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A cost-benefit analysis of fuel-switching vs. use MGO: A CHINA-Europe container route case

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Abstract. With the increasingly strict environmental regulations, the relationship between supply and demand of ships in the post-epidemic era is tense, and ship operators are under tremendous pressure. In view of the existing strict sulfur emission reduction regulations and ship freight operating at high levels in the post-epidemic era, ship operators must choose cost-effective compliance options to create better environmental benefits. This study uses a cost-effective framework to analyze ship operations Supplier's fuel switch and marine natural gasoline compliance options, and apply these options to specific liner routes through China's SECA. We selected an international freight liner as the research object, and calculated the net present value of the compliance option in consideration of the fuel cost of the ship, the installation and operation and maintenance costs of the compliance option. The study mainly considered the influence of the navigation distance in the emission control area on the proportion of the total navigation distance, and also considered the fuel price difference that has a greater impact on ship operating costs. Our results show that in the post-epidemic era, in accordance with the requirements of environmental protection regulations, considering the ratio of SECA and the price difference between MGO and high-sulfur fuels, the use of fuel conversion is a necessary option. We also calculated the emissions of ships, and the results show that with the expansion of the emission control area, the use of MGO can achieve better emission reduction effects. Our results show that in the post-epidemic era, Considering the ratio of SECA and the price difference between low-sulfur and high-sulfur fuels, fuel conversion is the best option. We also calculated the emissions of ships, and the results show that with the expansion of the emission control area, the use of MGO oil can achieve better emission reduction effects.

1. INTRODUCTION

The development of the shipping industry is driven by the development of foreign trade and at the same time promotes the development of world trade. (Valentine V F, 2013) Shipping has the advantages of large volume and low cost. The global container trade volume in 2011 is estimated to be 151 million TEUs (20-foot equivalent units) [[1]].(K.Wang,2018) believes that while ship transportation promotes economic development, it also brings a certain degree of environmental pollution[[2]]. With the passage of time, the pollutants emitted by ships have been increasing, which has caused significant damage to human health and the environment. The most important pollutant is the pollution caused by the burning of sulfide in the fuel. The International Maritime Organization has



decided to formulate global regulations (IMO, 2008) to use 0.1% MGO oil in emission control areas starting in 2020 [[3]]. On the one hand, the implementation of the regulations has reduced the discharge of pollutants during the voyage of ships, and on the other hand, it has increased the operating costs of ship operators. In order to comply with the emission requirements of the emission control area formulated by the Maritime Organization, considering the investment cost of compliance options that meet the regulations, ship operators can choose to switch to fuel, or use MGO directly. (Boer, 2015) compliance options with higher investment costs include the installation of scrubbers and the use of clean fuel LNG [[4]]. The behaviour of ship operators to choose compliance options for emission reduction depends to a large extent on the investment and operating costs of the compliance options and the emission reduction effect. The reasons for this article are mainly due to the tight supply-demand relationship of MGO oil and high prices, as well as the tight supply-demand relationship of ships in the post-epidemic era. Considering the cyclical and asset-heavy nature of the shipping industry, there are two types of compliance that require small initial investment and short transformation time. As shipping environmental protection regulations become more stringent, (Lu Zhen, 2020) ship operators need to consider factors such as the possibility of the expansion of emission control areas and the uncertainty of emission reduction compliance options to choose economically efficient compliance options [[5]]. (Kevin Cullinane, 2014) Previous research focused on the impact of emission regulations on the shipping industry [[6]]. No meaningful suggestions have been given to ship operators on how to make decisions about compliance options. In view of some of the above-mentioned researchers using models to analyze emission reduction options, (M. Acciaro, 2014) use option models to discuss compliance options, and at the same time analyze the uncertain fuel prices and investment costs of compliance options [[7]]. (C. Wang, 2007) According to the analysis of the cost-benefit ratio of the compliance options, the cost-benefit ratio of the West Coast of the United States depends on the size of the control area and the requirements of the sulfur content of the emission regulations [[8]]. (ZL Yang, 2012) using the life cycle method to evaluate three alternatives for compliance options: HFO combined with scrubber and SCR, MGO combined with SCR, and LNG compared with HFO [[9]]. Reduce the impact on particulate matter, photochemical ozone formation, acidification and terrestrial eutrophication potential during the life cycle. (Metzger D, 2019) By evaluating the overall net present value (NPV) of the compliance options, it provides decision-making recommendations for ship operators in solving the initial investment in large compliance options [[10]]. (Choi Y, 2020) Use NPV to analyze the capital cost, operating cost and fuel cost of ship sulfur emission reduction compliance options, and provide investors with recommendations on compliance options [[11]]. (Panasiuk I, 2015) used several financial methods (including NPV, discounted payback period, and return on investment) to compare scrubbers with MGO, and concluded that the time factor has a significant impact on the evaluation of different alternatives [[12]]. In summary, this article aims to study the current tight supply and demand of container liner transportation on China-Europe routes in the post-epidemic era. Choose a Fuel-switching with a short transformation period, small investment, and high economic benefits, and use MGO oil for NPV comparison to analyze the economic and environmental benefits of choosing the route from China to Europe based on the ship fuel price and the proportion of the distance traveled in the emission control area under uncertain environments, to provide ship operators with compliant emission reduction options for economic and environmental benefits.

2. Research methods and materials

This section mainly uses the NPV model to analyze compliance options for reducing sulfur emissions: using MGO and using fuel switch. Direct use of MGO, no need to change the engine or other modification investment. MGO can be used throughout the journey to meet the requirements of the International Maritime Organization. Due to the nature of MGO with high viscosity, it will have a certain impact on the navigation of the ship. The price of MGO is high, and the later fuel cost is higher. For Fuel-switching, use VLSFO (0.5% sulfur content) outside the emission control area and use MGO (0.1% sulfur content) in the emission control area.

The round-trip distance of the liner service is D , and the proportion in the emission control area is w . The distance within the emission control area is wD . According to the ship operation schedule, it is known that the ship operates once a week. Assuming that the number of ships operating on this route of the shipping company is N , the operating speed of the ship is V , and the time that the ship is anchored in the port is P , the number of ships operated by the ship:

$$N = \frac{\frac{D}{V_s} + P}{168} \quad (1)$$

Price is the unit freight rate of the ship's standard container. K is the number of TEUs loaded on the ship, L is the loading factor of the ship, and n is the number of round trips that the ship can take in a year.

$$B_i = 2nNKL \text{ Price} \quad (2)$$

The total cost of a ship is the fuel cost of the voyage and the operating cost of the ship, as well as the increased cost of investment in compliance options that occur in the reduction of ship emissions. For the compliance option $i=[1,2]$, when $i=1$, it represents the compliance option marine diesel, and $i=2$ represents the use of Fuel-switching. CT_i is the voyage cost of the ship's compliance option, ct_{1i} fuel cost is the main cost of the ship operator. ct_{2i} is the operating cost of the vessel, ct_{3i} is the operating and maintenance cost of using the compliance option. According to reading literature, it is concluded that the fuel consumption of a ship is related to the speed of the ship and has nothing to do with the type of fuel used. Model based on the cost of the ship to get the model:

$$CT_i = ct_{1i} + ct_{2i} + ct_{3i} \quad (3)$$

(H.N. Psaraftis, 2013; M. Doudnikoff, 2014) According to empirical calculations, the ship's fuel consumption and speed show a cubic relationship ([13],[14]). The fuel cost of the compliant option mainly includes the fuel cost of the main engine fuel and the fuel cost of the auxiliary engine of the ship. The boiler and other fuel consumption of the ship are ignored in this article. According to the literature, the fuel consumption of a ship is related to the third power of the ship's speed. The calculation of fuel consumption of ships in this paper is based on the power and fuel curve of ship engines and references. Calculate fuel properties such as ship fuel combustion properties. In summary, model the fuel consumption of marine gasoline:

$$ct_{11} = F^M \frac{DV^2}{V_s^3} + F^A \left(\frac{D}{V} + P \right) \quad (4)$$

$$F^M = \frac{SFOC^M EL^M PS^M}{10^6} \quad (5)$$

$$F^A = \frac{SFOC^A EL^A PS^A}{10^6} \quad (6)$$

SFOC is the specific fuel consumption of the engine (g/KWh), PS^M is the power of the engine, PS^A is the power of the ship's auxiliary engine, EL is the engine load (%) during sailing. M represents the main engine and A represents the auxiliary engine. In this study, we used (M. Doudnikoff, 2014; JJ Corbett, 2009) parameter values, where $SFOC^M = 206$ g/kWh, $SFOC^A = 221$ g/kWh, $EL^M = 0.8$ and $EL^A = 0.5$ respectively represent the utilization rate of the main engine and auxiliary engine of the ship([15],[16]). V_s is the design speed, and V is the average speed of the ship. Regarding fuel consumption for Fuel-switching:

$$CT_{12} = F^M \frac{wDV^2}{V_s^3} + F^M \frac{(1-w)DV^2}{V_s^3} + F^A \left(\frac{D}{V} + P \right) \quad (7)$$

ct_{2i} Operating costs The daily fixed cost of the ship and the annual operating time of the ship are calculated based on 350 days. Ship operating costs mainly include crew, ship maintenance, insurance

and management costs. The data selected in this paper is the ship operating cost calculated by Clarkson Information Network.

Regarding MGO, it is mainly about the transformation of MGO related pipelines. The initial investment cost for MGO is mainly about the cost of upgrading the line and the cost of fuel consumption. For Fuel-switching, a Fuel-switching system and other facilities and equipment need to be installed. The capital expenditure of using the Fuel-switching system is your initial investment in the Fuel-switching of the ship. According to the size and type of the ship, the capital expenditure of converting a ship to burning MGO fuel is between 10,000 and 150,000 Euros. This article chooses 150,000 euros, calculated based on the exchange rate relationship between the euro and the U.S. dollar 1 euro = 1.191 U.S. dollars. The capital expenditure for the MGO fuel system is zero, and the cost of modification and installation of the compliance options using MGO fuel and Fuel-switching is estimated in this paper to be \$6/kW. (Mo Zhu, 2017; Antturi, 2016) The maintenance cost of MGO is estimated in this paper to be 0.6 USD/kW ([18],[19]). The operation and maintenance cost of Fuel-switching is estimated to be 3% of the initial investment. According to the service life of the ship and economic considerations, 10 years are used for simplified calculation.

Figures and tables, as originals of good quality and well contrasted, are to be in their final form, ready for reproduction, pasted in the appropriate place in the text. Try to ensure that the size of the text in your figures is approximately the same size as the main text (10 point). Try to ensure that lines are no thinner than 0.25 point.

Table 1. Investment cost and operation and maintenance cost of compliant line selection.

Compliance options	Initial investment cost		Operation and maintenance costs for compliance
MGO	0	6	0.6 USD/kW
Fuel-switching	178650	6	3% of Initial investment cost

In summary, the net present value model of the ship after the compliance option is installed: $\{CAPEX\}_i$ The initial investment for the transformation of compliance option i , $\{CT\}_i$ is the cost of the ship, Y is the life of the ship, and r is the discount rate. Choose 5% according to the literature.

$$NPV^i = -CAPEX^i + \sum_{t=0}^{Y-1} \frac{B_t - CT_t}{(1+i)^t} \quad (8)$$

The emission volume of the compliance option can be calculated according to the data in the research literature of the IMO, and the emission factor of the compliance option can be obtained by multiplying the fuel consumption of the ship and the emission factor of the unit fuel consumption:

Table 2. Pollutant emission coefficient of ship fuel

	CO ₂	SO _x
VLSFO	3.206	0.0097753
MGO	3.206	0.00195506

Note: The emission factor is calculated according to the third IMO Greenhouse Gas Study Specification (IMO, 2014) ([17]).

3. case analysis

3.1. Benchmark case

We chose the container route from Shanghai to Europe. The information on container ships on the main routes from China to Europe comes from Clarkson Information Network, and the data on

container services comes from the company's website. The following table provides detailed information on the routes and ships of the case study. In the research process of this article, the fuel price adopted by Clarkson Shanghai in June 2021 is the fuel price of VLSFO and MGO, which are US\$524.25/ton and US\$607.25/ton respectively, at a discount rate of 5%, and container freight is in US dollars. 6198/TEU. In this study, we compared the operator compliance options between Fuel-switching and MGO on specific container liner shipping routes, using NPV analysis in the following situations:

(1) The benchmark under the current situation, considering the net present value analysis of different proportional distances under the possibility of future expansion of the emission control area.

(2) Under the uncertainty of the increasingly stringent emission control regulations, the net present value analysis of ships in different navigation distances in the emission control area

(3) The impact of the different price gaps between MGO and VLSFO (100 USD, 200 USD, 300 USD) on the net present value of ship operations.

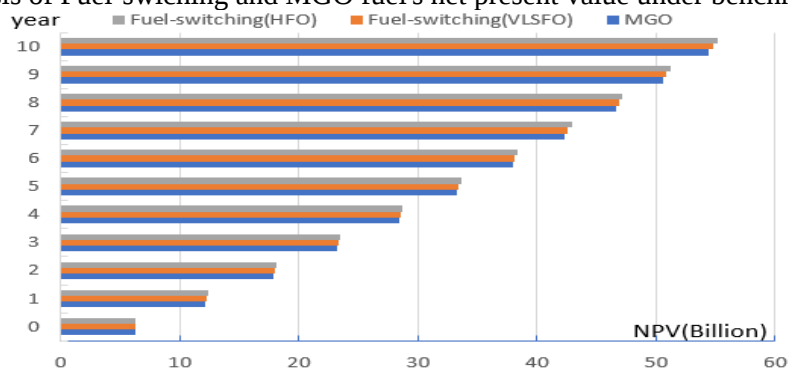
Table 3. Basic route information.

Number of ships operating on the route	Sailing distance (nautical miles)	Navigation distance in emission control area (nautical miles)	Design speed (nautical mile/hour)	Port berthing time round trip (h)	Sailing time round trip (h)	Number of round trips within a year
N=11	22333	1405%	22.5	754.4166667	1356.433333	3

Table 4. Basic ship information.

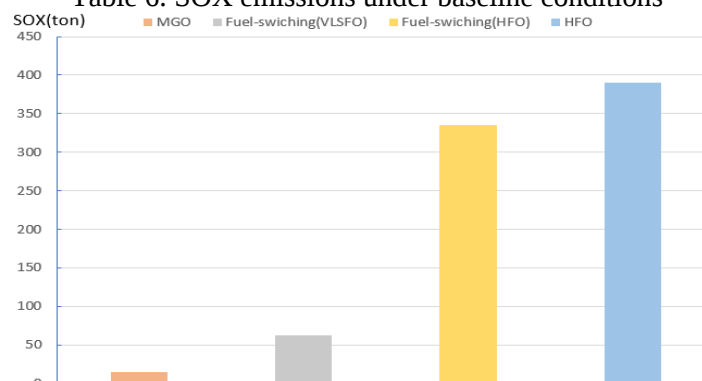
Gross tonnage (ton)	Ship main engine power (KW)	Ship auxiliary engine power (KW)	Design speed (nm/h)	total capacity (TEU)
194852	55000	8289	22.5	20000

Table 5. Analysis of Fuel-switching and MGO fuel's net present value under benchmark conditions.



Illustrates the use of Fuel-switching and the NPV of the MGO during its service life. It is obvious that the NPV using the MGO option is always low. With the increase of service life, due to the lower initial investment of MGO fuel price and usage, the reconstruction period is short,

Table 6. SOX emissions under baseline conditions



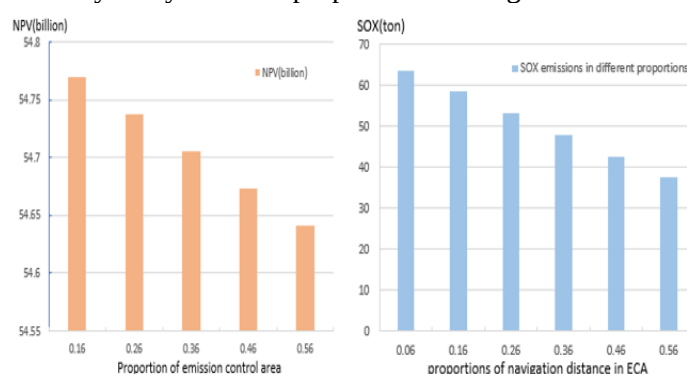
The emissions per ship per voyage for the compliance options are 14.5 tons of sulfide emissions from MGO, 57.5 tons of sulfide emissions using Fuel-switching, and 390 tons of sulfide emissions from HFO. Use the new Compliance options can achieve good emission reduction results. Compared with MGO, Fuel-switching has the best emission reduction effect using MGO, and it is more in line with the requirements of future environmental regulations.

Use a two-column format, and set the spacing between the columns at 8 mm. Do not add any page numbers. Note: The emissions per ship per voyage for the compliance options are 14.5 tons of sulfide emissions from MGO, 57.5 tons of sulfide emissions using Fuel-switching, and 390 tons of sulfide emissions from HFO. Use the new Compliance options can achieve good emission reduction results. Compared with MGO, Fuel-switching has the best emission reduction effect using MGO, and it is more in line with the requirements of future environmental regulations.

3.2. Sensitivity analysis on the proportion of the ship's navigation distance within the emission control zone

Because different routes have different proportions of navigation distance in the emission control area. At the same time, the laws and regulations of emission control areas in various countries are continuously improved and perfected, emission control areas are constantly increasing, and the proportion of distance traveled in emission control areas on routes is increasing. This trend will result in an increase in operating costs, and ship operators need to consider the impact of different compliance options on the NPV results of ship operations with changes in the navigation distance within the emission control area. This paper studies the proportion of navigation distance in different emission control areas. The analysis results show that as the navigation distance in the emission control area increases, the net present value of ship operations gradually decreases, but it is better than the NPV using MGO. It can be concluded that ships using Fuel-switching can adapt to the environment of the future expansion of emission control areas and have better economic and environmental benefits.

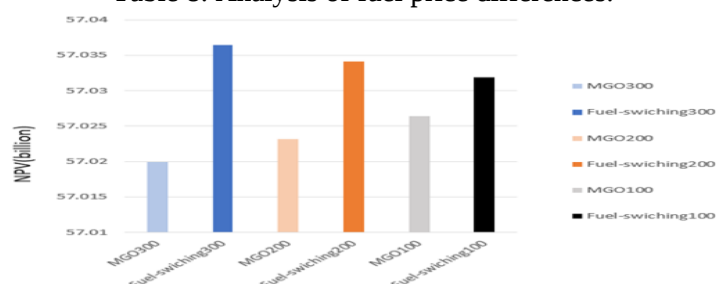
Table 7. Sensitivity analysis of the proportion of navigation distance in the ECA.



3.3. Analysis of the difference in fuel prices

As the price gap between MGO and VLSFO increases, the net present value of using Fuel-switching is larger, and the net present value of using MGO fuel is lower. When the difference between the two oil prices is large, choose Fuel-switching, and when the difference between the two oil prices is small, choosing MGO has a better emission reduction effect.

Table 8. Analysis of fuel price differences.



4. conclusion

In this article, we discussed the feasible compliance options for the emission control zone regulations and performed relevant analysis, especially for the tight supply and demand of the shipping industry in the post-epidemic era, choosing compliance options that use MGO and fuel-switching with less initial investment, and use cost-effectiveness. We conduct modeling analysis based on the method of modeling and analysis. We calculate and analyze the net present value of the two compliance options with less initial investment and short renovation period based on key factors such as fuel prices in international container liner transportation and the distance traveled in the emission control area. And emissions show that in the post-epidemic era, the shipping industry's tight supply-demand relationship can achieve better economic benefits by choosing Fuel-switching. In the current market situation where ship freight is at a high level, ship operators can choose to use MGO to obtain better emission reduction effects.

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