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ECONOMIC ANALYSIS OF MEASURES FOR SHIPOWNERS UNDER SULFUR EMISSION CONTROL

By

Yu Luyao

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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.

Signature: …………………………..

Date: …………………………..

Supervised by: …………………………..

Supervisor's affiliation: …………………………..

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I have gained a lot during this period of study from 2020-2021. As a novice in the maritime field, I started from the knowledge of diesel engine and learned a lot about the origin of IMO, the background of various maritime conventions including SOLAS, the amendment process and the controversies in the practical application during the MSEM study program. Thanks to all the professors from WMU and DMU, although many courses were done on zoom because of COVID-19, it was still hard to hide the wonderful content of the professors' lectures. This year-long learning experience is the source of inspiration and knowledge base for this work.

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ABSTRACT

Title of Dissertation: **Economic Analysis of measures for shipowners under Sulfur Emission Control**

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A wide array of technical and operational solutions is available to shipowners in order to comply with the International Maritime Organization's (IMO) 2020 global sulphur limit. Based on the relevant IMO regulations, this thesis provides a brief introduction to the measures that shipowners can take under the sulphur limit order. For maritime shipping, low sulphur fuel oils (LSFOs), scrubbers and Liquefied Natural Gas (LNG) are the most commonly applied approaches in practice. In this paper, a 13,208 20-foot equivalent unit (TEU) container ship sailing between the Far East and Europe was used as an example to identify a more economical approach to sulfur reduction. Through a cost-benefit analysis, the use of scrubbers proved to be more economical because of their higher net present value and lower annual unit cost. Sensitivity checks showed that scrubbers were more attractive in most cases, except for the two cases where LSFOs were more popular. This finding explains well the current popularity of scrubber installation among shipowners, although the retrofit still faces many challenges.

KEYWORDS: Sulfur Control, Cost-benefit analysis, Shipping, Environment protection

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

BWMS	Ballast Water Management System
ECA	Emission Control Area
GHG	Greenhouse Gas
HSFO	High Sulfur Fuel Oil
IMO	International Maritime Organization
LNG	Liquefied Natural Gas
TEU	Twenty-foot Equivalent Unit

CHAPTER 1 INTRODUCTION

1.1 Environmental Issues in the Maritime Field

Shipping accounts for more than 80% of global trade and provides livelihoods for a variety of businesses in almost all countries of the world. Container shipping accounts for a large share of the shipping industry, and the ensuing environmental problems have caused widespread concern in society.

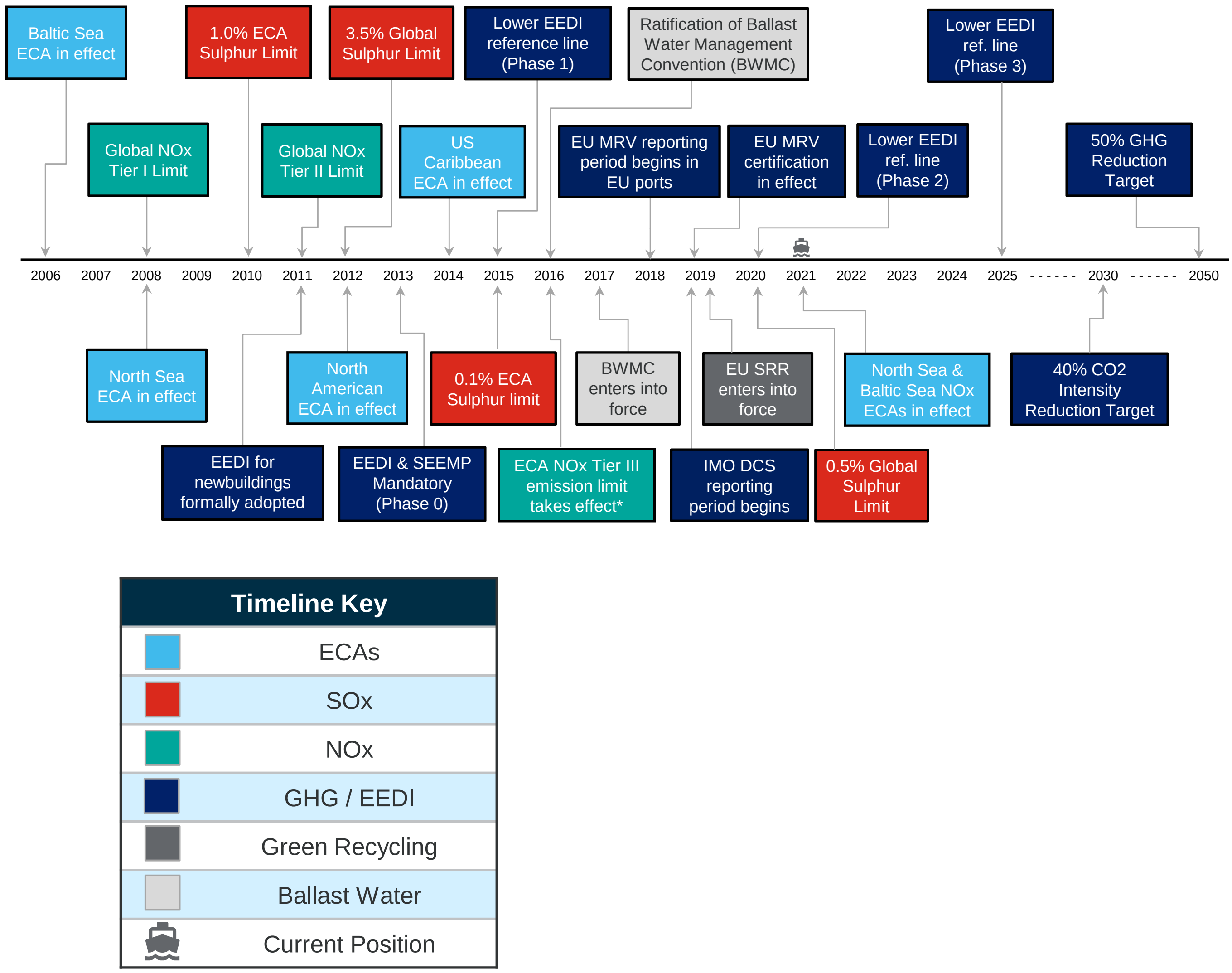
Due to the nature of the fuel used in ship engines, maritime transport is an important contributor to SOx emissions; the International Maritime Organization (IMO) noted in its 2014 GHG study that about 12% of global SOx emissions come from shipping, and the proportion is increasing(Fan et al., 2020).

The European Union has formulated requirements for ship sulfur oxide emission control through the promulgation of amendments to the 2005/33 Decree and the 2012/32/EC Decree amendments. Relevant laws and regulations have been implemented successively since August 2006, and apply to ships entering the Baltic Sea, the English Channel and the North Sea, as well as ships and inland vessels between ports within the European Union(Oirere, 2018).

The California Marine Fuel Regulations of the United States clearly stated that seagoing vessels entering the 24 nautical miles of the California coastline (including only the territorial sea and the contiguous zone) must use clean fuel with a mass score of not more than 0.5% from July 1, 2009; Starting from January 1, 2012, clean fuel with a mass score of no more than 0.1% must be used; some ships are required to use shore power technology during berthing from January 1, 2014.

From Table 1, it is known that international maritime transport faces regulation by different policy participants (i.e. International Maritime Organization, hereafter IMO, EU) from 2006 until 2030 to improve the ecological performance of maritime transport and will face more regulation in the future. In order to address the growing environmental concerns, the MPO Annex VI on the prevention of air pollution from ships entered into force in 2006. The annex covers sulfur and particulate matter, nitrogen oxides, ozone-depleting substances, and energy efficiency of ships. Coming into force on January 1, 2020, MARPOL Annex VI reduces the sulfur limit to 0.50% in marine fuel oils used on ships operating in areas outside designated emission control areas. Compliance with sulfur emission limits and effective uniform enforcement are essential to ensure a level playing field, as compliant ships are unlikely to compete with non-compliant ships(Bilgili, 2020).

Table 1 The Regulatory Timeline Continues to Accelerate



Source: Clarksons Research, (2021)

1.2 Status of Container Ship Trade

The seaborne container trade continued its strong rebound in March, with global box volumes up 11% year-on-year and 6% over 2019 levels, reaching the highest monthly absolute level on record(Clarksons Research, 2021a). Following strong growth in the second half of 2020, the container shipping market maintained its impressive progress in the first quarter of 2021. After the severe negative impact of Covid19 in the first half of 2020, the rapid recovery of seaborne container trade combined with pronounced logistical disruptions and modest supply growth has created a "perfect storm" that has driven the box shipping and container ship chartering markets to extraordinary highs in recent months(Bai, 2018).

As shown in Table 2, the near-term outlook remains very positive and expectations are growing that the “disruption upside” could last for a long time(Clarksons Research services, 2021). As shown in Table 3, there are 820m TEU of container volumes in the world, and the growth ratio is still being increasing. Therefore, container ships have been chosen as the main subject of study for this thesis.

Table 2 Container Trade Summary,m TEU

Year	Total Mainlane	% Growth	% Mainlane Share	Non-ML E-W	% Growth	North-South	% Growth	Intra-Asia	% Growth	Other Trades	World Total	% Growth
2013	50.3	*3.0%*	*32.2%*	16.1	*3.6%*	27.3	*6.0%*	43.9	*7.8%*	18.9	**156.6**	***4.9%***
2014	52.0	*3.2%*	*31.6%*	17.2	*7.0%*	28.3	*3.7%*	46.7	*6.3%*	20.3	**164.4**	***5.0%***
2015	52.3	*0.8%*	*31.2%*	18.1	*5.0%*	28.4	*0.3%*	48.1	*3.1%*	20.9	**167.8**	***2.1%***
2016	54.7	*4.4%*	*31.2%*	19.1	*5.8%*	28.8	*1.6%*	51.1	*6.2%*	21.7	**175.4**	***4.5%***
2017	57.2	*4.7%*	*30.9%*	20.0	*4.6%*	30.6	*6.1%*	54.7	*7.1%*	22.7	**185.2**	***5.6%***
2018	58.5	*2.2%*	*30.3%*	20.5	*2.6%*	32.3	*5.7%*	57.8	*5.6%*	24.1	**193.2**	***4.3%***
2019	59.2	*1.2%*	*30.0%*	20.5	*-0.1%*	32.6	*0.8%*	59.5	*3.0%*	25.2	**196.9**	***1.9%***
2020	59.1	*-0.2%*	*30.4%*	19.3	*-5.6%*	32.2	*-1.3%*	59.4	*-0.2%*	24.7	**194.6**	***-1.2%***
2021"	61.7	*4.4%*	*30.0%*	21.3	*10.0%*	33.8	*5.1%*	63.0	*6.2%*	25.9	**205.7**	***5.7%***
2022"	63.3	*2.6%*	*29.7%*	22.2	*4.4%*	34.9	*3.1%*	66.2	*5.0%*	26.8	**213.4**	***3.7%***

Source: Clarksons Research, (2021)

Table 3 Container Trade Growth Trend

Container		**Est. m teu lifts/teu**			**Trade Growth Trend**			
Volumes		**2018**	**2019**	**2020**	**2021**	**2022**	**2021 %**	**2022 %**
m. teu lifts	Asia	446	459	459	489	509	6.4%	4.1%
	Europe	150	151	146	154	159	5.2%	3.6%
	North America	68	70	70	74	77	6.5%	2.8%
	Middle East/ISC	70	73	70	75	78	6.1%	4.6%
	Southern Hemisphere	77	75	75	79	82	6.2%	3.4%
	Total, m. teu lifts	**812**	**828**	**820**	**871**	**904**	**6.2%**	**3.9%**

Source: Timecharter et al., (2016)

1.3 Solutions in the face of the Sulphur limit

In response to the IMO 2020 sulfur limits, three approaches are widely available to help ship owners comply with the new requirements：

1) Continue to use high-sulfur fuel (HSFO with a sulfur content of 3.5%), but install a scrubber on the ship to remove most of the sulfur dioxide in the exhaust gas;

2) Change to shipping distillate or low-sulfur mixed jet fuel with a sulfur content of 0.5% or less;

3) Replace with low-sulfur fuels such as LNG or methanol.

As the deadline is approaching, refineries have adjusted their production plans to optimize the production of low-sulfur distillates and limit the production of high-sulfur residual oil (also known as residual oil). At the same time, US midstream companies have increased the export of light and sweet crude oil from the Permian and other shales, restricting exports to crude oil refineries that are only capable of handling heavy oil. Aviation fuel suppliers are also testing the blending of different fuels in order to be able to produce IMO 2020-compliant fuel in time. But in any case, shipowners have to face messy fuel prices.

Therefore, the biggest challenge for container ship owners is to choose the most appropriate way to respond to the new global sulfur limits in a cost-effective manner. Many efforts have been made in recent years to address this challenge. Unfortunately, the available studies have not reached a consensus on the most attractive approach, mainly due to the limitations of fuel prices, cost of installing scrubbers, sailing area, sailing speed and remaining ship life.

CHAPTER 2. THREE EFFECTIVE MEASURES TO TACKLE THE REQUIREMENT ON SULPHUR LIMIT

2.1 Use of Low Sulfur Oil

2.1.1 Current Market Status of Low Sulfur Oil

Low sulfur "compliant fuel oils", i.e. VLSFO and ULSFO. There are heavy oil and light oil for marine fuel. Heavy oil is divided into ordinary heavy oil (such as HSFO380CST), low sulfur heavy oil (LSFO380CST), and light oil is also divided into ordinary light oil (MGO) and low sulfur light oil (LSMGO). Vessels generally use heavy oil when sailing, and switch to low sulfur heavy oil in the low sulfur control area when in port, and use low sulfur light oil only if there is no low sulfur heavy oil replenishment that meets the requirements.

Light oil cannot be used for a long time because of its insufficient viscosity, otherwise it will adversely affect the ship's engine. It is technically simple and feasible to use low-sulfur heavy oil that meets the requirements directly, but it is more expensive than ordinary heavy oil in terms of cost, and there is the problem of short supply, which requires advance booking with oil suppliers. The price of marine bonded oil is directly linked to international crude oil, with Singapore price as the wind vane. As we can learn from Table 4, the price difference between MGO and VLSFO is around US$41/T, and the price variance between HSFO180cst and VLSFO is around US$154/T, according to the latest quotation from certain oil suppliers in Singapore in February 2020. The price difference between HSFO380cst and VLSFO is only around US$188. The main impact of the global sulfur restriction in 2020 is the choice between low sulfur heavy oil and high sulfur heavy oil. The sulfur content of heavy oil varies depending on the production area, a small amount of heavy oil from the production area is up to the standard, but most of it needs to be reprocessed to meet the standard, one of the processing methods is to blend high sulfur heavy oil with low sulfur light oil, therefore, price is between high sulfur heavy oil and low sulfur light oil.

Table 4 Prices of a few types of marine oil, Singapore

Date	HSFO 180cst Bunker Prices (3.5% Sulphur), Singapore $/Tonne	MGO Bunker Prices, Singapore $/Tonne	HSFO 380cst Bunker Prices (3.5% Sulphur), Singapore $/Tonne	VLSFO Bunker Prices (0.5% Sulphur), Singapore $/Tonne
Sep-2019	465.50	594.25	459.63	553.88
Oct-2019	393.38	580.38	360.75	540.38
Nov-2019	369.80	582.15	341.55	549.30
Dec-2019	370.00	626.00	340.13	626.25

Jan-2020	384.75	663.60	366.15	663.35
Feb-2020	349.50	513.25	315.00	503.00

Source: Clarksons Research, (2021)

2.1.2 Introduction of low sulfur oil

As global environmental problems continue to intensify, environmental protection requirements have been issued at home and abroad. Supplying low-sulfur marine fuel oil, recovering marine fuel oil tail gas, monitoring whether fuel oil is low-sulfur, and using low-sulfur fuel oil have turned into widespread concerns in the field.

Figure 1 Low Sulphur Oil

Source：IMO, (2020)

Marine fuel oil is mainly blended with atmospheric residue, vacuum residue, cracked residue, cracked diesel and catalytic diesel in the process of crude oil processing. Generally speaking, a homogeneous mixture of hydrocarbons is used as the basic raw material. Fuel oil has moderate viscosity, good fluidity, good atomization, high calorific value, complete combustion, high calorific value, and low corrosivity

Contemporarily, major marine oil desulfurization technologies are as follows:

a) Hydrocatalytic desulfurization process (HDS) technology

Hydrocatalytic desulfurization process (HDs) technology has the advantages of high oil yield, good technical economy, and simultaneous removal of nitrogen, oxygen and metals. Regulate the content of olefins and aromatics and other advantages, however, requires high temperature and high pressure, resulting in high equipment requirements for the hydrocatalytic desulfurization process; at the same time, the process has high energy consumption and many by-products, and is still inadequate for deep desulfurization of fuel oil, and it is difficult to remove heterocyclic compounds such as thiophene, dibenzothiophene and their derivatives from oil. HDs must fully consider the physical and chemical properties and reaction characteristics of thiophene compounds, explore new technologies for non-HDs, and technology combinations to achieve efficient deep desulfurization of fuel oil.

b) Oxidation desulfurization technology (ODS)

Oxidation desulfurization technology refers to a process of removing sulfur compounds and their derivatives from fuel oil by oxidizing sulfur compounds and their derivatives into strong polar sulfoxide or sulfone substances through the action of strong oxidants (H_2O_2, O_2, etc.) at room temperature and pressure and in the presence of catalysts, and then using suitable extraction agents to extract and separate the resulting sulfoxide or sulfone substances.

c) Electrochemical desulfurization technology (ECDS)

Electrochemical desulfurization method refers to the process of putting heavy oil into the electrolytic tank through the oxidation and reduction reaction in the anode and cathode areas, and the products are removed by extraction or separation.

d) Biological desulfurization technology (BDS)

Biological desulfurization technology refers to a new technology that uses aerobic and anaerobic in to remove sulfur bound in sulfur-containing heterocyclic compounds in fuel oil under relatively mild conditions (20-60℃, atmospheric pressure).

e) Adsorption desulfurization

Adsorption desulfurization is a kind of desulfurization that depends on the ability of an adsorbent. Through the physical, complexation and chemical adsorption methods, the process of removing sulfur compounds in fuel oil. At present, the more widely used adsorbents are mainly activated carbon, molecular sieve, metal oxides, etc. Oxidation desulfurization, electrochemical desulfurization and biological desulfurization technologies can significantly improve the desulfurization effect, but the regeneration of oxidation desulfurization agent is difficult, the treatment of waste liquid of electrochemical desulfurization is difficult and the reaction cycle of biological desulfurization is long, which limits the large-scale application of related technologies. It is a difficult problem that needs to be solved at present. Adsorption desulfurization, as an efficient sulfur separation technology, helps to realize the recovery and resource utilization of thiophene-like substances. The choice of desulfurization technology means that more processing costs or expenses will be added to the production of low sulfur fuel oil, and the refinery's base revenue will be further reduced.

According to Kuwaiti estimates, 1% of fuel oil desulfurization requires $20 / ton, and Japan estimates that it requires $60 / ton, indicating that the price of 1% of fuel oil desulfurization will rise by $20 to $60 / ton, which will bring a huge challenge to ship owners and oil suppliers.

2.1.3 Application status of low sulfur oil

Compared with traditional marine heavy oil, low sulfur fuel oil has low flash point and low viscosity, low specific gravity, low lubricity, low calorific value and low sulfur content. The direct use of low sulfur fuel oil in ship engines can fundamentally solve the problem of sulfur oxide emission from ships. However, under the current shipping industry downturn, the use of low sulfur fuel oil still have some inevitable problems such as unstable oil quality and low sulfur fuel oil deviation.

Through the analysis of the raw material market, to achieve low sulfur fuel to meet the requirements of ship use, there is still a certain degree of difficulty. Now light distillate type low sulfur fuel can be produced on a large scale. It can meet the market demand. But this oil is used for a long time in the medium and low speed diesel engines of ships, which puts forward higher requirements and greater safety risks to the fuel conversion and equipment of ships. The problems of unstable fuel quality and deviation of low sulfur fuel price need to be solved.
The main manifestations are:

a) Impact of oil prices

According to Wood Mackenzie and BIMCO, more than 90,000 merchant ships will be affected by the "sulfur restriction", and these ships are responsible for about 90% of global trade transportation. A large 5,000-case container ocean-going vessel, for example, consumes about 90 tons of fuel per day. In 2017, the average market price of HSFO 380 CST was about $260/ton and VLSFO was about $460/ton. The difference between them is about $200. Fortunately, in March 2021, the average market price of HSFO380CST heavy oil is about $386/ton and the price of VLSFO is about $498/ton. The difference between them is about $112. Therefore, based on the data in 2017, it is estimated that an ocean-going container ship with 5,000 containers will need to pay an extra US$18,000 per day for fuel after the full implementation of the "0.5% sulfur limit" policy for ships. And based on 2020 data, the extra fuel cost for this vessel is US$10,080 per day. This is significantly more than previously estimated. Fluctuating oil prices have greatly influenced shipowners' choice of whether to try low-sulfur oil. In addition, the fuel oil change includes modifications to the vessel's equipment, which is also a cost pressure that needs to concern.

b) Adaptation of conventional diesel engines

Currently, most ships' diesel engines and fuel supply systems are designed according to the viscosity and lubrication performance of conventional fuels. When low-sulfur fuel with low viscosity and poor lubricity is used, a series of failure problems occur. At the same time, the quality of fuel oil cannot be guaranteed and its composition differs from that of conventional fuel oil to some extent, leading to failure of marine engines due to unstable combustion. The quality of 0.50% sulfur fuel and its suitability for use on board may negatively affect safety. Increased blending may also reduce the compatibility and stability of residue-like fuels with low sulfur content. In addition, the wide variation in technical parameters of low sulfur oils sold in various regions, including sulfur content, will further exacerbate the potential for frequent engine fuel changes and accidents. Information shows that after the implementation of ECA (Emission Control Area for ships) in European and American waters, about 30% of runaway ship accidents may be related to the conversion of low-sulfur oil. The upcoming "sulfur restriction" has put high demands on the performance of engines. Under the current background of reduced demand for ocean-going trade vessels and excess ship capacity, enterprises are required to update the main engine and increase investment in environmental protection, which is not only technically difficult, but also increases the cost of enterprises and increases the pressure on the industry(Nagata et al., 2017).

c) Mismatch with marine lubricants

In order to reduce the sox emission caused by the fuel, the lubricating oil often has a certain alkali value to neutralize part of the sulfide, but if the switch to use low sulfur oil and high alkali value lubricating oil is not changed accordingly, especially cylinder oil and medium speed engine oil, the alkali material is easy to produce precipitation. Combustion chamber residual excessive alkaline calcification will accelerate the cylinder liner and piston ring wear, leading to poor cylinder seal, increase fuel oil and spare parts consumption. So switching light and heavy oil puts higher requirements on the applicability of lubricant.

d) Poor lubricity

Causes of oil supply system failure Production of low sulfur fuel oil is mainly realized by hydrogenation and other means. Hydrogenation removes sulfide and at the same time removes some polar substances containing oxygen and nitrogen which have better lubricity, and at the same time reduces the natural lubricity of the oil because polycyclic aromatic hydrocarbons are cracked. The lubricity of the oil is reduced. It tends to cause the failure of the high-pressure oil pump and injector adhesion and wear.

e) Causes incompatibility of fuels

Low sulfur fuel has low aromatic hydrocarbon content, so low asphaltene is less soluble. When heavy fuel containing large amounts of asphaltene is converted with low-sulfur fuel, the equilibrium state of asphalt in the oil is disrupted, which may lead to filter clogging and machine and equipment stopping due to incompatibility.

f) Increase fuel oil wear

In order to improve the production of light oil, adding catalysts containing silicon and aluminum elements in crude oil refining, like abrasives, or into the fuel system to accelerate the wear of high-pressure oil dish plunger sleeve coupling, outlet valve jamming, injector needle valve wear 'or direct contact cylinder liner, piston ring, and in serious cases even cause pulling cylinder, piston ring fracture, etc..

2.2 Desulfurization tower

2.2.1 The current market situation of scrubber

At present, a total of 4,014 ships have installed desulfurization towers, most of which are open-loop desulfurization towers (3249 ships), followed by 678 ships with hybrid desulfurization tower systems and 634 ships with closed-loop desulfurization towers. DNV GL data shows that among the ships installed with desulfurization towers, the number of newly built ships is 1054, and the remaining 2960 ships are conversion projects(Mcloughlin et al., 2019).

In the 13th months since the global sulfur limit came into effect, the number of ships equipped with scrubbers has doubled, driving the growth of high sulfur fuel sales. There are currently 4,006 vessels equipped with scrubbers, up from 2,010 in January 2020 (BIMCO, 2021).

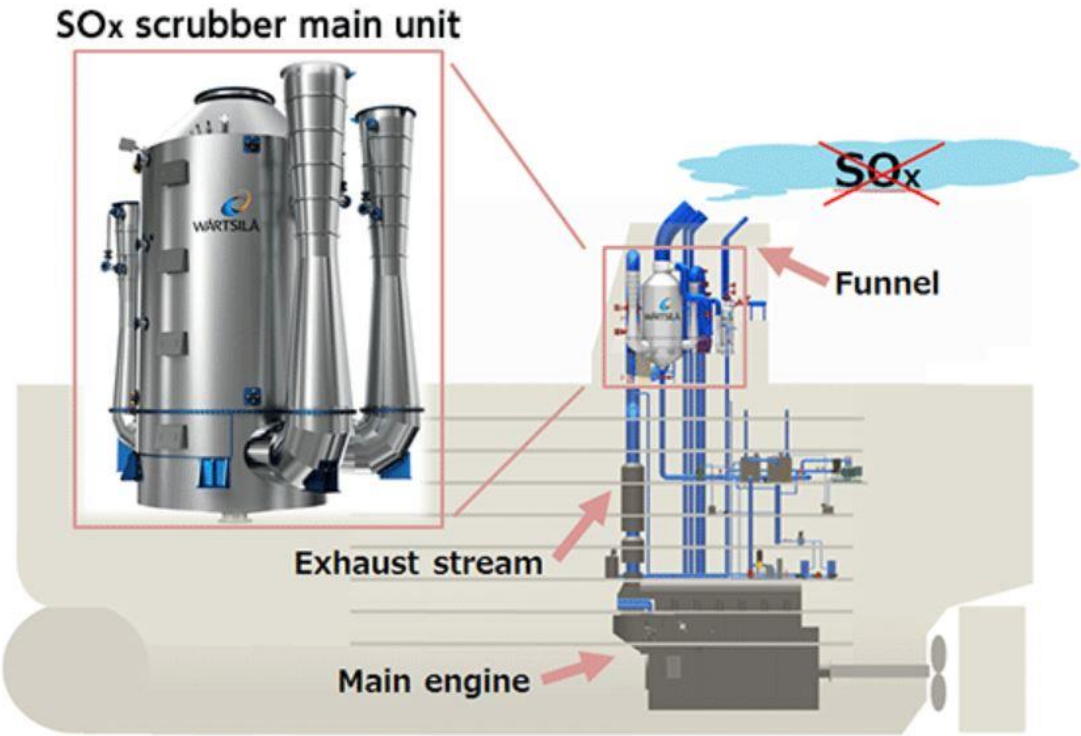


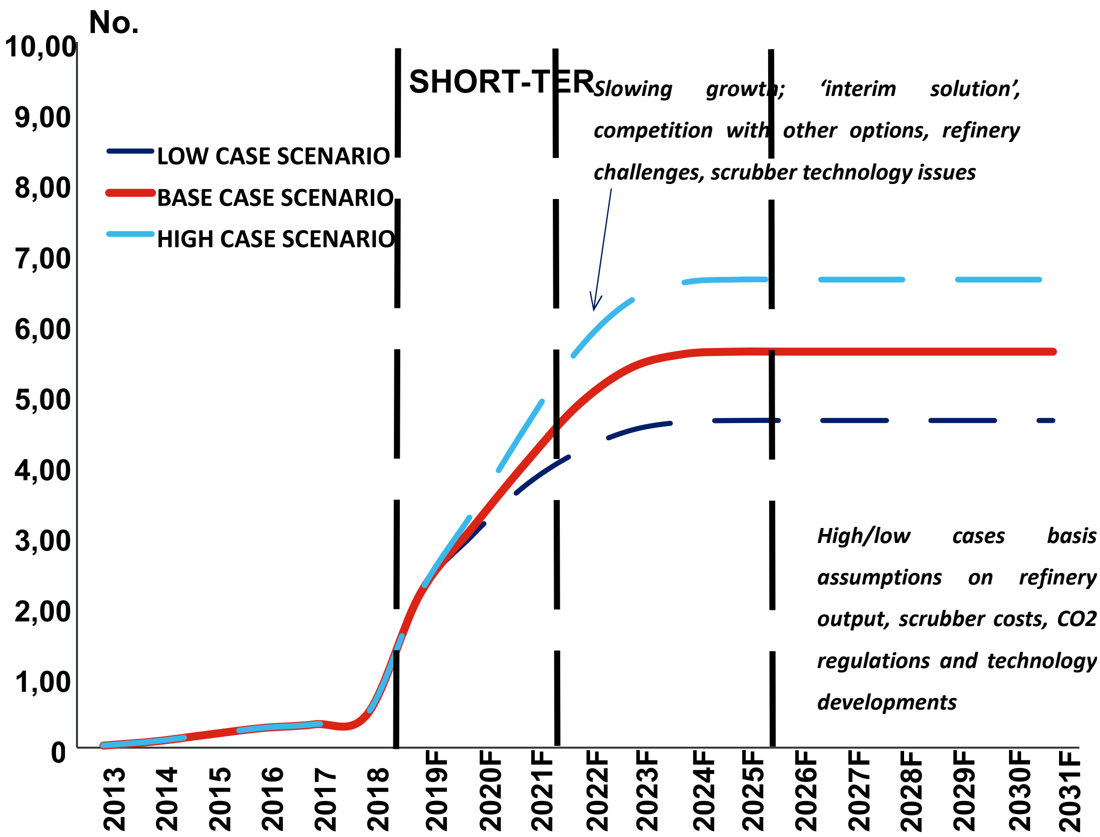
Figure 2 – Figure of SO_X Scrubber System

Source：MOL, (2016)

As can also be seen in Table 5, the high growth period for vessels equipped with scrubbers is around 2018 to 2022, with the curve expected to flatten out after 2022. This is precisely due to the impact of the implementation of the sulfur limit in 2020. As can also be seen from Table 6, the 15,000 TEU+ fleet has the highest share of scrubbers among the existing fleet that has chosen to install scrubbers, which is predicted to be an economic trade-off due to the price difference between low and high sulfur oil(Liu, 2020).

As can be seen from Table 7, the percentage of total standard containers reached 49%, with 8,000-11,999 TEU and 15,000+ TEU accounting for the largest share, which shows that the installation of scrubber towers in the container ship market is a promising prospect.

Table 5 Provisional SOx Scrubber Equipped Fleet Dev. Scenarios (End Year)



Source: Clarksons Research, (2021).

Analysis takes into account new deliveries into the fleet with scrubbers as well as retrofit demand.

Some other forecasts are based on a refinery perspective; this model approaches from the point of view of scrubber demand and potential yard capacity to install both scrubber units and BWMS.

- Short term uptick in retrofit demand expected alongside implementation of SOx ,2020, followed by reduced demand from 2025.

Table 6 SOx Scrubber Equipped Boxship Fleet (Fitted And Pending) By Size Range - Numbers

Vessel Type	Fleet With Scrubbers	% Total Fleet No.	Of Which Fitted At	Of Which Retro-fitted	Of Which Retrofit	Orderbook No.	% Total Obk No.

	No.*		Newbuilding		Pending		
Sub-3,000 TEU	270	*9%*	123	132	15	28	*15%*
3,000-5,999 TEU	109	*10%*		94	15		
6,000-7,999 TEU	53	*20%*		52	1		
8,000-11,999 TEU	219	*35%*	6	175	38	12	*57%*
12,000-14,999 TEU	167	*62%*	20	105	42	5	*11%*
15,000+ TEU	130	*71%*	34	86	10	84	*66%*
Total	**948**	***17%***	**183**	**644**	**121**	**129**	***30%***

Source: Clarksons Research. Figures will underestimate the total; data excludes some scrubber orders still to be linked/validated to individual vessels, and there may also be reporting lags. * 'Fleet with Scrubbers' includes delivered newbuilds, completed retrofits and pending retrofits.

Table 7 SOx Scrubber Equipped Boxship Fleet (Fitted And Pending) By Size Range - m TEU

Vessel Type	Fleet With Scrubbers m TEU*	% Total Fleet TEU	Of Which Fitted At Newbuilding	Of Which Retro-fitted	Of Which Retrofit Pending	Orderbook m TEU	% Total Obk TEU
Sub-3,000 TEU	0.52	*12%*	0.24	0.26	0.03	0.06	*17%*
3,000-5,999 TEU	0.48	*10%*		0.41	0.07		
6,000-7,999 TEU	0.35	*20%*		0.35	0.01		
8,000-11,999 TEU	2.01	*35%*	0.07	1.61	0.33	0.14	*58%*
12,000-14,999 TEU	2.26	*61%*	0.27	1.43	0.56	0.07	*11%*

15,000+ TEU	2.52	*71%*	0.74	1.61	0.17	1.55	*67%*
Total	**8.15**	***34%***	**1.31**	**5.67**	**1.17**	**1.81**	***49%***

Source: Clarksons Research, (2021)

Figures will underestimate the total; data excludes some scrubber orders still to be linked/validated to individual vessels, and there may also be reporting lags. * 'Fleet with Scrubbers' includes delivered newbuilds, completed retrofits and pending retrofits.

2.2.2 Introduction of scrubbers

Scrubber is the equipment for washing SO_2 from exhaust gas stream with scrubbing water. The retrofitting of scrubbers on ships is a relatively new technology, which requires a certain installation space for ships and controllable cost. Scrubber system needs to be designed to fulfil the requirements of Class, flag, MARPOL Annex VI, Regulation 4 IMO Resolution MEPC.259 (68), Scheme B. This means that, outside ECA the ratio SO_2/CO_2 shall be no higher than 21.7, which is equal to 0.5% Fuel Oil sulfur content. During operating time in ECA the ratio SO2/CO2 shall be no higher than 4.3, which is equal to 0.1% Fuel Oil sulfur content with open loop(Li et al., 2020).

According to incomplete statistics, there are more than 200 kinds of flue gas desulfurization technologies developed and used in the world. There are three main types of current scrubber towers: Open type, closed type and composite type. The composite type desulfurization device can be switched between open-loop as well as closed-loop modes(Ji, 2020).

a) Open loop scrubber

In open-loop mode, the unit "cleans" the sulfur content of the tail gas primarily by seawater. The method is to use seawater absorb the SO_2 in the exhaust gas. The driving factor for sulphur acid neutralization, and therefore SO_2 reduction, is the alkalinity of sea water used to ‘wash’ the exhaust gases, rather than its salinity. In contrast, in closed-loop mode, the appropriate chemicals are added to achieve desulfurization. Since the closed-loop desulfurization system has to retain the waste effluent on board, it is impractical for ships sailing long distances. Open-loop scrubbers are easily accepted by the crew due to their simplicity of operation, and about 63% of ships currently choose to install open-loop scrubbers. But the sulfur emissions, while not entering the atmosphere, enter the seawater, and about 70% of the pollutants remain at sea(Doudnikoff & Lacoste, 2014).

b) Closed loop scrubber

The closed-loop desulfurization tower uses closed circulating clean water. This water will be treated with some alkaline water, such as caustic soda neutralizer. The washing water will be recycled, and the lost part will be added with new fresh water. A small amount of washing water will be sent to the sewage treatment system for treatment and then discharged into the sea. Through this system, a storage cabinet can also be designed to achieve true zero emissions.

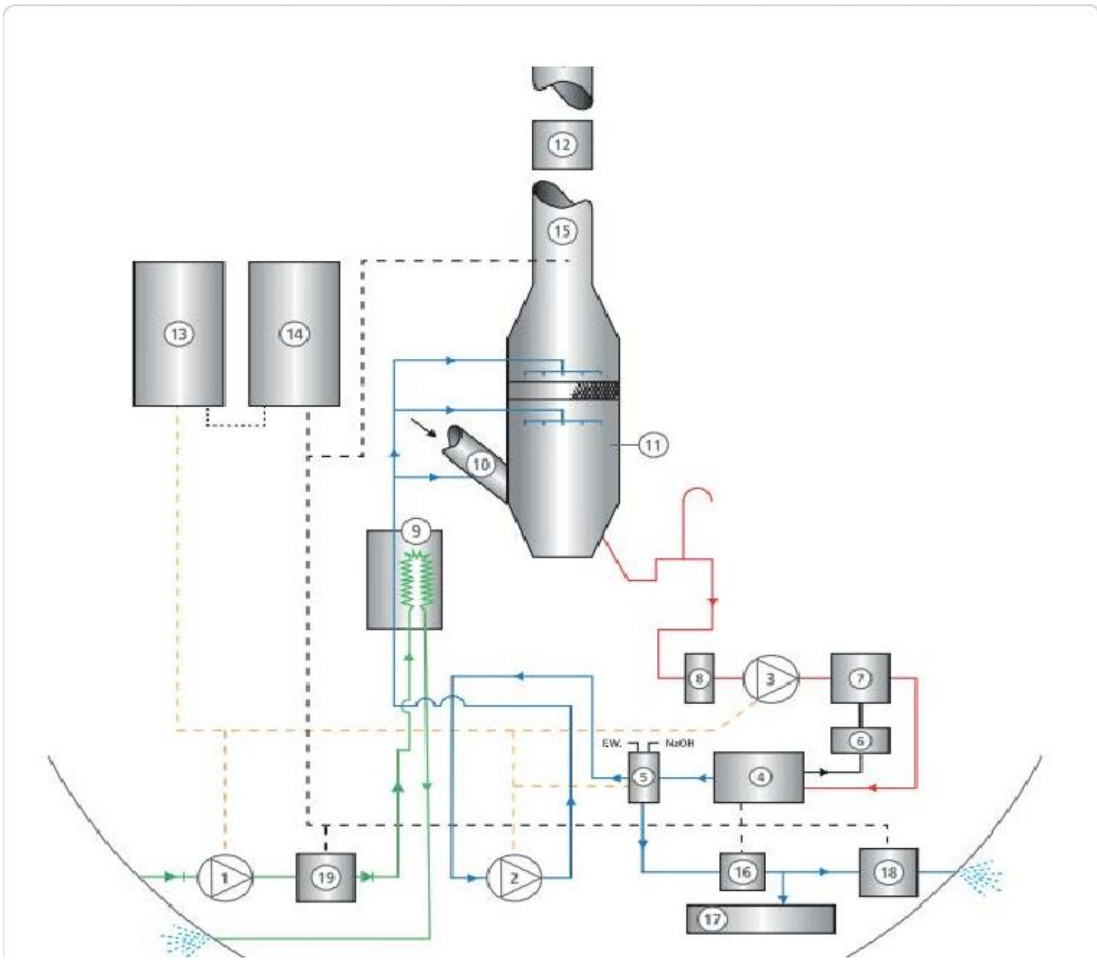


Figure 3 Closed loop scrubber

Source: Internet, (2021)

c) hybrid scrubber

The hybrid desulfurization tower, as its name suggests, is a collection of various systems. This name is defined as a system with both open loop and closed loop, which enables the operator to flexibly switch between low-concentration alkali and high-concentration alkali areas. The hybrid series also includes some other products. For example, the open-loop system adds a certain amount of caustic soda to the clean water to make the alkalinity of the discharged liquid reach a suitable level.

From the structure of the tower body, the desulfurization tower is divided into I type, U type, single inlet, multiple inlet and other designs. Each ship can choose according to the characteristics of its own ship type and fuel-consuming equipment.

Scrubbing water is sprayed towards the exhaust gas flow via spray nozzles inside the scrubber. Scrubbing water is also sprayed at the U-jet section of exhaust gas inlet(s) to decrease the temperature and reduce the particulate matter (PM) of the exhaust gas from the engine. While the temperature is lower, the velocity of exhaust gas, together with the pressure drop, will be lower, and the efficiency will be higher. Scrubbing water passes through the packed bed inside the scrubber and is eventually collected and removed through the sump at the bottom. The scrubbing water absorbs sulfur oxides (SOx), heat and other components from the exhaust gas stream. The scrubbing water will be discharged from the bottom of the scrubber to overbroad directly. Gas and water analysis equipment monitors the quality of the cleaning process. Once the system was switched on, the scrubber runs automatically. The scrubber is constantly self-adjusted to minimize energy consumption and control the process water in balance with SOx, pH, concentration of PAH and turbidity level(Bluesoul, 2019).

With increasingly stringent environmental rules, it is unknown whether sewage will be allowed to be discharged into the sea in the future. From the quotation of shipping companies and manufacturers of desulfurization devices, the cost of desulfurization devices, together with installation costs and the consumption of installation time, is high for each desulfurization device for very large container ships. For large container ships, each scrubber unit requires an investment of approximately $8 million. Installing scrubber units avoids the high cost of modifying engines and fuel supply systems. The main engines can continue to use cheap heavy fuel oil, thus avoiding all kinds of ship operation risks caused by changing low sulfur oil. Using LNG as fuel will have to bear huge retrofitting costs, while it can save ship owners a lot of money on fuel costs(Chen et al., 2019).

With the implementation of the "Sulfur Emission Control", the cost of installing scrubber equipment for 5,000 container ocean-going vessels can be recovered within two years of operation. Compared with burning low-sulfur fuel oil, the cumulative net present value after 10 years of operation will reach 168.3 million yuan(Binbin & Gang, 2019). The cost advantage is very clear. BP also said exhaust gas cleaning units are the cheapest way for large ships to meet the 2020 global 0.5% sulfur requirement(Zhu et al., 2020).

2.3.3 Controversy about open loop scrubber

Countries have been arguing about whether the washing water of the open-type desulfurization tower will pollute the marine environment. Some countries and ports have begun to restrict it for environmental protection and other purposes.

In May 2019, 28 EU countries jointly submitted a document to the IMO, stating that the use of open-loop scrubbers “may cause the deterioration of the marine environment because the discharged wastewater contains toxic substances”.

Japan's Ministry of Land, Infrastructure, Transport and Tourism (MLIT) has also carried out a similar study, and the results prove that the open-loop scrubber does not have an "unacceptable" impact on marine organic matter and seawater quality during use.

In May 2019, in response to the above discussion, IMO finally stated that it would continue to carry out environmental risk assessment of wastewater from open-type desulfurization towers. Nevertheless, for environmental protection and political purposes, many countries and regions have already determined restrictions on open desulfurization towers.

For areas where open desulfurization towers are prohibited, ships using open desulfurization towers can be switched to low-sulfur oil, while ships using hybrid desulfurization towers can be switched to closed type to deal with it. Therefore, in any case, it is necessary to reserve a certain amount of low-sulfur oil on the ship(Yue, 2017).

2.3 LNG-powered container ships

2.3.1 Current market status of LNG-powered container ships

CMA CGM Group decided in 2017 to order 9 22,000 container ships that were classified by Det France Bureau of Shipping to use liquefied natural gas LNG as engine fuel. This decision is regarded as a turning point in the industry's adoption of liquefied natural gas as a marine fuel. In the past, liquefied natural gas was considered a niche market option, most suitable for ships operating only in the field of emission control, such as ferries, offshore service vessels or tugboats. This technology is well known because all natural gas carriers have used LNG as part or most of the engine fuel for many years. But before CMA CGM made this landmark decision, no large ocean-going merchant ship operator chose natural gas LNG as its engine fuel. In addition, more than 20 cruise ships ordered in the next 10 years will use liquefied natural gas as engine fuel, a move that will improve the air quality of cruise ship destination ports. Recently, Qatar Petroleum Company disclosed plans to build more than 100 LNG ships in the next ten years, with a total value of US$20 billion. This order will increase the global LNG ship capacity by nearly 20%(Aihua, 2019).

On December 5, 2019, the media reported that the 25,000 TEU dual-fuel container ship designed by China State Shipbuilding Corporation (CSSC) obtained the AIP certificate of the classification society. The ship is 432.5 meters long, 63.6 meters wide, and has a carrying capacity of 25,600 TEUs. Equipped with 20,000 cubic meters of liquefied natural gas tanks, it can use both marine fuel oil and LNG power(Xu, 2020).

Figure 4 DNV-GL and Dalian Shipbuilding to develop 23,000 TEU LNG-fuelled container ship

Source: Onthemosway, (2021)

As can be learned from Table 8, the current fleet of LNG-powered container vessels is only 18, accounting for 0.3% of the total fleet number. The reason may be due to the current imperfection of LNG refueling facilities in ports and a large amount of time and high initial cost required for conversion to LNG. Of course, with the implementation of the 2020 sulfur restriction, it can also be seen that LNG-powered containerships account for 12% of the order book, with 12,000 teu+ vessels making up the majority of the fleet.

Table 8 LNG Fuel Capable Containerships By Size Range

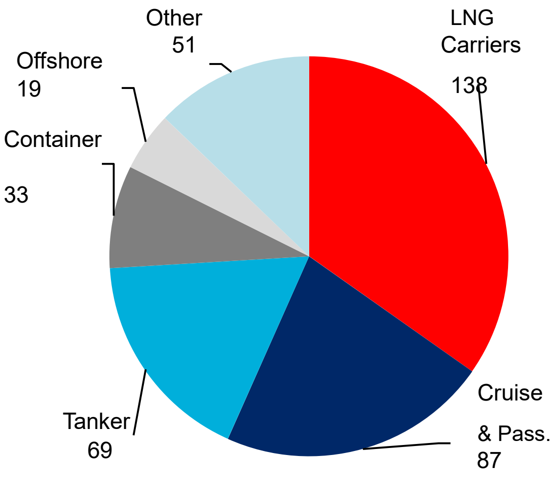
Vessel Type	Fleet No.	% Total Fleet No.	Fleet m TEU	% Total Fleet m TEU	Orderbook No.	% Total Obk No.	Orderbook m TEU	% Total Obk m TEU
Sub-3,000	7	*0.2%*	0.01	*0.20%*	4	*2.1%*	0.01	*2.2%*

TEU								
3,000-5,999 TEU	2	*0.2%*	0.01	*0.13%*				
6,000-7,999 TEU								
8,000-11,999 TEU								
12,000-14,999 TEU	3	*1.1%*	0.04	*1.21%*	17	*37.8%*	0.25	*40.7%*
15,000+ TEU	6	*3.3%*	0.14	*3.91%*	30	*23.4%*	0.53	*22.6%*
Total	**18**	***0.3%***	**0.20**	***0.83%***	**51**	***12.0%***	**0.78**	***21.3%***

Source: Clarksons Research, (2021)

From Table 9, the number of container ship with LNG power in orderbook in 2020 is 33.

Table 9 Number of vessels, as at start June ,2020



Source: Clarksons Research, (2021)

2.3.2 Introduction of LNG-powered container ships

LNG is a methane gas liquefaction. Hydrogen has the highest content per unit energy of methane. Therefore, it has low emissions of carbon dioxide, nitrogen oxides and sulfur oxides in the combustion process. Most of the exhaust gas emitted by ships is generated by the main engine and discharged into the atmosphere through exhaust gas turbochargers, exhaust gas mains and exhaust gas boilers. Alternative fuel technology refers to the technology of replacing traditional marine fuel oil with clean energy such as liquefied natural gas (LNG), biofuels, and methanol, among which LNG fuel is the most widely used. Using LNG can reduce SOx emissions by nearly 100%, while also reducing the emissions of other pollutants.

The use of LNG as an alternative offshore fuel to comply with ECA regulations is becoming more practical as research and sea trials increase and LNG-driven ships become a reality beyond the drawing board. Despite the enthusiasm shown by manufacturers and some ship owners following the successful launch of new vessels, the uncertainty associated with the use of LNG as an offshore fuel remains high. Very few vessels in the world are currently in use and only a few ports currently offer LNG as an offshore fuel, but many are planning to develop new bunkering facilities(Acciaro, 2016).

The reasons that currently limit the development of LNG as a power source are as follows:

a) High cost of installing LNG main engines

Taking Chinese inland waterway vessels as an example, inland LNG-powered vessels are mainly bulk carriers of 1000-3000 tons, sailing in the middle and lower reaches of the Yangtze River and Zhejiang water network areas. In the power conversion of LNG ships, when the price difference between diesel and LNG is RMB 2,500/ton, using LNG can save 30% of fuel cost for ship owners(Antturi et al., 2016). However, with the increase of national standards and specifications for LNG-powered vessels, the cost of retrofitting increases to at least 1 million RMB. Meanwhile, the price difference between diesel and LNG is getting smaller and the payback period is more than 8 years. In addition, there are controversies about the safety of the retrofitted ships. This will greatly discourage ship owners.

b) The size of LNG bunkers is large

The density of LNG is less than half of the heavy oil used on board, and the volume of LNG bunkers is much larger than that of fuel oil bunkers. As a flammable and explosive dangerous gas, when LNG is present in gaseous form, it must be transported in double-walled pipelines. The annular space between the double-walled pipes needs to be inerted or vented. It also allows for real-time leak monitoring, so the system is complex and the layout is difficult. Also, the installation of cylindrical LNG storage tanks results in the loss of some transport space. The premise of observing a safe distance between the safety storage tank and the transport equipment creates challenges for the inversion of the mainframe and tank(Lindstad et al., 2015).

c) Incomplete refueling facilities

The lack of LNG refueling infrastructure is one of the bottlenecks in the development of LNG-powered ships. The convenience and safety of LNG resources in transportation have been difficult to compare with oil. LNG ships are characterized by complex extraction technology, simple processing technology, high risk of transshipment and high loss. Therefore, there is an imbalance in the global distribution. This will indirectly lead to difficulties in refueling LNG-powered ships during the voyage. Data show that the average construction cost of a 30,000 square meter refueling station in China is 30 million RMB, and the high construction cost also restricts the improvement of refueling facilities. There are now 118 ports with LNG bunkering facilities, including 22 that started up in 2019, and port calls at LNG bunkering capable ports in the year to May accounted for 13.4% of the global total (up from just 4.8% in 2015). A further 45 ports are scheduled to install LNG bunkering facilities by the end 2021, though Covid-19 may lead to project delays. LNG bunkering availability varies by region, with the majority of capable ports in NW Europe and East Asia. However, there are significant developments elsewhere; in the Mediterranean, just 9 ports had active facilities by the end of 2019, but this is scheduled to expand to 20 in the coming years(Clarksons Research services, 2020).

2.4 Comparison of the three measures

From Table 10, it can be seen that all these three measures have advantages and disadvantages. The most important problem which shipowners concern is which one is the cheapest scheme.

Table 10 Comparison of three Sulphur limitation schemes

	Low-sulfur oil	Scrubber	LNG
Advantages	1)Smaller vessel modifications 2)less initial installation costs.	1)Continue to use common heavy oil 2)Cheaper	1)Environmentally-friendly, meet environmental requirements. 2)LNG is cheaper than fuel oil for the same energy.
Disadvantages	1)Low sulfur oil is more expensive than high sulfur fuel. 2)Low sulfur fuel is not viscous enough and may damage the	1)The ship structure is modified to a large extent, and the related capital investment is large. 2)Routine maintenance	1)The equipment and supporting system are expensive. 2)Large space occupied by fuel tanks. 3)Inadequate port refueling

	main engine. 3)Low sulfur oil may be in short supply and the price is not controllable.	and repair of this equipment is required, which increases the workload of the crew; routine maintenance and repair of this equipment is required. 3)The residual waste after cleaning still needs to be disposed of and requires certain maintenance cost.	facilities. 4)Insufficient range during ocean voyage. 5)Safety is controversial.

CHAPTER 3. ECONOMIC ANALYSIS ON THREE MEASURES

3.1 Basic assumptions

1) The ship is sailing at uniform speed whether inside or outside the eca.
2) The price of fuel oil and LNG does not fluctuate with the market and is calculated at the current market price.
3) There are no subsidy measures to support.
4) Consumption of light oil in port is minimal and negligible.
5) Discount rate is based on 10%.

3.2 Model Construction

$$NPV=\sum(CI_i-CO_i)(1+r)^{\wedge}(-t) \tag{1}$$

With:

NPV is Net Present Value, which is investment income analysis, reflecting the profitability of project investment.

CI_i is the cash inflow of type i.

CO_i is the cash outflow of type i.

r is discount rate which is set to be 10%.

The time that a vessel is sailing in ECA zones is determined by the speed of the vessel and by the distance sailing in the ECA zones. The fuel consumption of the vessel, using different measures to mitigate the ECA regulations is then determined by the following formula.

$$FC_{Voyage;i} = FC_{ECA,i}+FC_{NONECA,i} \tag{2}$$

In which $FC_{Voyage,i}$ is the fuel cost for a voyage for vessel type i, while $FC_{ECA,i}$ is the fuel costs for a voyage in ECA zones. $FC_{NONECA,i}$ is the fuel costs for a voyage in non-ECA zones.

$$CI_i = FC_{Voyage;i} + C_{other,i} \tag{3}$$

$$CO_i = C_{freight} * k_i \tag{4}$$

$$FC_{ECA,i}= (D_{ECA} / V_{Speed,i})*C_{i,j}* V_{Speed,i}^3*PF_j * \Delta_i^{2/3} /(W_i *C_{admin,i}) \tag{5}$$

With:

D_{ECA}= the distance sailed in the ECA zones (nm).

$V_{Speed,i}$ = the speed of vessel type i.

Ci,j = the specific fuel consumption of the considered engine type or installation j (LNG, MDO or scrubbers) for vessel type i (tonnes/h). The deltas represent the displacement of the vessel, both for the payload and for the lightweight and are both expressed in cubic meters.

k_i is the loading factor of vessel type i.

PFj = the fuel price per ton for fuel type j (HFO, MDO or LNG).

Δ_i = the displacement of the vessel, both for the payload and for the lightweight and are both expressed in cubic meters.

W_i = the installed engine power in kW

$C_{admin,i}$ = the admiralty constant of vessel type i (kW/(kn^3.tonne$^{2/3}$)) (Mohseni et al., 2019).

With the formula above, the model needs some data to be able to quantify the fuel consumption. In order to calculate the fuel consumption of each vessel type, Table 11 is used to consider the fuel consumption of HFO, LNG, and MGO.

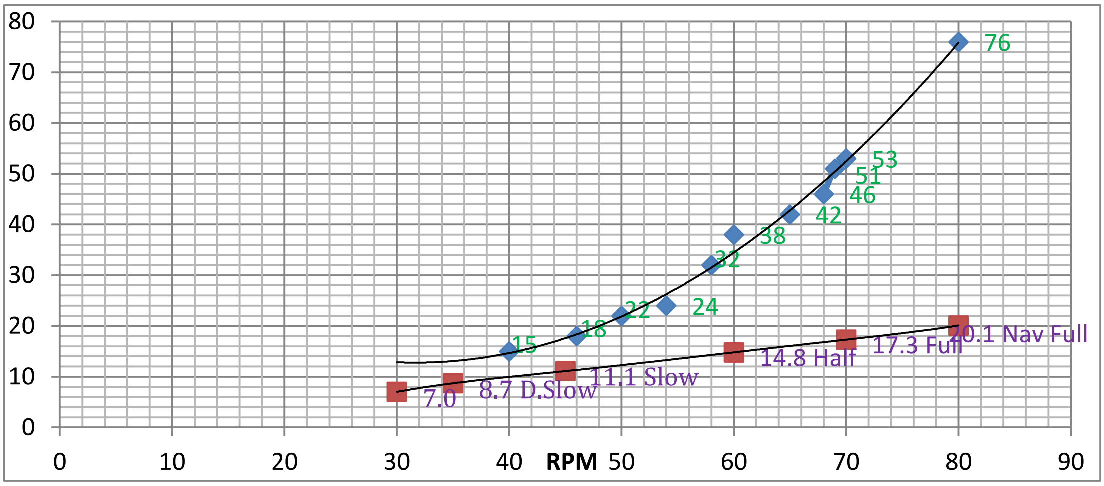
Table 11 Specific fuel oil consumption

Specific fuel oil consumption (typical for 52 MW engine)	
Type of fuel	Fuel consumption (kg/KWh)
HFO	0.18
MGO	0.18
LNG	0.13
Pilot fuel	0.02

Source:(Mohseni et al., 2019)

The relationship between ship speed and fuel consumption will be approximated based on the data in Table 12.

Table 12 Speed/ Fuel oil consumption



Source: Draw based on the data from Di, (2021)

3.3 Example analysis

Taking a 13,208 TEU container ship sailing between Far East and Europe as a case study, three kinds of measures to sulfur control are calculated separately.

The fuel price can be acquired from Table 13.

Table 13 Far East and South Pacific Bunker Fuel Price

COMMODITY	PRICE	CHANGE	UNIT	UPDATED
SINGAPORE				
IFO 180	540.68	12.4(2.35%)	$US/MT	10-Mar-21
IFO 380	411	-10(-2.38%)	$US/MT	18-Jun-21
LSMGO 0.1%	586	-8(-1.35%)	$US/MT	18-Jun-21
MGO	526	-48.5(-8.44%)	$US/MT	27-Apr-21
MGO 0.1%	546.5	-9.5(-1.71%)	$US/MT	17-Mar-21
VLSFO 0.5%	529	-13(-2.4%)	$US/MT	18-Jun-21
VLSFO max				17-Feb-21
0.5%	517	8(1.57%)	$US/MT	

Source: From *Oil Monster*, (2021)

3.3.1 NPV of vessel type with scrubber

The average investment cost depends on the type and size of the ship. It is estimated that the service life of the ships under the three schemes is 10 years. Because of the high cost of counterfeiting of LNG container ships, it is estimated that the service life of LNG container ships is 27 years. For LNG ships, the annual investment cost is determined by dividing the average investment cost by the total life (27 years). The longer the ship has been operating in the emission control area, the shorter the payback period of the desulfurization tower investment, and the more it is necessary for the ship to install it. For the scrubber technology, the annual investment cost is calculated by dividing the average investment cost by 10 years. As shown in Table 14, for a vessel of 13,208 TEU, the cost of installing a scrubber is $3,568,710 and the cost of using LNG is $22,601,830.

Table 14 Investment cost for LNG propulsion and scrubber system of ship types

Vessel Size, TEU	Average investment, $		Investment cost, $ per year	
	LNG	Scrubber	LNG	Scrubber
5466	17,843,550	2,973,925	660,872	297,392
9115	20,222,690	2,973,925	748,988	297,392
13,208	22,601,830	3,568,710	837,105	356,871
18,800	23,791,400	3,568,710	881,163	356,871

Source: Own composition based on Fan et al., (2020)

In addition to the adjustment of fuel costs, it is expected that the operating costs of container ships will also have some cost impact. These operating costs include crew costs, repair costs, maintenance costs, and insurance costs. These costs are given in Table 15. According to Mandiesel and Turbo (2011), the usage of LNG as fuel increases crew costs, maintenance and repair costs by 10% compared to using MDO or HFO. At the same time, by applying the scrubber scenario, crew costs, maintenance and repair costs will increase by 20%.

From Table 15, the general data can be acquired. The max engine power and the fuel consumption can be got from Table 16. The information about the auxiliary engine can be acquired from Table 17.

Table 15 General data of the vessel with scrubber

Project	Data
Vessel Type	13,208 TEU
IMO Number	XXXXX
Flag state	Hong Kong
Classification society	ABS

Retrofit/New Building	Retrofit
Scrubber type	U-tpye
Operation mode	OPEN LOOP

Source: Bluesoul, (2019)

Table 16 Main engine data of the vessel with scrubber

Technical data	**M/E**
Engine type	MAN B&W 12S90ME-C9.2
Quantity	1
Max engine power (MW)	54
Max exhaust gas flow (kg/h)	522,149
Fuel cons. (kg/MWh)	166.27
Exhaust gas Temp. (℃)	380
Design load (%)	80%

Source: Bluesoul, (2019)

Table 17 Auxiliary engines data of the vessel with scrubber

Technical data	**A/E**
Engine type	Daihatsu 8DC-32e
Quantity	4
Max engine power (MW)	3.65
Max exhaust gas flow (kg/h)	30,435
Fuel cons. (kg/MWh)	207.5

Source: Bluesoul, (2019)

The data of the cash flow is from Clarkson Research. Based on the formula in the model and the data in the calculation example, the opportunity cost is calculated as 10%. Enter the expected ten-year data in the excel software and the NPV results are shown in Table 18.

Table 18 NPV of vessel type with scrubber

Year	Cash outflow, $	Cash flow, $	NPV
0	-3,568,710		
1	-2567631	9520000	$2,751,625.45
2	-2567631	9520000	$8,497,384.96
3	-2567631	9520000	$13,720,802.69
4	-2567631	9520000	$18,469,364.26
5	-2567631	9520000	$22,786,238.42
6	-2567631	9520000	$26,710,669.47
7	-2567631	9520000	$30,278,334.07
8	-2567631	9520000	$33,521,665.52
9	-2567631	9520000	$36,470,148.65
10	-2567631	9520000	$39,150,587.86

Source: my own calculation based on the data above.

3.3.2 NPV of vessel type with low sulfur oil

The information another container vessel of 13,208 TEU is in Table 19.

Table 19 MONITORING - EEOI (Energy Efficiency Operational Indicator)

Port						**Fuel oil consumption**	
Leg	**Speed (Knot)**	**Cargo Weight (mt)**	**% DWT summer**	**No. of Reefer at Departure (unit)**	**Distance (Nm)**	**LSFO (mt)**	**MDO/MGO (mt)**
GDN	65.2					0	29.7
GDN-ZEE	11.15	113,868	60%	312	1,071	0	180.2
ZEE	26.8					0	21.6

ZEE-FXT	9.02	140,922	74%	364	61	0	9.0
FXT	118.8					0	63.7
FXT-WHV	18	101,000	53%	263	277	0	66.8
WHV	39.3					0	32.3
WHV-PIR	16.7	119,495	62%	387	3,116	532.4	145.5
PIR	40					2.8	20.6
PIR-SUZ	14.6	154,119	81%	333	590	101.28	0.1
SUZ	20.8					26.08	3.0
SUZ-SIN	17.78	154,119	81%	333	4,969	1194.8	0.2
SIN	41.6					17.52	0.7
SIN-YTN	17.16	135,430	71%	199	1,457	349.68	0.0
YTN	36.5					15.6	5.6
YTN-SHA	13.98	93,562	49%	94	762	158.96	0.0

Source: talk with a captain from a famous company.

Based on the formula in the model and the data in the calculation example, the opportunity cost is calculated as 10%. Enter the expected ten-year data in the excel software and the NPV results are shown in Table 20.

The initial investment of modifying the vessel to use low sulfur oil is distinctly lower than to use scrubber. Meanwhile, for comparing the long time installing scrubber and using low sulfur oil, the cash flow of using low sulfur oil is larger than installing scrubber in the first year.

Table 20 NPV of vessel type with low sulfur oil

Year	Cash outflow	Cash flow	NPV
0	-568,710		
1	-8002887	11760000	$2,846,847.27
2	-8002887	9996000	$4,494,048.10
3	-8002887	9996000	$5,991,503.40
4	-8002887	9996000	$7,352,826.39

5	-8002887	9996000	$8,590,392.75
6	-8002887	9996000	$9,715,453.08
7	-8002887	9996000	$10,738,235.20
8	-8002887	9996000	$11,668,037.12
9	-8002887	9996000	$12,513,311.60
10	-8002887	9996000	$13,281,742.94

Source: my own calculation based on the data above.

3.3.3 NPV of vessel type with LNG

Table 21 NPV of vessel type with LNG

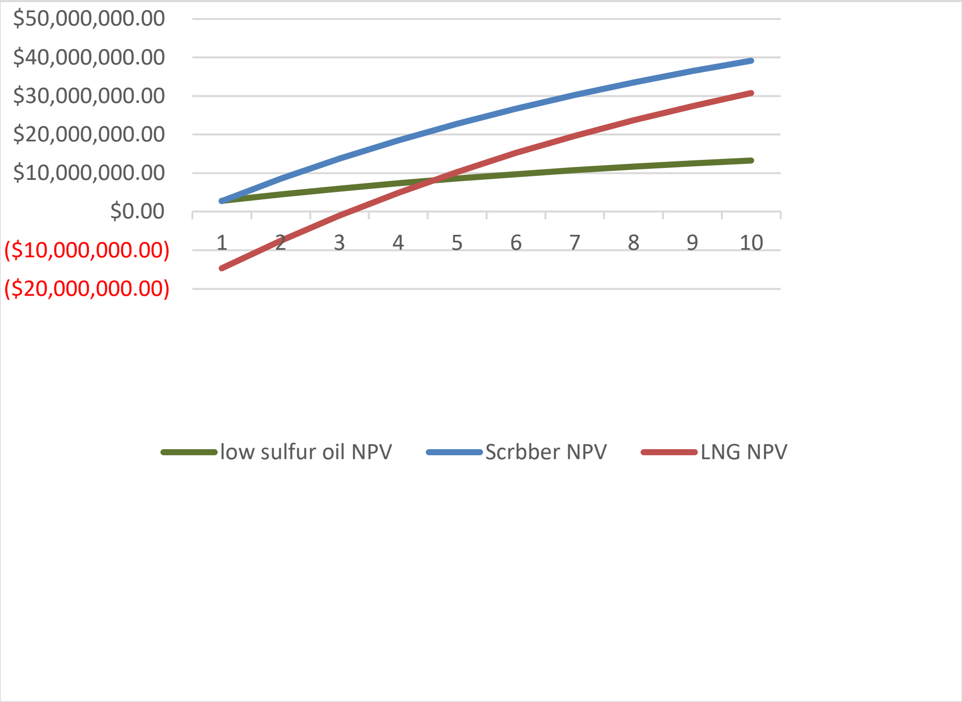
Year	Cash outflow	Cash flow	NPV
0	-22,601,830		
1	-837,105	9520000	-$14,708,289.09
2	-837,105	9520000	-$7,532,342.81
3	-837,105	9520000	-$1,008,755.28
4	-837,105	9520000	$4,921,778.83
5	-837,105	9520000	$10,313,173.49
6	-837,105	9520000	$15,214,441.35
7	-837,105	9520000	$19,670,139.41
8	-837,105	9520000	$23,720,774.01
9	-837,105	9520000	$27,403,169.10
10	-837,105	9520000	$30,750,801.00

Source: my own calculation based on the data above.

3.3.3 Calculation results

Based on the above data analysis, the economic analysis of the investment that shipowners can make under the three measures under the sulfur limit order is as follows:

Table 22 The NPV of three measures in 10 years



In the current market, for a 13,208 TEU container ship, the expected return for the first year of the measure is close between the installation of a scrubber and the change to low sulfur oil, but as the year progresses, the installation of a scrubber is the better choice according to the calculations of this model. This is because the installation of a scrubber takes some time, so it is more efficient to replace it with low sulfur oil if the benefits are to be seen in the short term. After the scrubber is installed, HSFO can continue to use. The difference in oil prices between MGO and HSFO in the current market dictates that if the price difference remains the same for the next ten years, then a scrubber is the better choice. For LNG vessels, LNG-powered container ships are not as attractive as the other two options under this modeling algorithm due to the expensive initial investment and the fact that the tonnage used in the example is not the prevailing tonnage for LNG installations.

CHAPTER 4. SENSITIVITY ANALYSIS ON THREE MEASURES

4.1 Result Analysis

The above results are obtained under the current economic environment, and the service life of ships is as high as 20 to 30 years. In these years, unstable factors such as energy prices and equipment price changes will cause fluctuations in related costs.

The most important factor in this model is the price of the fuel oil. For the same scenario and speed change, the calculation is repeated by changing the fuel prices of MGO and LNG. The goal is to figure out how changes in fuel prices affect the shipping market.

4.2 Adjust the fuel price difference

Table 23 NPV of measure to using low sulfur oil when narrow the spread of MGO and HSFO

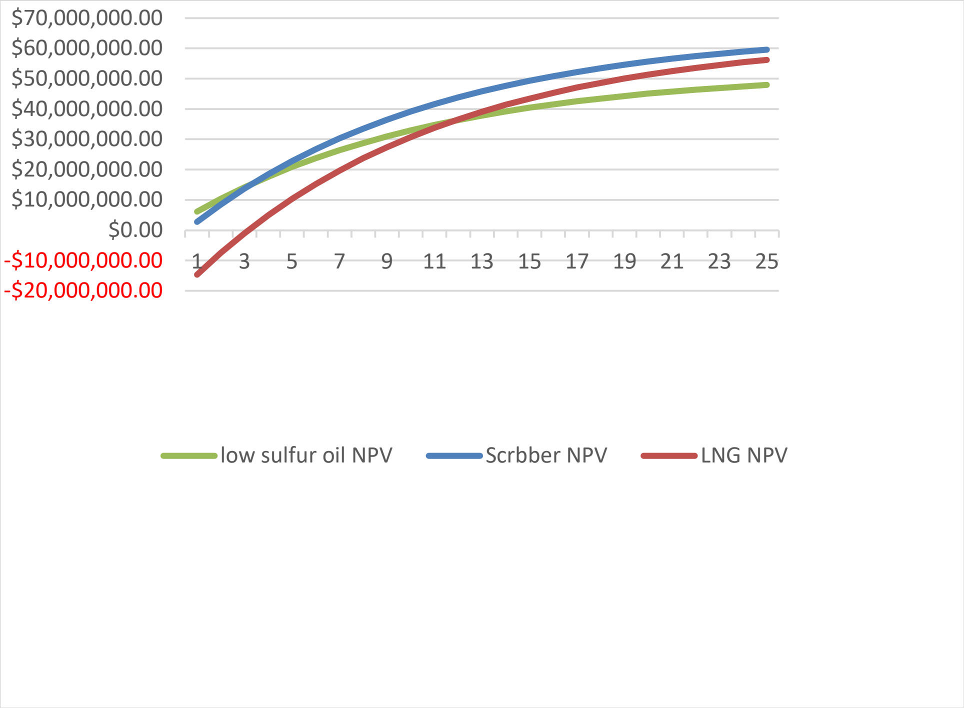
Year	Cash outflow	Cash flow	NPV
0	-568,710		
1	-4,401,588	9520000	$6,120,755.59
2	-4,401,588	9520000	$10,350,848.28
3	-4,401,588	9520000	$14,196,387.08
4	-4,401,588	9520000	$17,692,331.45
5	-4,401,588	9520000	$20,870,462.69
6	-4,401,588	9520000	$23,759,672.92
7	-4,401,588	9520000	$26,386,227.66
8	-4,401,588	9520000	$28,774,004.71
9	-4,401,588	9520000	$30,944,711.11
10	-4,401,588	9520000	$32,918,080.57

Source: my own calculation based on the data above.

Regarding the installation of desulfurization towers and the use of low-sulfur fuels, according to BIMCO, despite the price fluctuations in 2020, the difference in average annual oil prices will be approximately US$100 per ton. Based on the HSFO oil price, the difference between HSFO and MGO oil prices was adjusted. It was found in Table 23 that when the oil price difference was about 20% of the original price, the two options of installing a desulfurization tower and using low-sulfur oil were more comparable.

4.3 Extend the service life of the ship

Table 24 NPV of measure to using low sulfur oil when extend the service life of the ship



From Table 24, it can be learned that when extend the service life of the ship from 10 years to 25 years, measure to use low sulfur oil is not as attractive as the other two measures. Meanwhile, measure to install scrubber still is the best choice in long term.

CHAPTER 5. CONCLUSIONS

The application of NPV in shipping field seems very promising. In more advanced applications, these models can take into account the uncertainties associated with the shipping operating environment and allow for the inclusion of complex options.

The development of environmental regulations may increase the complexity of investment decisions that shipowners must make. On the one hand, many measures that can be used for ECA compliance have the potential to improve the energy efficiency of ships, but on the other hand, there are still various uncertainties in the availability, reliability and cost related to such measures. Increasing environmental regulation. The rigor and the uncertainties associated with certain technological alternatives require the development of investment assessment tools and decision support models to take into account the flexibility and diversity of strategic options available to shipowners.

Comparing the equal annual costs of the three measures, measure of installing scrubber in container ship for shipowners is the better plan. Comparing the NPV of installing scrubber and using LNG, installing scrubber can be the faster recovery of funds shows that under the current market environment, installing scrubber can be adopted to cope with the sulfur limit order and quickly recover funds. Through sensitivity analysis, in the long run, as the demand for oil and gas and other energy sources in various industries increases and oil and gas prices rise at the same time, the using of LNG power is less expensive for liner companies to operate, and LNG-powered ships are more environmentally friendly.

This thesis only evaluates these three schemes by calculating the NPV value, and in the actual investment process, the choice of these three schemes is interfered by many factors. In an ideal environment, whether it is to adjust the fuel price difference or to extend the service life, on the basis of the model constructed in this article, installing a scrubber is the long-term best choice for a 13,208TEU container ship.

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