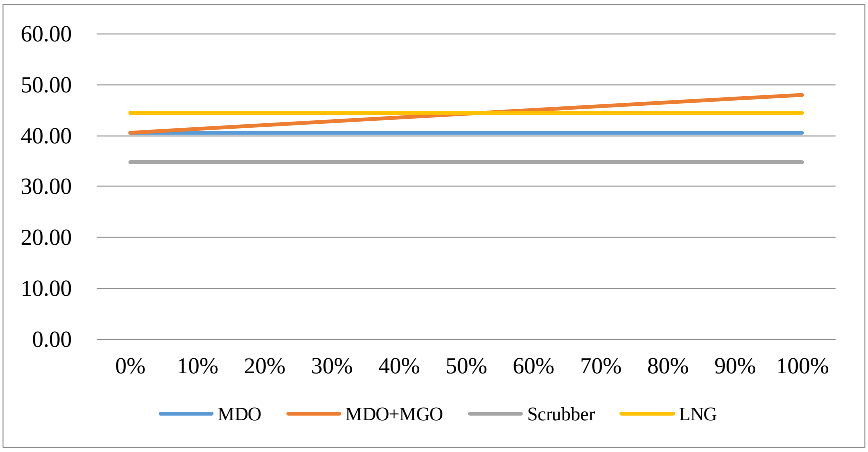

Figure 4. The impact of changing emission control zones on total costs

It can be seen from the figure that changing the scope of emission control area only affects scheme 2.In other words, when emission regulations become more stringent in the future, only 0.1% sulfur content fuel can be used in the control zone. In this case, option 1 is no longer suitable, and alternative fuel is option 2.Therefore, it can

be predicted that the cost of switching to fuel will increase further and lose competitiveness under the further tightening of emission regulations in the future.
The cost of mitigation options under different life cycles is shown in Figure 5.

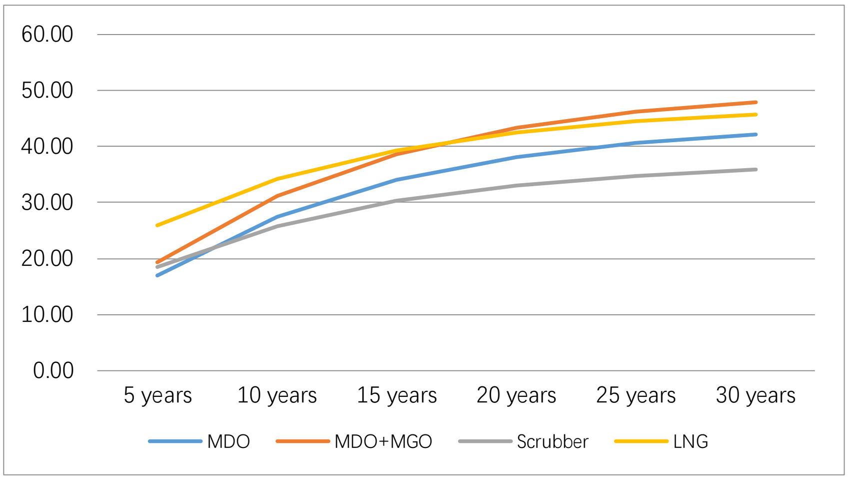

Figure 5. Influence of ship's remaining life on total cost

The longer the ship's remaining life is, the better the refitting scheme will be. Under option 1, which has a residual life of about 7 years, it is preferable to switch to diesel with a sulphur content of 0.5% in this case. For ships with more residual life, it is obvious that the cost of option 3 is relatively small, that is, heavy oil is used after refitting the scrubber tower.

4. Conclusion

This paper presents a method to estimate the environmental and economic benefits of ships by combining AIS data and NPV method. Taking a typical coastal container ship as an example, four emission reduction scenarios including 0.1% and 5% low sulfur oil, installation of scrubber tower and conversion to LNG were analyzed in depth, and the optimal emission reduction scheme for the ship was obtained. At the same time, this study carried out sensitivity analysis of parameters for different influencing factors. The life of the ship, fuel price, time in the emission control zone, and the influence of possible emission policies on the choice of emission reduction measures are analyzed.

Case study shows that using LNG can greatly reduce the emission of pollutants, which is the best environmental benefit emission reduction scheme. However, due to the high cost of refit, LNG is not competitive in commercial application. Scrubbers have a wide range of applications and are generally considered to be the most cost-effective emission reduction scheme. Only when ships are older, the scrubbers cost is higher than MDO. Price sensitivity analysis shows that when the difference between MDO and HFO is less than $125/ton, switching to MDO will be the most cost-effective mitigation measure.

The main contribution of this study is to study at the same time the mainstream emission reduction measures of environmental and economic benefits, at the same time the wobble in oil, Marine life, engine working conditions, emission control area expansion area or require upgrade etc policy made further analysis, for the comprehensive assessment and choose all kinds of measures to reduce emissions have important reference value.

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