Complying with the 2020 global sulphur limit

A cost comparison between scrubber systems and fuel-switching

Bachelor Thesis

GEORG FREDRIKSSON
JOEL WIBERG

Department of Mechanics and Maritime Sciences
Chalmers University of Technology
Gothenburg, Sweden, 2018

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Chalmers University of Technology
SE-412 96 Gothenburg
Sweden

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JOEL WIBERG
GEORG FREDRIKSSON
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Abstract

International Maritime Organization (IMO) has decided that the global sulphur limit in ship emissions shall be decreased from 3.5% to 0.5% in year 2020. This is a major change for the shipping industry which can have a large economic impact. There are numerous different compliance methods that ship owners can invest in before and after 2020. Two of these compliance methods are scrubber systems and fuel-switching operation. Scrubber systems allow ships to continue operating on HFO (heavy fuel oil, 3.5% sulphur) which is a relatively cheap bunker fuel. Fuel-switching is when ships switch between operating on ULSFO (Ultra low-sulphur fuel oil, 0.5% sulphur) and MGO (Marine Gas Oil, 0.1% sulphur). HFO is cheaper than MGO and ULSFO which makes operative costs lower, but the installation of scrubber systems is associated with a higher capital cost.

Ship owners must decide what type of compliance method their vessels will use after 2020. This thesis presents total lifespan costs for scrubber systems and fuel-switching systems on two types of newbuilt vessels after 2020. This thesis also presents break-even number of years for the scrubber, compared to the fuel-switchning compliance method.

The results indicate that the scrubber option is always cheaper for a specific container vessel and a tanker vessel after a 15-year lifespan. The break-even point is reached around 3-5 years for both vessels.

Key words: SECA, Sulphur, LNG, Methanol, Emissions, Scrubber, Fuel-switching

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Sammanfattning

International Maritime Organization (IMO) har fastställt att 2020 ska alla fartyg under IMO:s regulationer drivas av bränslen med en maximal svavelhalt på 0,5% globalt. Den nuvarande svavelgränsen är 3,5% globalt, vilket innebär reducering av tre procentenheter. Detta är en stor förändring som kan medföra en stor ekonomisk påverkan på sjöfartsbranschen. Det finns ett antal olika metoder för fartyg att uppfylla de nya kraven. Två av dessa metoder är skrubbersystem och dubbla bränslesystem. Skrubbersystem tillåter fortsatt användning av HFO (heavy fuel oil) som innehåller 3,5% svavel och är ett billigt bränsle på marknaden. Dubbla bränslesystem innebär skiftning mellan drift på ULSFO (Ultra low-sulphur fuel oil, 0,5% svavelhalt) och MGO (Marine gas oil, 0,1% svavelhalt) som är dyrare än HFO.

Detta examensarbete presenterar de ekonomiska skillnaderna mellan att driva fartyg på skrubbersystem eller dubbla bränslesystem för nybyggda fartyg med en 15 års livslängd. Detta görs genom totala kostnadsberäkningar för de två olika metoderna för två olika fartygstyper. Avhandlingen redovisar också break-even beräkningar som visar vilket år ett alternativ blir billigare än det andra.

Resultaten visar att skrubbersystem är billigare än dubbla bränslesystem efter en 15 års period. Enligt beräkningarna så kan skrubbersystem vara upp till 142% billigare än dubbla bränslesystem för containerfartyg. För tankfartyg så kan skrubbersysten vara 94% billigare än dubbla bränslesystem. Break-even punkten sker efter 3 - 5 år för båda fartygstyperna.

Nyckelord: SECA, Sulphur, LNG, Methanol, Emissions, Scrubber, Fuel-switching

List of abbreviations

ECA – Emission Control Area
FOC – Flags of Convenience
HFO – Heavy Fuel Oil
IMO – International Maritime Organization
LNG – Liquefied Natural Gas
MARPOL – International Convention for the Prevention of Pollution from Ships
MDO – Marine Diesel Oil
MGO – Marine Gas Oil
NM – Nautical Mile
NOx – Nitrogen Oxides
ODS – Ozone Depleting Substances
PM – Particulate Matter
SECA – Sulphur Emission Control Area
SOx – Sulphur Oxides
ULSFO – Ultra-low Sulphur Fuel Oil
VOC – Volatile Organic Compounds

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Georg Fredriksson
Joel Wiberg
Gothenburg, February 2018

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1 Introduction

The emissions of sulphur from vessels has been an issue since vessels started to operate on fuel oils in the early 20th century. It is estimated that in the present day, the shipping industry is responsible for 5-10% of the total sulphur emissions from non-natural sources (OECD, 2016).

The International Maritime Organization (IMO) has reduced the global sulphur limit in marine fuel that enters into force 1st January 2020. The reduced global limit will decrease the amount of sulphur from 3.5% to 0.5% in marine fuel used by all ships regulated by IMO globally. This could impact the world economy as a result of increased fuel prices, increased transport costs and higher product prices for consumers. Experts in the field of maritime economics and industry leaders believe that the new global sulphur limit will increase costs for shipping companies by up to 60 billion USD annually (Wood Mackenzie, 2017).

To comply with the 0.5% global sulphur limit, shipping companies will have to invest in a compliance method that is the less economically damaging for their vessels. This thesis aims at presenting a theoretical background to the sulphur limit regulations and at comparing the total costs for two compliance methods: scrubber systems and fuel-switching.

1.1 Aims and goals

This work will consist of two parts; a literature review part that will gather findings from other scientific research and a cost calculation part for two compliance methods. The literature review will also identify the possible difficulties for the shipping business to adjust and prepare for the new maritime economic ecosystem.

1.2 Research questions

- What are the contributing factors to the economic aspect of the 2020 global sulphur limit?
- How are environmental regulations created and what challenges do they meet?
- What are the compliance options for a vessel that trades internationally and what are their total lifespan costs? This will be exemplified by making total lifespan cost calculations and breakeven point calculations for scrubber systems and fuel-switching.

1.3 Limitations

1.3.1 Literature review

The literature review part of this thesis will not specifically target health, environmental or social aspects of the 2020 global sulphur limit, even though these constitute the reason behind the new regulations.

1.3.2 Economic projections

A substantial contributing factor to the economic aspect of the 2020 global sulphur limit is fuel prices and what fuel type will be the most used in different compliance options. The authors of this review will make assumptions on fuel prices**,** though it is recognized that prices are dependent on a myriad of both internal and external factors to shipping that are out of the scope of the current analysis.

2 Background and Theory

2.1 Environmental and health effects caused by sulphur emissions

The emissions of sulphur from vessels is a global issue that affects plants, animals and water bodies. Sulphur emissions are a product of the fuel combustion process in vessels that operate on high sulphur fuel oils. Sulphur is a component in crude oil, and when the oil is heated the sulphur reacts with the oxygen from the atmosphere and creates the derivate sulphur dioxide.

2.1.1 Acid rain

Acid rain is a broad term that describes the event when acid falls out from the atmosphere through precipitation. The atmosphere becomes acidic when sulphur dioxide from emissions interact with reactants present in the atmosphere. Acid rain causes the acidification of soil and water bodies. The acidification of soil has large impacts on ecological systems because soil contains nutrients for plants. When soil becomes acidified, the acid leaches nutrients and the fertility of the soil is heavily decreased. The decreased fertility in the soil leads to a decreased growth of plants and trees which has a negative impact on agriculture (Singh, 2006).

The acidification of water bodies has several detrimental effects on aquatic ecological systems. An increase of pH levels in water affects living organisms that are pH sensitive and can lead to either an increase or a decrease of aquatic organisms in an area. The acidification of water also leads to a higher mortality rate and decreased reproduction of fish in lakes and rivers (Singh, 2006).

Acid rain also causes damage to buildings and structures made of marble, limestone and carbonate compositions. The structures erode and becomes disfigured which requires maintenance. In 1981 the maintenance cost was estimated to be 2-10 USD for each person living in Europe. Acid rain also damages cultural artefacts such as paintings, libraries, religious houses, statues and other cultural treasures (Singh, 2006).

2.1.2 Effects on human health

The emission of sulphur oxides has been proven to cause damage to human health. It causes diseases such as chronic obstructive pulmonary disease, heart failure and bronchitis. Sulphur emissions has also been proven to be connected to early deaths. The numbers of early deaths per year has been estimated to be up to 60.000 globally and is predominantly enhanced in large port cities with a high concentration of vessels (Corbett, et al., 2007).

2.2 Environmental Regulations

Environment regulations are legislated by IMO (International Maritime Organization). The IMO is the regulatory agency for the maritime sector. The UN (The United Nations) describes IMO`s global mandate as "safe, secure and efficient shipping on clean oceans" (UN-business, 2018).

2.2.1 The structure of IMO

2.2.1.1 Flag states and legislative procedures

IMO describes their organizational structure on their official website as following:

"*IMO currently has 172 member states and three Associate members. The Organization consists of an Assembly, a Council and five main Committees: The Maritime safety committee,* ***the Marine Environmental committee*** [emphasis added]**,** *the Legal committee, the Technical cooperation committee and the Facilitation committee*".
(International Maritime Organization, 2018)

2.2.1.1.1 The Assembly

The IMO Assembly consists of all the member States in the organization. It is the main body of the organization and holds the most power in decision making processes. It's the Assembly that elects new organs of IMO, controls the budget and control the overall activities of the IMO. The Assembly take advice from sub-organs of the organization in their decision making. The Assembly also elects the Council. The assembly meets once every two years to discuss and elect new organs such as the Council (International Maritime Organization, 2018).

2.2.1.1.2 The Council

The council is the executive organ of IMO. The council is elected once every two years by the Assembly. The Assembly makes decisions that the Council actualize between Assembly sessions. The Council consists of 40 flag states which are divided in three categories:

a) 10 states with the largest interest in providing international shipping services: China, Greece, Italy, Japan, Panama, Norway, Republic of Korea, Russian Federation, United Kingdom, United states.
b) 10 states with the largest interest in international seaborn trade: Australia, Brazil, Canada, France, Germany, India, Netherlands, Spain, Sweden, United Arab Emirates.
c) 20 states not elected under (a) or (b) above, which have special interests in maritime transport or navigation and whose election to the Council will ensure the representation of all major geographic areas of the world: Bahamas, Belgium, Chile, Cyprus, Denmark, Egypt, Indonesia, Jamaica, Kenya, Liberia, Malaysia, Malta, Mexico, Morocco, Peru, Philippines, Singapore, South Africa, Thailand, Turkey.

(International Maritime Organization, 2018)

Some States have a higher interest in certain areas of the shipping business because their economy and ecology are dependent on shipping. For example; Panama, Liberia and Marshall

Islands account for 40% of the world fleet. Even though they are small countries relative to other flag States, they have a larger interest in the shipping business. These States are also examples of FOC States (Flag of convenience States). FOC has been defined as:

"*Flag of any country allowing the registration of foreign-owned and foreign-controlled vessels under conditions which, for whatever the reasons, are convenient and opportune for the persons who are registering the vessels. Under international law, an owner has full liberty to choose the flag for his or her ship. Consequently, every State has the right to set its own regulation and standards for registration of ships*."
(Karim, 2015)

The majority of large shipowners in the world has vessels flagged in a FOC State. This complicates law-making processes since FOC States might not share the same interest as more developed countries in matters such as environmental regulations. The fact that FOC States are representing shipowners and shipping companies could mean that decisions are solely made with economic motivations (International Maritime Organization, 2018).

2.2.2 The Regulatory process

The six main bodies of IMO that are involved in adopting new convention are the Assembly the Council, the Maritime Safety committee, the Marine Environmental Protection committee, the Legal committee and the Facilitation Committee. Developments in the shipping industry are discussed by members in these six bodies and any member can make suggestions of new amendments to existing conventions or present new possible conventions (Karim, 2015).

The first step in legislating a new convention is to get it approved by the six main bodies of IMO. After the convention is adopted it must be accepted formally by governments before it can entry into force. In many cases, governments sign a Treaty as "subject to ratification, acceptance and approval". This means that the government accepts the convention, but it does not signify the consent of the State to be bound by the rules applied by the convention. It does, however, oblige the State to refrain from committing actions that defeat the purpose of the convention in question (Karim, 2015).

Ratification is defined as the act when a State indicates that they consent to being bound by a Treaty if the required amount of ratifying States is met. The required amount of ratifying States is stated in the drafted convention. For example, in Article 18 of the "International Convention for the Control and Management of Ship´s Ballast Water and Sediments" following is stated:

"*Entry into force: This Convention shall enter into force twelve months after the date on which not less than thirty States, the combined merchant fleets of which constitute not less than thirty-five percent of the gross tonnage of the world's merchant shipping, have either signed it without reservation as to ratification, acceptance or approval, or have deposited the requisite instrument of ratification, acceptance, approval or accession in accordance with Article 17."*
(International Maritime Organization, 2004)

Article 18 states specifically that it requires the signing of States that constitute not less than 35% of the world's combined fleet size in total gross tonnage, without reservation to ratification, before the convention can enter into force. This is problematic when the flag states that represent a majority of the world's fleet size are FOC States. The top three flag states of 2017 in total gross tonnage size were Panama, Liberia and Marshall Island with a combined size of 41.85% (United Nations Conference on Trade and Development, 2017). As stated in chapter 2.2.1.1.2 in this thesis, FOC States often represent shipping companies and shipowners' interests in matters and not the States themselves. The fact that an environmental regulation convention requires signings from States, that are representing companies with economic motivations, is a challenge that makes IMO´s regulatory processes long and complicated (Karim, 2015).

2.2.3 MARPOL 73/78

The environmental regulations of the world maritime trade industry are legislated by IMO (International Maritime Organization). The most important environmental convention is MARPOL 73/78 (Marine pollution and the years 1973/1978) and it regulates marine pollution for all ships flagged in flag states that are accepted by the IMO. MARPOL Annex I came into force on 2 October 1983 as a reaction to the Torrey Canyon accident that created a large oil spill on south-west coast of England 1967. The first annex regulated discharge of oil into the ocean. Presently there are seven annexes that regulates air pollution, packing/marking, sewage disposal, garbage disposal, pollution of noxious liquid substances in large quantities and ballast water management (IMO, 2018).

2.2.3.1 MARPOL Annex VI: Emission control areas

In 1997, IMO added Annex VI to the MARPOL convention. The Annex regulates the air pollution related to SOx (i.e. sulphur oxides), NOx, ODS and VOC (i.e. nitrogen oxides, ozone-depleting substances and volatile organic compounds) emissions from ships (Table 1). The Annex established ECAs (Emission Control Areas) and the first area was the Baltic sea with a sulphur limit of 1.5 %. The second area, the North Sea, was added in 2005. Since 2011 there are in total five ECAs including the North Sea, Baltic Sea, North American coast, Canadian coast and the US Caribbean (IMO, 2018).

Table 1, Sulphur limits

	Sulphur limits in fuel (% m/m)	
Year	SOx ECA	Global
2005	1.5 %	4.5 %
2010	1.0 %	
2012		3.5 %
2015	0.1 %	
2020		0.5 %

Source: (International Maritime Organization, 2018)

2.3 Compliance methods

There are numerous different compliance methods for vessels to meet the 2020 global sulphur limit. Vessels can have a scrubber system installed, a fuel-switching method can be used (switch between 0.5% and 0.1% sulphur fuels when operating in both ECA and non-ECA regions) or they can operate on a different fuel type such as LNG or Methanol.

When a shipping company decides which alternative is economically the best for their operating vessels, there are several factors that impact their decision making, for example: vessel size, lifespan of vessel, trading areas, bunker fuel prices and freight rates. Presently the most common compliance method to meet the sulphur regulations is fuel-switching and scrubber systems (IMO, 2017). The use of LNG (Liquefied Natural Gas) is starting to become more popular, but the yet deficient infrastructure makes shipowners and refineries hesitant to invest in the alternative fuel system for their vessels (Notteboom & Wang, 2014).

2.3.1 Fuel-switching

The most common ECA compliance method today is the use of fuel-switching. Fuel-switching is when a vessel operates on a high-sulphur grade fuel outside of ECAs and then switches to a low-sulphur grade fuel when they enter an ECA. Because fuel with a high-sulphur grade is cheaper than the low-sulphur alternative, vessels have made it standard practice to operate outside ECA for as much as possible before entering an ECA. After 2020, the global sulphur limit will be 0.5% and the ECA limits will remain at 0.1%. The replacement fuel for meeting the 0.5% sulphur limit will be ULSFO (Ultra low-sulphur fuel oil) which may have a limited supply after 2020 since not all refineries are equipped with de-sulphurisation capabilities (DNV GL - Maritime, 2016).

2.3.1.1 Costs of Fuel-switching

Before 2020, vessels that operate on fuel-switching use HFO (Heavy Fuel Oil, 3.5% sulphur) outside of ECAs and MGO (Marine Gas Oil, 0.1% sulphur) inside of ECAs. HFO has presently an average price of 400 USD/mt (Global 20 ports average, 2018-02-06, (Ship & Bunker, 2018). MGO has presently an average price of 655 USD/mt (Global 20 ports average, 2018-02-06, (Ship & Bunker, 2018). ULSFO will be a blend between low-sulphur fuel oils and distillates that differs between oil companies. The price is difficult to predict, but it will likely be cheaper than MGO and more expensive than HFO.

2.3.2 Scrubber systems

A scrubber system is an exhaust cleaning system that removes SOx (Sulphur oxides) and PM (Particulate matters) from fuel exhausts. A vessel fitted with a scrubber system can still operate on HFO while meeting the requirements of the 2020 global sulphur limit. There are two types of scrubber systems: wet scrubbers and dry scrubbers (Fredriksson, Wiberg, & Örtlund, 2016).

Wet scrubbers use seawater to “shower” the exhausts to remove chemicals. There are two types of wet scrubber systems: open loop and closed loop.

Open loop uses the seawaters natural alkalinity to capture sulphur oxides from the exhaust gases. The contaminated water is released into the sea after a loop is completed.
Closed loop uses freshwater mixed with sodium hydroxide to capture sulphur oxides from the exhausts. This system is suitable for vessels that operate in areas where the seawaters alkalinity is not enough to be used as a cleaning reagent (Fredriksson, Wiberg, & Örtlund, 2016).

Hybrid scrubbers are a combination between open and closed loop. Hybrid scrubbers are beneficial for vessels that operate in different sea areas because they can be switched between the two loop modes. This is the most commonly used scrubber system onboard vessels today (Fredriksson, Wiberg, & Örtlund, 2016).

Dry scrubbers use calcium or sodium powders as a reagent to capture the sulphur oxides from the exhausts. The collected residue is stored in a sludge tank onboard and is discharged in ports. The capital costs of dry scrubbers (installation) is less than wet scrubbers, but the operative costs are higher (Fredriksson, Wiberg, & Örtlund, 2016).

2.3.2.1 The costs of scrubber systems

The sharp turn that IMO took when they decided to enforce the 2020 global sulphur limit instead of 2025 could have a large impact on capital costs for shipping companies. The installation of scrubber systems as a compliance method could be the best financial option for a large shipping company, but it might not be financially possible for a smaller shipping company to pay the initial capital costs. Shipping companies are already under financial stress because of the low transport costs, caused by the overcapacity of vessels in the global fleet (Richter, 2017).

The cost of installing a scrubber is between 3-6 million USD depending on the size of the vessels engine. Vessels that retrofit a scrubber must drydock for a period which results in off-hire losses. Off-hire losses is the total lost revenue during a period when a vessel is non-operational. Another result is the cargo capacity loss caused by the physical space occupied by the scrubber system. Maintenance costs of the scrubber system is another economic factor of installing a scrubber system (Platts, 2017).

The greatest advantage of using a scrubber system is that the vessel can still operate on HFO. HFO is cheaper than distillate fuels (MDO, MGO). However, scrubber systems with an open loop must operate on MGO while sailing in waters with low alkalinity. Another advantage of using a scrubber system is that there is a larger supply of HFO than the other fuel alternatives. These factors usually result in lower operative costs for vessels fitted with a scrubber than vessels operating on low-sulphur fuel oils (Dierico, 2015).

2.3.3 Alternative fuel options

A possible compliance method to meet the 2020 global sulphur limit is to operate a vessel on an environmental friendly fuel such as LNG (Liquefied Natural Gas) or Methanol.

2.3.3.1 LNG (Liquefied Natural Gas)

Ships have started to switch fuel systems to operate on LNG (Liquefied Natural Gas). Shell describes LNG as following:

"Liquefied Natural Gas (LNG) is a clear, colourless and non-toxic liquid that forms when natural gas is cooled down to -162C. The cooling process shrinks the volume of the gas 600 times, making it easier and safer to store and ship."
(Shell, 2018).

LNG is a compliance method that is relatively new in the shipping business. There are several positive aspects of using LNG as a fuel system:

- Reduced SOx, NOx, PM and VOC.
- Lower price than distillate fuels (ULSFO, MDO/MGO).

(Notteboom & Wang, 2014)

The negative aspects of using LNG as a fuel system are:

- Lacking infrastructure in ports resulting in lack of supply.
- Major redesign of fuel systems onboard vessels and special tanks are required to cool and store LNG.
- Requires an increased crew competence.

(Notteboom & Wang, 2014)

The shipping businesses are generally positive to switching over to LNG, however, the lack of infrastructure in the market today makes many shipowners and operators hesitant to fully commit to LNG as the main fuel system onboard their vessels. Likewise, fuel suppliers are hesitant to invest in expanding the LNG infrastructure without a commitment from the shipowners (Notteboom & Wang, 2014). When IMO decided that the 0,5% global sulphur limit will enter into force by 1st January 2020, several shipping companies started to order new LNG vessels. One example is CMA CGM, one of the world leaders in maritime container transports, has announced that they have ordered 9 new LNG fuelled container vessels (CMA CGM, 2017).

2.3.3.2 Methanol

Methanol is a carbon-based liquid that has been used in land-based industries for a period of time. Recently it has gained attention as a possible environmental friendly fuel alternative, mainly because there are several ways to produce it. Compared to LNG, it is easier to store and operate because it is not cooled and it is not as flammable.

Emission of SOx, PM and NOx are very low compared to petroleum products. Methanol is a suitable alternative fuel system for existing vessels because the retrofitting costs are lower than the cost of retrofitting LNG. Methanol is the most environmental friendly alternative because it has the lowest global warming potential (Andersson, Brynolf, & Fridell, 2014).

Methanol is presently not a common fuel alternative used onboard vessels. The reason is the high capital costs of installing/retrofitting the fuel system and the presently low MGO price which makes the fuel-switching alternative more attractive to investors. In a case where the MGO price is very high, and the methanol price is low, the methanol option might be financially viable for vessels after 2020 (DNV GL, 2016).

2.4 Economic factors of the 2020 global sulphur limit

The complex nature of shipping economics makes it difficult to predict the economic impact of the 2020 sulphur limit. There are many different factors of the economic aspect of the regulatory change in 2020. The different factors will influence shipowners` decision making when they choose what compliance method they will invest in before and after 2020 to meet the 0.5% global sulphur limit.

2.4.1 Bunker prices

The cost differences between the different bunker fuels will be a large contributing factor to what compliance method shipowners will invest in for their vessels. If the MGO and ULSFO prices are relatively low, existing vessels will continue operating on fuel-switching because they can avoid the expensive capital costs of alternative compliance methods.
If the MGO and ULSFO prices are high, the scrubber and LNG options will be preferable for shipowners because the capital investments in the latter options pay off.

2.4.2 Supply and Demand

According to an analytics report by CE Delft, the major refineries are capable to meet the predicted bunker demand after 2020. The maximum amount of fuel that the refineries will be capable of producing is 24% above the estimated demand. If the refineries are not able to meet the demand after 2020, they must expand their capacity to produce more low-sulphur fuel. The refineries that can produce the low-sulphur fuel oils are predominantly based in Europe, Middle East and Latin America. Refineries in these regions might have to export to other regions to meet the bunker demand (CE Delft, 2016).

Refineries ability and capacity to produce the different low-sulphur fuels to meet the demand in 2020 is a contributing factor to the economic impact of the 2020 global sulphur limit regulation. Larger and more complex refineries are predicted to be able to increase their production capacity for low-sulphur fuels and they have the possibility to gain an advantage in the upcoming bunker fuel market in 2020. Smaller refineries could have a more difficult task to upgrade their equipment to be able to meet the demand (CE Delft, 2016).

3 Method

This chapter describes the method used for data collection and calculations that were used to fulfil the aims and goals of this thesis.

3.1 Literature collection

The data in this literature review was retrieved by using the databases Scopus, Web of Science and Google scholar. The search keywords used were “Sulphur” and “Shipping” to get a wide selection of scientific articles. The results were narrowed down by only collecting data from literature published after year 2000. To verify the validity of the selected scientific articles the authors looked at the number of citations of each article and reviewed the references in the selected articles.

3.2 Calculation methods

To gain further insight into how shipping companies will comply with the 2020 global sulphur limit, calculations that compares cost differences between scrubber installation and fuel switching will be presented in this thesis. The calculations are made for a 15-year period starting in 2020 for two newbuilt vessels.

The calculation method used are based on calculations from a scientific article entitled “*Scrubbers: A potentially overestimated compliance method for the Emission Control Areas*” (Gu & Wallace, 2017). The calculations were verified before being adopted for use in this thesis.

The two vessels used in the calculations are one mid-size container vessel operating in a loop and a Panamax tanker that sails a specific distance during a one-year period. The vessels operate both inside and outside of ECAs.

The calculations are made for three different fuel price scenarios for HFO and ULSFO. The three scenarios are low, medium and high cost. The HFO and ULSFO costs are fixed in the different scenarios and increase with increments of 200 USD/mt. The MGO price is in the range 250-900 USD/mt with 10-USD increments.

Table 2, Fuel cost matrix

Scenario	HFO	ULSFO
Low cost	200	400
Medium cost	400	600
High cost	600	800

The calculation results will be presented in two different forms: total lifespan cost difference and breakeven point calculation.

3.2.1 Total lifespan cost difference

The total lifespan cost difference will be calculated by summarizing the total fuel-switching cost for a set MGO price and subtracting it with the total lifespan cost of a scrubber system. A positive result indicates that the scrubber option is cheaper, and a negative result indicates that the fuel-switching method is cheaper. The specific MGO price that makes fuel-switching more expensive than the scrubber option will be presented when the cost difference shifts from negative to positive (see Figure 1).

$$Cost^{life}_{difference} = Cost^{life}_{fuel\text{-}switching} - Cost^{life}_{scrubber}$$

Figure 1, Cost life difference formula Source: (Gu & Wallace, 2017)

3.2.1.1 Scrubber costs calculations

The total lifespan cost of a scrubber system can be divided in two parts: an operational cost and a fixed cost.

The operational cost consists of fuel consumption ($F^{loop\ traditional}$), HFO price (P^{HFO}) and total number of round trips (n), as shown in Figure 2. The discount rate d is also added in the equation. The discount rate is the projected decreasing monetary value over the increasing number of years. The used discount rate in the calculations is fixed at 9%/year. The factor t refers to the calculated year and results are summed up for the 15-year period (Gu & Wallace, 2017).

$$Cost^{operation}_{scrubber} = \sum_{t=0}^{T} \frac{n \times P^{HFO} \times F^{loop}_{traditional}}{(1+d)^t}$$

Figure 2, Cost operation scrubber formula Source: (Gu & Wallace, 2017)

The fixed cost consists of the total capital cost ($Cost^{capital\ Scrubber}$), Cargo capacity loss ($Cost^{Capacity\ Scrubber}$) and the maintenance cost ($Cost^{maintain\ scrubber}$) during a one-year period. It also includes the discount rate (see Figure 3). The off-hire costs are excluded in the present calculations.

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

Figure 3, Cost fixed scrubber formula Source: (Gu & Wallace, 2017)

The capital costs are assumed to be 135 USD/kW of the total main engine power. The physical space occupied by the scrubber system results in a cargo capacity loss that is assumed to be 1% of the total earnings/day. Scrubber systems also requires additional maintenance costs that are assumed to be 1% of the initial capital costs. (Gu & Wallace, 2017)

3.2.1.2 Fuel-switch costs calculations

The fuel-switching calculations use two fuel types: ULSFO outside ECAs with a sulphur level of 0.5% and MGO inside ECAs with a sulphur level of 0.1%. The ULSFO price is kept fixed in each calculation for the different price scenarios. The MGO price varies in the range 250-900 USD/mt with 10-USD/mt increments.

The operational cost for fuel-switching consists of number of loops (n), ULSFO price (P^N), fuel consumption outside of ECA/loop ($F^{N\ traditional}$), MGO price (P^{ECA}), fuel consumption inside ECA ($F^{ECA\ traditional}$) and discount rate/year (d), as shown in Figure 4. (Gu & Wallace, 2017)

$$Cost^{operation}_{fuel\text{-}switching} = \sum_{t=0}^{T} \frac{n \times \left(P^N \times F^N_{traditional} + P^{ECA} \times F^{ECA}_{traditional}\right)}{(1+d)^t}$$

Figure 4, Cost operation fuel-switching formula

Source: (Gu & Wallace, 2017)

3.2.2 Breakeven point calculation

The calculation results correspond to the year when the scrubber option becomes cheaper than the fuel-switching option. This is done by adding the total costs for each year for the two options and comparing them. The calculation uses three fixed MGO prices: 400, 600 and 800 USD. The HFO and ULSFO prices are fixed for the three different price scenarios used in the total lifespan cost calculations (see Table 2, Fuel Cost Matrix).

3.2.3 Container Vessel input data

The container vessel input data (see Table 3) represent a mid-size container vessel that operates on a time-charter both inside and outside ECAs.

Table 3, Container Vessel input data

Container Vessel input data	Value
Ship Capacity	6000 TEU
Main Engine Power	48 000 kW
Ship speed	17.15 kt
Fuel consumption	54.28 mt/d
Lifespan	15 years
Initial Capital cost	135 USD/kW
Maintenance cost (percentage of initial capital cost)	1% /year
Capacity loss (percentage of yearly income)	1% /year
Earnings/day	23 000 USD
Discount rate	9% /year
Voyage days	200 days
Distance in SECA	5932 NM
Distance outside SECA	4356 NM
Time spent in SECA	58%
Loops/year	8

Source: (Gu & Wallace, 2017)

3.2.3.1 Container Vessel Loop data

The container vessel operates on a typical loop (see Table 4) for a mid-size container vessel on a time-charter. The total sailing distance outside of ECAs is 4356NM (nautical miles). The total sailing distance inside ECAs is 5932NM.

Table 4, Container Vessel Loop data

Leg	Departure Port	Arrival Port	Distance ECA/non ECA	Sea days
1	Gothenburg	Halifax	1225 / 1635 NM	6.95
2	Halifax	Houston	2285 / 38 NM	5.65
3	Houston	Gothenburg	2422 / 2683 NM	12.40

Source: (Gu & Wallace, 2017)

3.2.4 Tanker Vessel input data

The input data for the tanker vessel (see Table 5) represent a Panamax tanker that sails a total distance of 52 000NM during a period of 180.6 days. The vessel data was provided by Marinvest Shipping AB, a shipping company based in Gothenburg, Sweden.

Table 5, Tanker Vessel input data

Tanker Vessel input data	Value
Deadweight	74 996 mt
Main Engine Power	13 560 kW
Ship speed	12,00 kt
Fuel consumption	20,86 mt/d
Lifespan	15 years
Initial Capital cost	135 USD/kW
Maintenance cost (percentage of initial capital cost)	1% /year
Capacity loss (percentage of yearly income)	1% /year
Earnings/day	10 000 USD
Discount rate	9% /year
Voyage days	180.6 days
Distance in SECA	13 000 NM
Distance outside SECA	39 000 NM
Time spent in SECA	25%
Loops/year	1

Source: Marinvest Shipping AB (Gothenburg, Sweden)

3.2.5 Assumptions

- Fuel type - For the fuel-switching method it is difficult to make a prediction of which fuel type will be preferred. This is because there are different blends of fuels in different bunker ports globally. The authors assume that they will use ULSFO in non-ECA regions and MGO inside 0.1% ECAs.
- ECA limit – The calculations are made for the time period 2020 - 2035. The global limit will remain at 0.5% and the ECA limit will remain at 0.1% for the entire period.

3.2.6 Limitations

- Average speed – The speed for the two different vessels are constant both inside and outside of ECAs. Thus, the speed is not adjusted in relation to the fuel prices.
- Route and speed optimization – The sailing pattern of the vessels are not optimized for decreasing total sailing distance inside ECAs.
- Off hire/Shipyard costs – The calculations do not include off hire/shipyard costs.
- Port days – Fuel consumption in port is not considered in the calculations.

4 Results

4.1 Calculation results

The results of the calculations show a percentage difference between the cost of using a scrubber and the cost of using the fuel-switching method on a vessel during a 15-year lifespan. If the percentage result is positive it means that the scrubber option is cheaper (see chapter 3.2.1, Total lifespan cost formula). The fuel used by vessels using scrubbers is HFO which has a fixed price in the different price scenarios (see Table 2, Fuel cost matrix). The MGO price is varying in all calculations in the range 250-900 USD/mt. The ULSFO price is fixed for each of the three different price scenarios (low, medium and high, see Table 2, Fuel cost matrix).

4.1.1 Container vessel calculation results

The following results correspond to a container vessel trading in one specific loop with a set average speed of 17.15kt. The three ports in the loop are Gothenburg, Halifax and Houston and the total distance sailed per loop is 10 288 nautical miles (see Table 4, Container vessel loop data).

4.1.1.1 Total lifespan cost difference and Breakeven point

The total lifespan cost difference was calculated by summarizing the yearly costs. The net present value is calculated by taking into account a discount rate of 9%.

The breakeven points were calculated by summarizing the costs year by year for the two compliance methods. By comparing the total yearly costs of the two methods, the year which one option becomes cheaper is presented.

4.1.1.1.1 Low price scenario

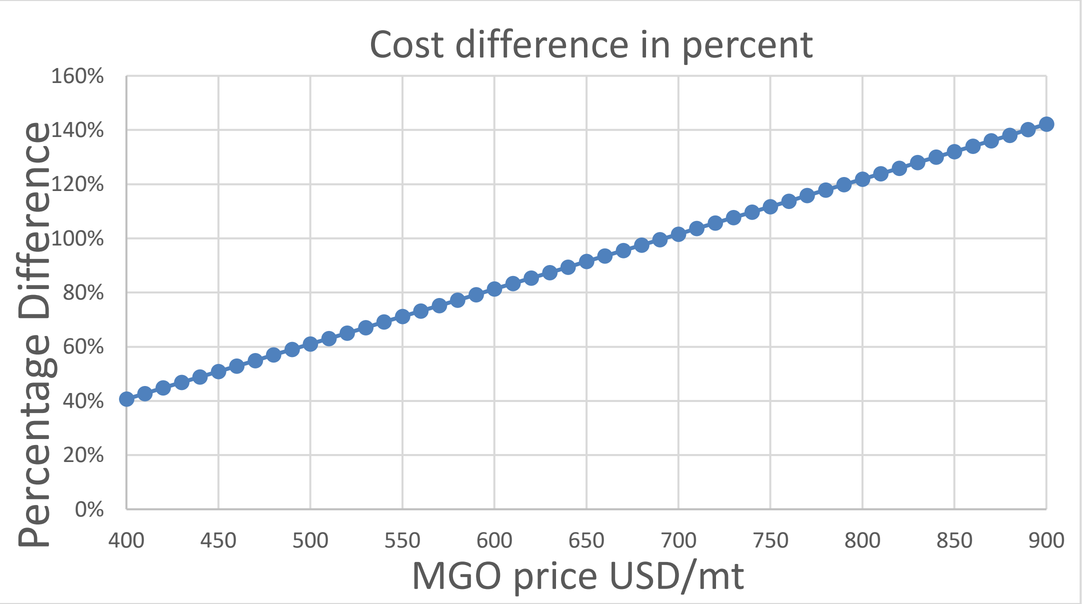

Figure 5, Container vessel Low price scenario

The results of the low-price scenario (see Figure 5) calculation for the container vessel shows that the total lifespan cost is cheaper for the scrubber regardless of what the MGO price is set to. The scrubber option is 41% cheaper if the MGO price is 400 USD/mt during the 15-year period. The scrubber option is 142% cheaper than the fuel-switching method if the MGO price is set to 900 USD/mt.

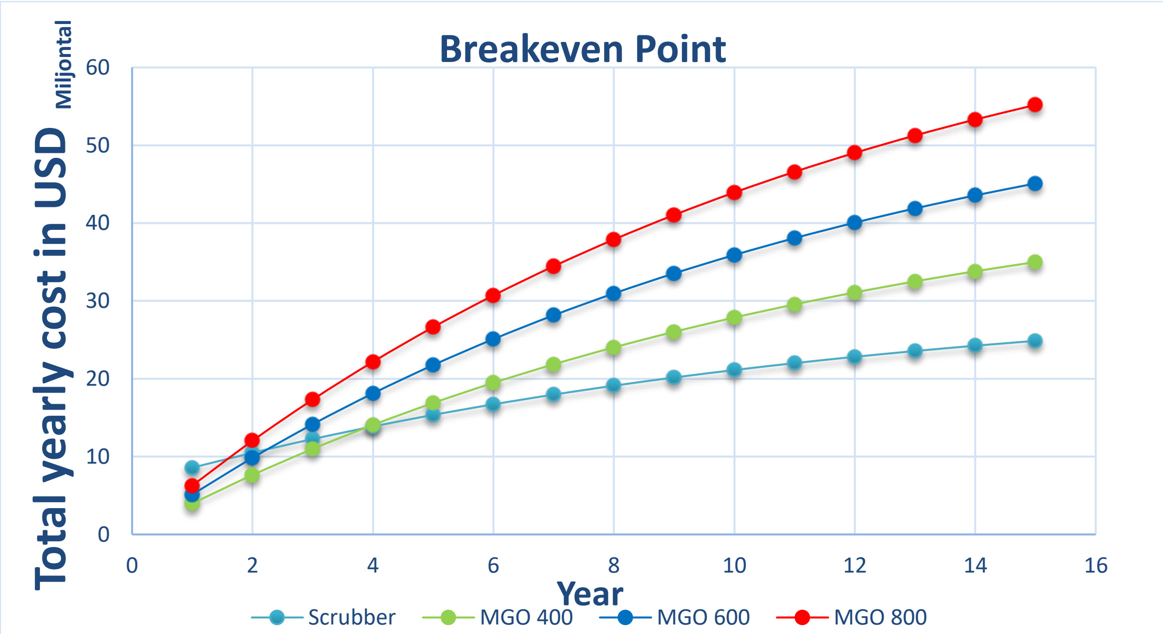

Figure 6, Container vessel breakeven point Low price scenario

The breakeven point is presented (see Figure 6) when the MGO lines (400, 600, 800 USD/mt) cross the scrubber line. If the MGO price is set to 400 USD/mt, the breakeven point is after four years of operation. If the MGO price is set to 800 USD/mt, the breakeven point is within the second year of operation.

4.1.1.1.2 Medium price scenario

In the medium price scenario, the ULSFO price is set to 600 USD/mt but the MGO price is varying in 10-USD increments from 250 – 900 USD. The MGO price in the price range 250 – 600 USD/mt is irrelevant since the ULSFO price is expected to be lower than the MGO price (based on the distillate grade). Figure 7 therefore only presents the calculation result from 600 – 900 USD/mt.

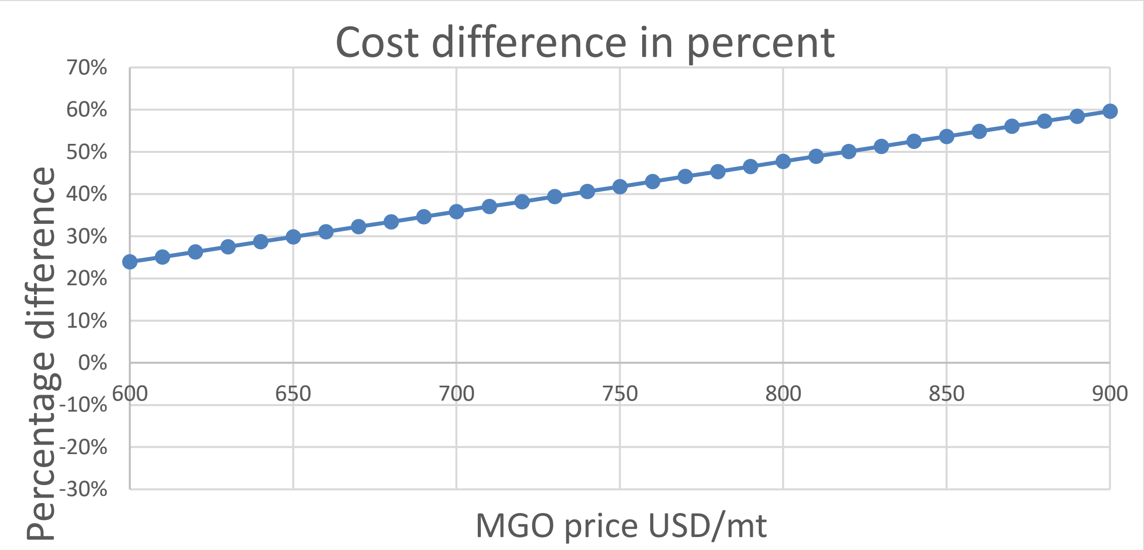

Figure 7, Container vessel Medium price scenario

As seen in figure 7, the medium-price scenario shows that the total lifespan cost for the scrubber option becomes the cheapest alternative if the MGO price is minimum 600 USD/mt. If the MGO price is at 900 USD/mt, the scrubber option is 60% cheaper than the fuel-switching option.

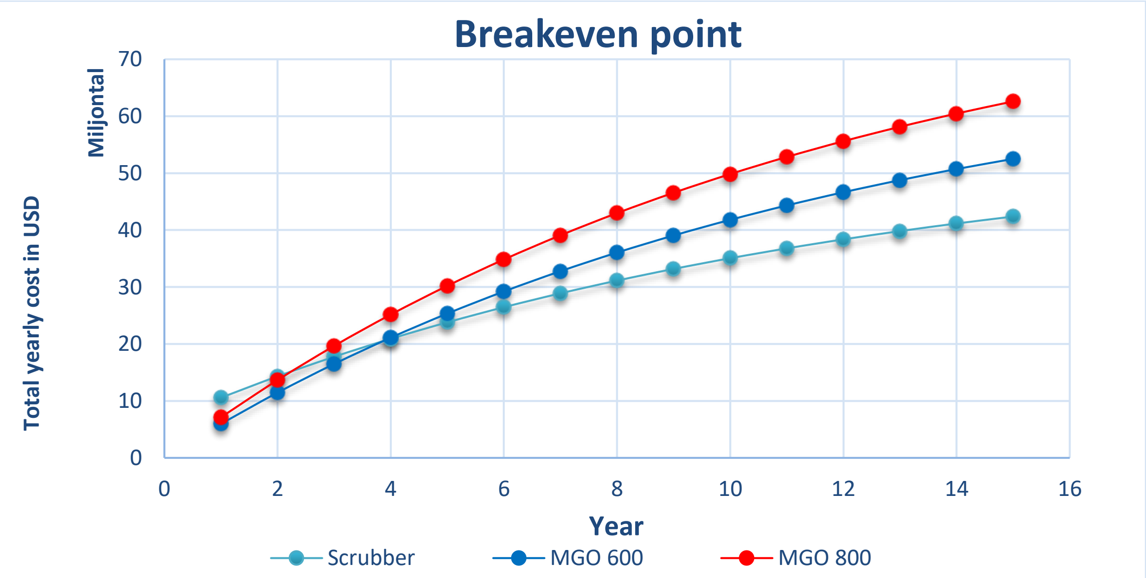

Figure 8, Breakeven point container vessel Medium price scenario

Figure 8 shows that if the MGO price is set to 600 USD/mt, the breakeven point is after four years of operation. If the MGO price is set to 800 USD/mt, the breakeven point is within the third year of operation.

4.1.1.1.3 High price scenario, Container vessel

In the high price scenario, the ULSFO price is set to 800 USD/mt but the MGO price is varying in 10-USD increments from 250 – 900 USD. The MGO price in the price range 250 – 800 USD/mt is irrelevant since the ULSFO price is expected to be lower than the MGO price (based on the distillate grade). Figure 9 therefore only presents the calculation result from 800 – 900 USD/mt.

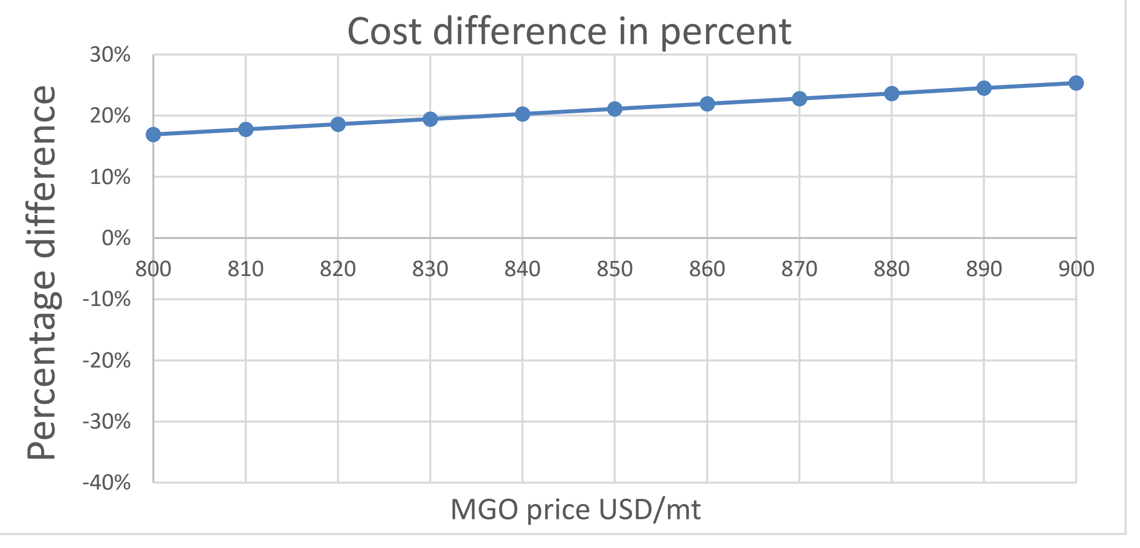

Figure 9, Container vessel High price scenario

As seen in Figure 9, the high price scenario results show that the scrubber option is cheaper when the MGO price is higher than 800 USD/mt.

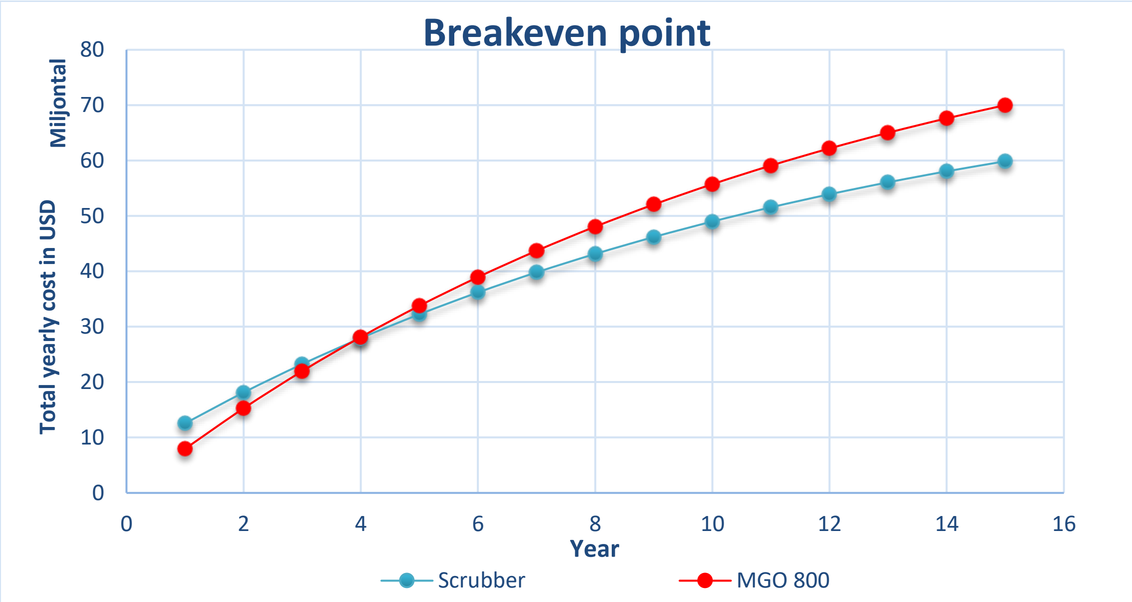

Figure 10, Breakeven point container vessel High price scenario

Figure 10 shows that if the MGO price is set to 800 USD/mt, the breakeven point is after four years of operation.

4.1.2 Tanker vessel calculation results

The following results correspond to a Panamax tanker vessel trading in one specific loop with a set average speed of 12,0kt. The total distance sailed per year is 52 000 nautical miles, of which 25% is inside SECA (0.1% sulphur limit area).

4.1.2.1 Total life cost difference and Breakeven point

The total life cost difference was calculated by summarizing the yearly costs. The net present value is calculated by taking into account a discount rate of 9%.

The breakeven points were calculated by summarizing the costs year by year for the two compliance methods. By comparing the total yearly costs of the two methods, the year in which one option becomes cheaper is presented.

4.1.2.1.1 Low price scenario

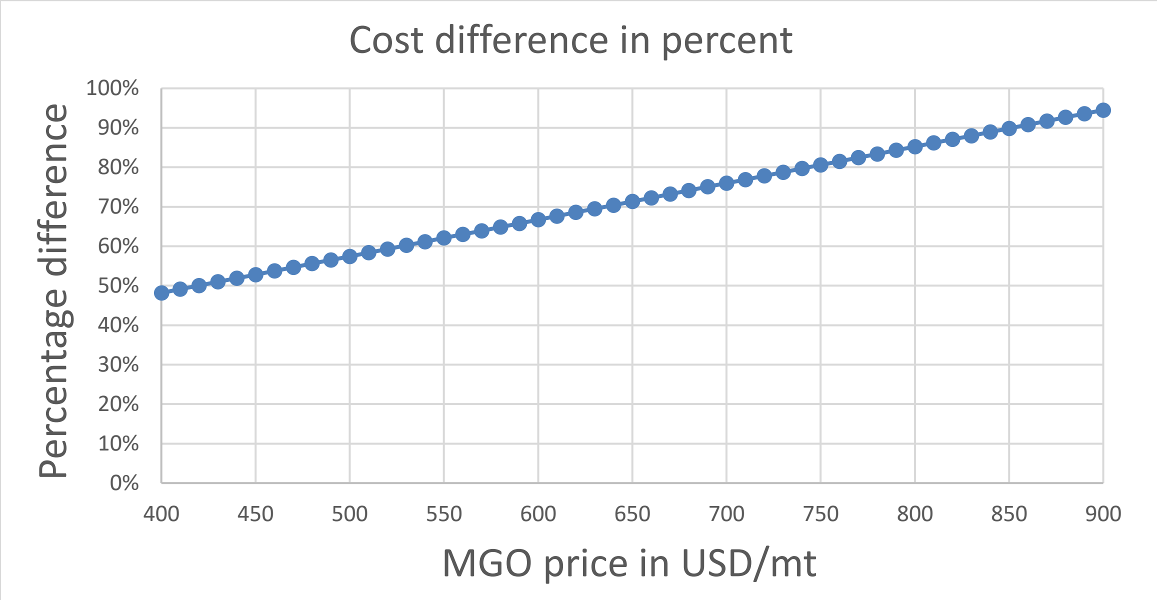

Figure 11, Tanker vessel Low price scenario

The results of the low-price scenario (see Figure 11) calculation for the tanker vessel shows that the total lifespan cost is cheaper for the scrubber regardless of what the MGO price is set to. The scrubber option is 48% cheaper if the MGO price is 400 USD/mt during the 15-year period. The scrubber option is 94% cheaper than the fuel-switching method if the MGO price is set to 900 USD/mt.

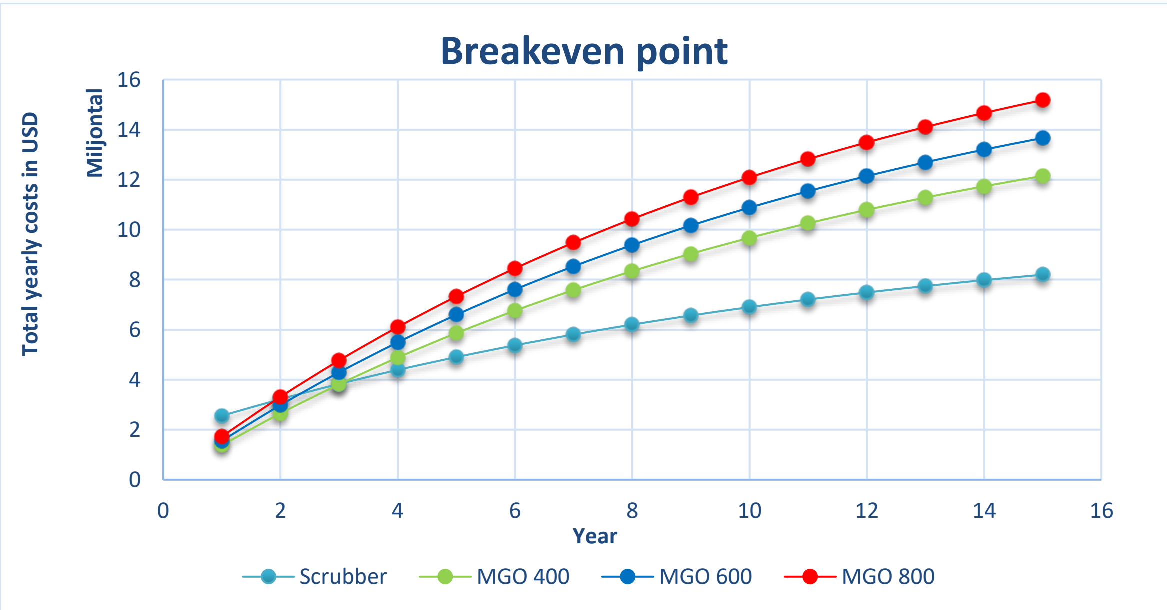

Figure 12, Breakeven point tanker vessel Low scenario

Figure 12 shows that if the MGO price is set to 400 USD/mt, the breakeven point is after three years of operation. If the MGO price is set to 800 USD/mt, the breakeven point is after 2 years.

4.1.2.1.2 Medium price scenario

In the medium price scenario, the ULSFO price is set to 600 USD/mt but the MGO price is varying in 10-USD increments from 250 – 900 USD. The MGO price in the price range 250 – 600 USD/mt is irrelevant since the ULSFO price is expected to be lower than the MGO price (based on the distillate grade). Figure 13 therefore only presents the calculation result from 600 – 900 USD/mt.

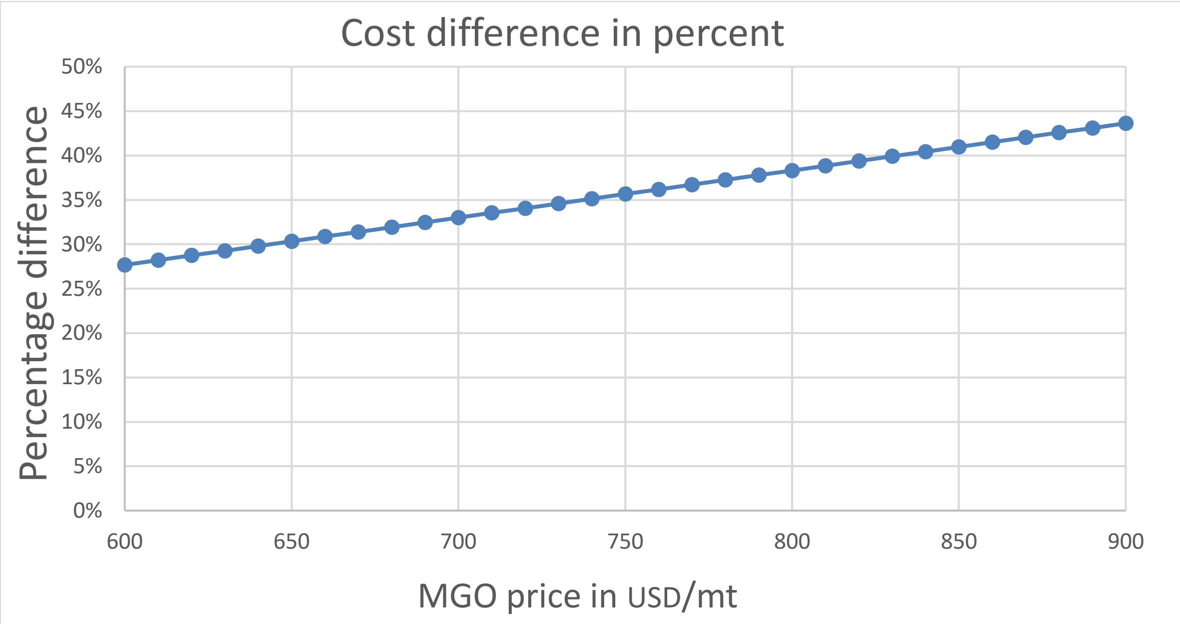

Figure 13, Tanker vessel Medium price scenario

The results of the medium-price scenario (see Figure 13) calculation for the tanker vessel shows that the scrubber option is 28% cheaper if the MGO price is 600 USD/mt during the 15-year period. The scrubber option is 44% cheaper than the fuel-switching method if the MGO price is set to 900 USD/mt.

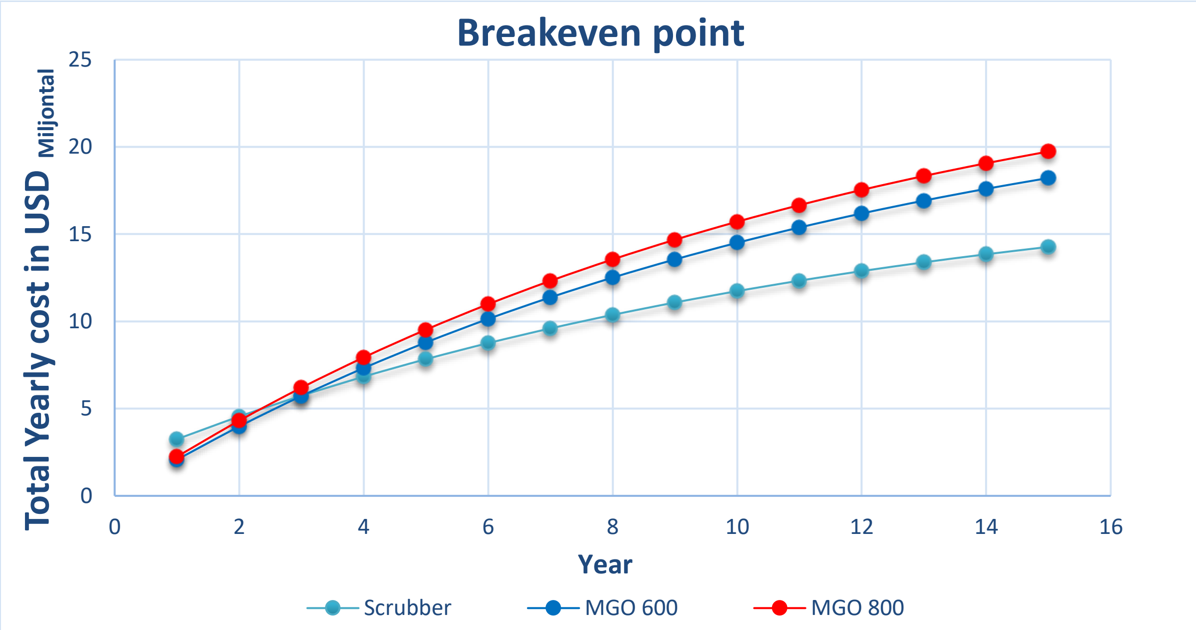

Figure 14, Breakeven point tanker vessel Medium scenario

Figure 14 shows that if the MGO price is set to 600 USD/mt, the breakeven point is after three years of operation. If the MGO price is set to 800 USD/mt, the breakeven point is within the third year.

4.1.2.1.3 High price scenario

In the high price scenario, the ULSFO price is set to 800 USD/mt but the MGO price is varying in 10-USD increments from 250 – 900 USD. The MGO price in the price range 250 – 800 USD/mt is irrelevant since the ULSFO price is expected to be lower than the MGO price (based on the distillate grade). Figure 9 therefore only presents the calculation result from 800 – 900 USD/mt.

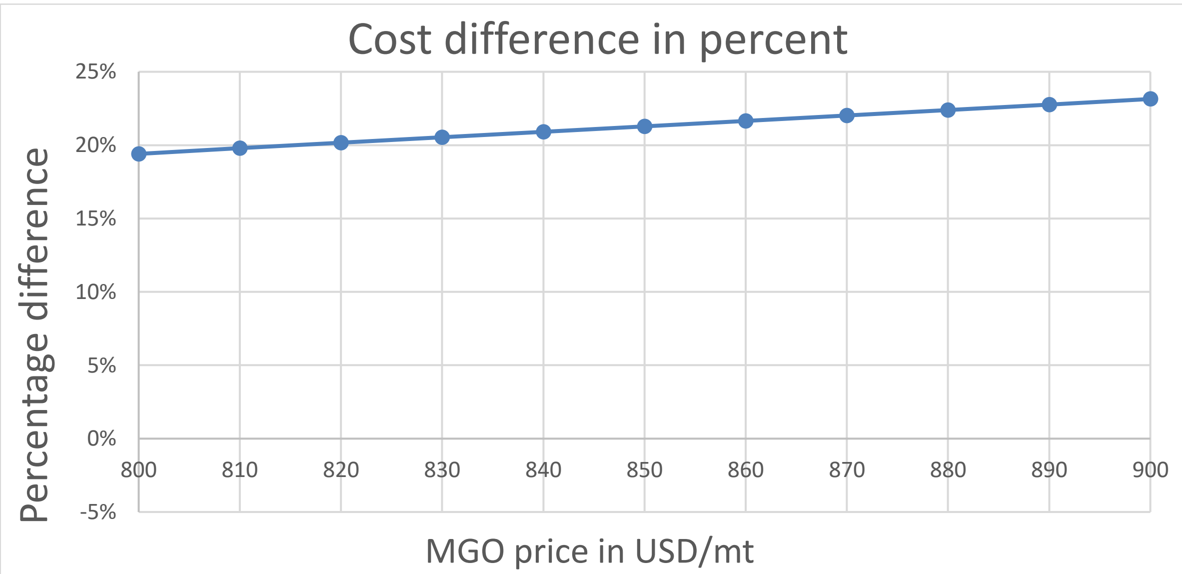

Figure 15, Tanker vessel High price scenario

The results of the high-price scenario (see Figure 15) calculation for the tanker vessel shows that the scrubber option is 19% cheaper if the MGO price is 800 USD/mt during the 15-year period. The scrubber option is 23% cheaper than the fuel-switching method if the MGO price is set to 900 USD/mt.

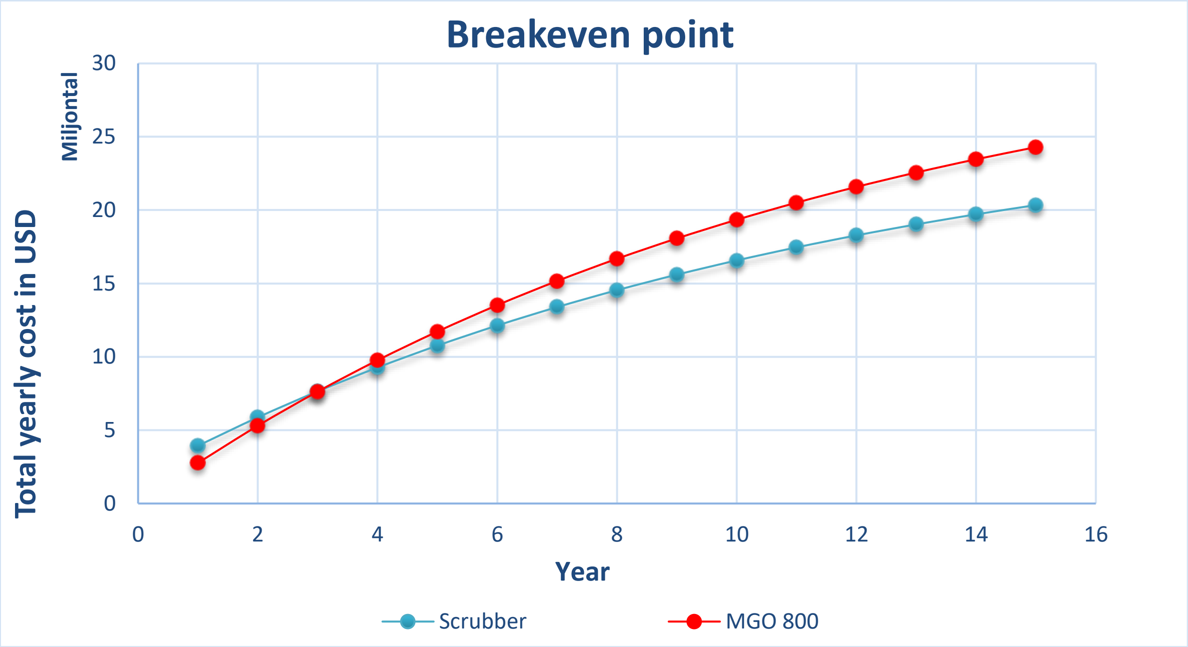

Figure 16, Breakeven point tanker vessel High price scenario

Figure 16 shows that if the MGO price is set to 800 USD/mt, the breakeven point is after three years.

5 Discussion

This thesis is divided into two parts; a literature review and a compliance method cost calculation part. The literature review functions as a theoretical background and the calculations function as a practical example of what different compliance methods will cost. The discussion will connect the two parts and give the reader a larger understanding of the economic aspects of the 2020 global sulphur limit.

5.1 Analysing the calculation results

There are limitations to the calculation method (see chapter 3.3.6) and the results should be regarded as a general economic comparison between the exhaust cleaning system method (scrubber) and the fuel-switching alternative.

An important aspect of the calculations are the different fuel prices. In the calculations, the HFO and ULSFO prices are fixed in the different price scenarios while the MGO price is varying from 250-900 USD/mt (see Table 2, chapter 3.3). MGO is a middle distillate and is normally more expensive than ULSFO. This leads to some unrealistic calculations results where the ULSFO price is higher than the MGO. For example, in the low-price scenario, the ULSFO price is set to 400 USD/mt while the MGO price starts at 250 USD/mt. This means that all the calculation results for an MGO price lower than 400 USD/mt are not realistic and should be discarded in the analysing part.

Another important limitation is the exclusion of the off-hire costs for exhaust cleaning system installation. A scrubber system adds construction time and a faulty system could require repairs in a shipyard. The off-hire period could be weeks or months, and if a vessel is earning 23 000 USD/day, it will add up to a substantial amount of lost earnings. The exclusion of off-hire costs makes the results more positive for the scrubber option than it is in reality.

An important limitation in this thesis is the exclusion of route and speed optimization for the fuel-switching method. Vessels that operate on fuel-switching plan their voyages for sailing outside of ECAs as much as possible, and they keep a higher average speed outside of ECAs and lower the speed when they enter ECAs. This is common practice that decreases bunker fuel costs for the shipowner in the fuel-switching approach. This is not included in this thesis which makes the cost difference percentage larger between scrubber operation and fuel-switching than it is in reality.

5.1.1 Container vessel calculations

The total lifespan cost calculations yield the added costs for using a scrubber system or fuel-switching on board a vessel for a 15-year lifespan period. The breakeven calculations results in a year when the scrubber system becomes cheaper than the fuel-switching method.

5.1.1.1 Total lifespan cost difference

The total lifespan cost difference in the three price scenarios shows that the scrubber option is always the cheapest in a 15-year lifespan period. In the low-price scenario, the total lifespan cost for the scrubber option is 41% cheaper if the MGO price is 400 USD/mt. If the MGO price is 900 USD/mt, the scrubber option is 142% cheaper.

In the medium-price scenario, the MGO price starts at 600 USD/mt and fuel-switching is minimum 24% higher than operating on a scrubber. The highest MGO price of 900 USD/mt results in a 60% higher cost for fuel-switching.

In the high-price scenario, the MGO price starts at 800 USD/mt. This results in a 17% higher lifespan cost for fuel-switching than the scrubber option. The maximum cost difference is 25% higher for fuel-switching.

The reason for the maximum cost difference being 142% in the low-price scenario and 25% in the high-price scenario is that the price relation between HFO and MGO differs. In the low-price scenario, the HFO price is set to 200 USD/mt and the maximum MGO price is 900 USD/mt which results in a 700 USD difference. In the high-price, the HFO price is set to 600 USD/mt and the maximum MGO price is 900 USD/mt which results in a 300 USD difference.

The relation of the different fuel prices is important for the results in these calculations. In the low-price scenario, the ULSFO price is 400 USD/mt and the HFO price is 200 USD/mt. The ULSFO is in this case 100% higher relative to the HFO price. This results in a cost difference range of 41% - 142% depending on the MGO price. In the medium-price scenario, the ULSFO price is 600 USD/mt and the HFO price is 400 USD/mt. The ULSFO is in this case 50% higher relative to the HFO price. This results in a total lifespan cost difference with a range of 24% - 60 % depending on the MGO price.

This indicates that the price difference in percentage between ULSFO and HFO affects the total lifespan cost difference between scrubber operation and fuel-switching. However, the scrubber capital costs in these calculations are fixed and do not change in the different price scenarios. This makes the total cost difference results larger than they might turn out if scrubbers installation prices adjust to the fuel price scenario, based on supply and demand for scrubbers.

For container vessel companies, these results would imply that installing scrubber systems in newbuilt vessels after 2020 is the cheapest option. There is also an uncertainty about the low-sulphur bunker supply after 2020 and what the fuel will cost, which is another incentive for a container vessel shipping company to continue operating on HFO. If bunker suppliers increase the price of low-sulphur fuel because of the high demand, the cost difference between HFO and ULSFO will have a large impact on the total lifespan cost difference.

If fuel-switching remains as the most popular compliance method after 2020, the HFO price could decrease because of the storage surplus. The production of HFO could also be lowered because of the decreased demand, bringing prices to an equilibrium.

Another factor to consider is the capital costs of scrubber installations on newbuilds and retrofitted vessels. If the scrubber option becomes the most popular, more vessels must drydock before 2020 to retrofit their vessels with scrubber systems. The number of shipyards are limited and if the demand for dry-docking increases, they could increase their price. An increased demand of scrubber systems could also increase the price of the scrubber installation.

5.1.1.2 Breakeven point calculations

In the low-price scenario, the breakeven point is after four years when the MGO price is set to 400 USD/mt. When the MGO price is set to 600 USD, the point is reached in the third year and if the price is set to 800 USD/mt the point is reached in the second year.

In the medium-price scenario, the breakeven point after four years of operation if the MGO price is set to 600 USD/mt. If the MGO price is set to 800 USD/mt, the breakeven point is during the second year.

In the high-price scenario, the breakeven point is after four years if the MGO price is set to 800 USD/mt.

In all the different price-scenarios, the breakeven point is 3-5 years which is relatively early in the 15-year lifespan that is calculated. This indicates that installing a scrubber system on newbuilt vessels is the best financial option after 2020.

5.1.2 Tanker vessel calculations

The total lifespan cost calculations yield the added costs for using a scrubber system or fuel-switching onboard a vessel for a 15-year lifespan period. The breakeven calculations results in a year when the scrubber system becomes cheaper than the fuel-switching method.

5.1.2.1 Total lifespan cost calculations

The total lifespan cost calculations for the tanker vessel shows that the scrubber option is always the cheapest option during a 15-year period. For the low-price scenario, the scrubber option is 48% - 94% cheaper. For the medium-price scenario, the scrubber option is 28% - 44% cheaper. For the high-price scenario, the scrubber option is 19% - 23 % cheaper.

These results indicate that it is more cost efficient to operate with a scrubber system on a tanker in all bunker price scenarios. Tanker vessel usually operate on a smaller main engine with lower power output than other vessel types in the same size-range. The tanker in this calculation operates with an average speed of 12.0 kt and a fuel consumption of 20.86 mt/d. This results in lower operative costs and capital costs than other vessel types.

5.1.2.2 Breakeven point calculation

In the low-price scenario, the breakeven point is after three years when the MGO price is set to 400 USD/mt. When the MGO price is at 600 USD, the point is reached between 2-3 years and if the price is set to 800 USD/mt the point is reached in the second year.

In the medium-price scenario, the breakeven point after three years of operation if the MGO price is set to 600 USD/mt. If the MGO price is set to 800 USD/mt, the breakeven point is during the second year.

In the high-price scenario, the breakeven point is after three years if the MGO price is set to 800 USD/mt.

The total lifespan of tanker vessels is shorter than the lifespan of other vessel types. This is because the consequences of faults in an old tanker vessel can cause severe damage to the environment in the case of a spill.

The volatile nature of the crude oil market is a contributing factor to the compliance method choice that shipping companies need to make before and after 2020. When the market is strong, the lifespan of tanker vessels is longer than if the market is receding. Peter Sand, a writer for BIMCO.org, said in an article in 2012:

"The fundamental balance between supply and demand tipped into heavy oversupply of capacity. As ship owners attempted to cut losses and to rebalance the market for crude oil tankers, the tanker tonnage sold for demolition got younger." (Sand, 2012)

The scrubber option in these calculations has a breakeven point of 3-5 years which could appeal to shipping companies if the lifespan of tankers is relatively low.

5.2 Supply and Demand

The fuel-switching method is predicted to be the most common compliance method to meet the 2020 global sulphur limit requirements. This means that MGO and ULSFO would be the bunker fuels with the highest demand. If this will be the case, the demand for HFO will be very low compared to the present market. A decreased demand would either lead to decreased production or a decreased price of HFO because of production overcapacity. As concluded in chapter 5.1.1.1, the total lifespan cost for a scrubber installation is lower if the MGO price is relatively high. A decreased HFO price as a result of a lowered demand could in that case be a benefitting economic factor for shipowners with vessels equipped with scrubber systems.

The introduction of 0.5% sulphur fuels in the market requires refineries to invest in de-sulphurisation equipment of residue oils. The capital investments required will not be an issue for large refineries, but smaller refineries might not be able to adapt before 2020. If smaller refineries fail to supply the low-sulphur fuels, the market will be dominated by larger oil companies and they would gain a larger control of the bunker fuel price setting. This could lead to increased distillate fuel prices for a few years after 2020 until the market have been levelled, which would be a further incentive for shipowners to invest in scrubber systems or alternative fuels.

5.3 Method discussion and future work

The calculation methods were adequate to gain a better understanding of the total cost difference between scrubber systems and fuel-switching. The calculation input data and formulas used in the container vessel calculations were retrieved from a study (Gu & Wallace, 2017) that used similar methodology but for a different purpose. The input data and calculation methods were verified before application in this thesis. The tanker vessel input data was provided by Marinvest Shipping AB and the formulas were obtained from the study by Gu and Wallace (Gu & Wallace, 2017).

The literature data in this thesis was retrieved from scientific articles, web sites and journal articles. The databases used were Scopus, Science direct and Google scholar. The search engine Google was used to find web sites with relevant information. It was a challenge to determine if a web site or journal article was a reliable source of information because of corporate author bias.

The limited time for writing of this thesis restricted the scope of the calculations and literature review. It would be interesting to make cost calculations for additional types of vessels in different shipping segments to obtain a more complete understanding of the economic effect of the 2020 global sulphur limit. It would also be interesting to add an in-depth literature review of the refinery business regarding the 2020 global sulphur limit. The relationship between refineries, bunker prices and freight rates would have been a good addition to this thesis in order to give readers a better understanding of the economic aspect of the shipping business.

The exclusion of route optimization from calculations on the fuel-switching method restricts generalization of the conclusions in this thesis. Vessels after 2020 that operate on fuel-switching will most probably optimize their route and speed in order to limit the consumption of MGO/MDO, which reduces the total lifespan cost for the fuel-switching compliance method.

6 Conclusion

The economic impact of the 2020 global sulphur limit is difficult to predict as there are many different contributing factors. Because of the volatile nature of the bunker market, it is problematic to make a reliable price projection. The supply and demand of the different fuels will have a large impact on what the bunker prices will look like after 2020.

The total lifespan cost calculation for the container and tanker vessel that indicates that installing an exhaust scrubber system is the best financial option for newbuilds after 2020, and possibly for existing vessels in operation. However, installing a scrubber system requires considerable capital investment, which small shipowners might not be able to afford, considering the volatility of the shipping market in recent history. Large shipowners with more capital should consider installing scrubber systems onboard their newbuilds if these vessels are planned to operate predominantly in ECAs.

Installing a scrubber requires more space relative to the ship size, which means that that vessel types that carries cargo with higher payment per volume might invest in other compliance alternatives. The breakeven calculations results show that the scrubber option is more expensive for lifespans of a few years, but it becomes cheaper than fuel-switching after 3-5 years of operation.

The calculations enable a general estimation of the total costs for scrubber operation and fuel-switching as compliance methods, and future work should include calculations on other viable compliance methods such as LNG-operation and methanol. Future work should also include route and speed optimization in their calculations yielding more realistic results.

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