Bachelor's thesis

NTNU
Norwegian University of Science and Technology
Faculty of Engineering
Department of Ocean Operations and Civil Engineering

Magnus Andreas Linde Mayer

Sulfur Oxides Restrictions

How does the IMO restrictions on sulfur oxides affect insurance claims on marine fuel engines?

Bachelor's thesis in Shipping Management
Supervisor: Bjørn Harald Bakke
December 2023

NTNU
Norwegian University of Science and Technology

gard

Magnus Andreas Linde Mayer

Sulfur Oxides Restrictions

How does the IMO restrictions on sulfur oxides affect insurance claims on marine fuel engines?

Bachelor's thesis in Shipping Management
Supervisor: Bjørn Harald Bakke
December 2023

Norwegian University of Science and Technology
Faculty of Engineering
Department of Ocean Operations and Civil Engineering

NTNU
Norwegian University of
Science and Technology

I. Summary

To develop a perception of IMOs restrictions on SOx and the consequences, the thesis focuses on the effect of the restrictions and tries to answer the research question *"How does the IMO restrictions on sulfur oxides affect insurance claims on marine fuel engines?"* The research problem is highlighted by three key elements to demonstrate the effect of the SOx restrictions. The thesis purpose is to explain the restrictions effect on fuel, the propulsion system on vessels and lastly how marine insurance claims on engines are affected.

Sea trade is vital to the world and needs international regulation as it has a considerable impact on the environment. The global sea trade accounts for over 80% of the world's total transportation. International collaboration on reducing emissions from ships has been successful in implementing and policing restrictions on the most prominent pollutants and greenhouse emissions. The sulfur oxide limit is one such restriction that has been implemented to reduce damage to the environment and health of the world's population. The consequences of these restrictions include new marine fuel blends, maintenance operations and development of solutions regarding wear and tear on engines.

Secondary data collected from Gard AS and CEFOR databases was used to construct valid results by comparing data material from both databases over the time-period where the SOx restrictions have been implemented.

The findings uncovered a fluctuation pattern in both yearly claim distribution and claims frequency. This fluctuating pattern of increases is often preluded by the implementation of stricter limits on SOx. Thus, supporting the notion that IMOs restrictions have had an impact on marine engine insurance claims. Another finding includes that human errors are decreasing whilst technical errors are increasing, leading to the assumption that the restrictions have influenced the procedures of the crew and the new fuel blends have impacted the wear and tear of engine components. The drastic rise in Hull & Machinery claims after the first limit cap was implemented, the change of human and technical errors and the pattern of fluctuation. This leads to the most probable conclusion that IMOs restrictions on SOx have adversely affected the insurance claims on engines.

II. Terms and Clarifications of Definitions

VLSFO	Very Low Sulphur Fuel Oil
MGO	Marine Gasoil
IMO	International Maritime Organization
MARPOL	The International Convention for the Prevention of Pollution from Ships
HFO	Heavy Fuel Oil
LNG	Liquified Natural Gas
ISO	International Organization for Standardization
SOX	Sulfur Oxide
ECA	Emission Control Areas
SECA	Sulphur Emission Control Areas
MEPC	The Marine Environment Protection Committee
ECGS	Exhaust Gas Cleaning systems
CEFOR	The Nordic Association of Marine Insurers
NOMIS	Nordic Marine Insurance Statistics
FONAR	Fuel Oil Non-Availability Report
P&I CLUB	Shipowners Liability Insurance to covers liabilities and expenses to third parties that arise from owning or operating a vessel.

Table of Contents

Figure list

Table list

1. Introduction

Transportation of goods with ships accounts for over 80% of all world trade. The global sea trade is vital to the world and any disruption or change in regulations will lead to delays and non-delivered goods (Grynspan, 2022). With the significant number of vessels operating around the world there is a need for regulation, especially to reduce emissions. Already in the early 1900s the first international agreement on combating pollution from ships was implemented (Gold, 2006, p. 116). Further international collaboration on reducing emissions from ships have been successful in implementing and policing restrictions on the most prominent pollutants. One such pollutant is Sulfur oxides, with the first limit cap being set in 2005 (IMO, 2023). All restrictions implemented internationally lead to a change in the maritime industry. The SOx restrictions were received with skepticism from the industry, because of the major changes to fuel production and the repercussions following such changes. One of the major skepticisms to the limit was what effect the new fuel blends would have on the engines, and how this effect would influence accidents and damage.

1.1 Research Problem

Based on the circumstances mentioned above, this thesis will focus on the effect of the SOx restrictions and try to answer the research question *"How does the IMO restrictions on sulfur oxides affect insurance claims on marine fuel engines?"*

1.2 The Thesis Purpose and Structure

To address the research problem, three crucial elements need to be studied. These are illustrated in figure 1. These elements are essential for a purposeful examination of the connection between the SOx restrictions on fuel, the effects on the propulsion system on ships and how marine insurance claims on engines are affected.

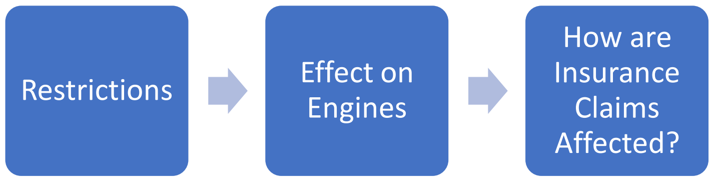


Figure 1: The Three Key Elements of The Research Problem

To elaborate on the effect of the SOx restrictions it will be useful to examine claims data dating back to the first SOx restriction and make continuous comparisons between the implementation of restrictions and the potential patterns and claims data to ascertain whether the SOx restrictions have had any effect on marine engine claims.

The initial part of the thesis will be delimitation to set clear boundaries and give focus to the research ahead. Related theories and research will be explored to assist in explaining the findings researched in this thesis. Following the theoretical segment, the methodology section will present the actions taken to investigate the research problem. At the same time, I will also be describing the techniques and processes I used to identify, select, and analyze the collected data. Ultimately, I will present my findings and discuss them in relation to the research problem.

1.4 Delimitation

Delimitations of the study is crucial in defining the boundaries of the research conducted in the thesis. Given the scope of the research problem, it is essential to show what I intend to delineate through exclusionary decisions based on the irrelevance and non-feasibleness of certain aspects.

Gard and CEFOR Claims Data

I have obtained two sets of data from Gard AS. One containing the claims data for the Hull & Machinery claims segment from 2005 to 2022. The other providing the total amount of ships insured in the Hull & Machinery segment, categorized by vessel groups. The datasets will be used in correspondence with each other to establish generalizability regarding the impact of the SOx restrictions on the Hull & Machinery of the insured vessels. Furthermore, the claims data from CEFOR will be used to ensure further generalizability and facilitate comparisons between the datasets.

Hull & Machinery Claims

Focusing on the Hull & Machinery segment within marine insurance will delineate the research, as the restrictions have likely had an impact on marine fuel oil that are related to claims in engines. Stemming from the effect of the implementation of restrictions on the fuel used in engines as outlined in ISO 8754:2003 (ISO, 2003). This standard permits diverse blending of marine fuel oils to meet the SOx limit that presumably holds significance for the operation of marine fuel engines. This effect will be examined in the theory segment of the thesis.

In the NoMIS database, machinery claims are the largest contributor to the overall claims by type and cost on marine insured vessels as depicted in figures 2 and 3.

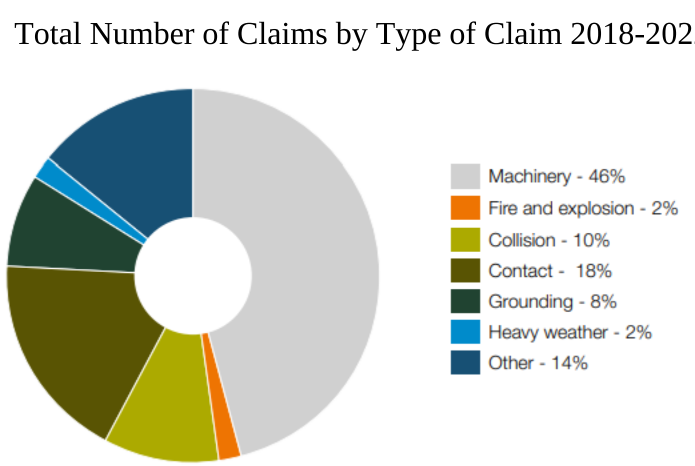


Figure 2: Total Number of Claims by Type of Claim 2018-2022 (CEFOR, 2022).

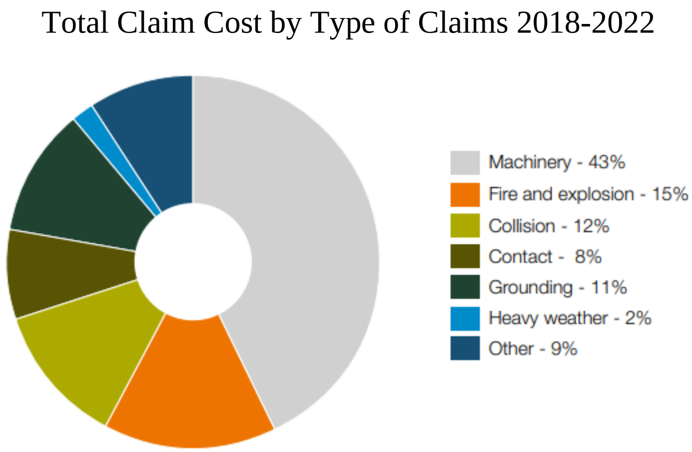


Figure 3: Total Claim Cost by Type of Claims 2018-2022 (CEFOR, 2022).

CEFORs database NoMIS uses reported data from the Nordic marine insurers, and in 2022, the numbers of registered vessels were 36 400 that is 34,5% of the world fleet (UNCTAD, 2023). In the Hull & Machinery segment, Gard insures 32,6% of the total vessels registered in the NoMIS database. Therefore, the data acquired from Gard and CEFOR can be considered as significant and valid sources for representing the insured vessel segment in the thesis.

The insured vessels in the dataset from Gard does not include all vessel categories within the world fleet. However, all major mercantile vessel groups are represented within the Hull & Machinery claims segment. These groups include Bulk, Gas Carriers, Container, Passenger, offshore, tankers, etc. These mercantile vessel groups are presumed to be sufficient for a representative sample of the vessels most likely to be affected by the SOx restrictions, thus merging vessel groups such as mobile offshore units, fishing vessels, smaller passenger vessels and recreational craft (Sjøfartsdirektoratet, u.d.). Each of the mercantile vessel groups insured by Gard is represented in figure 4.

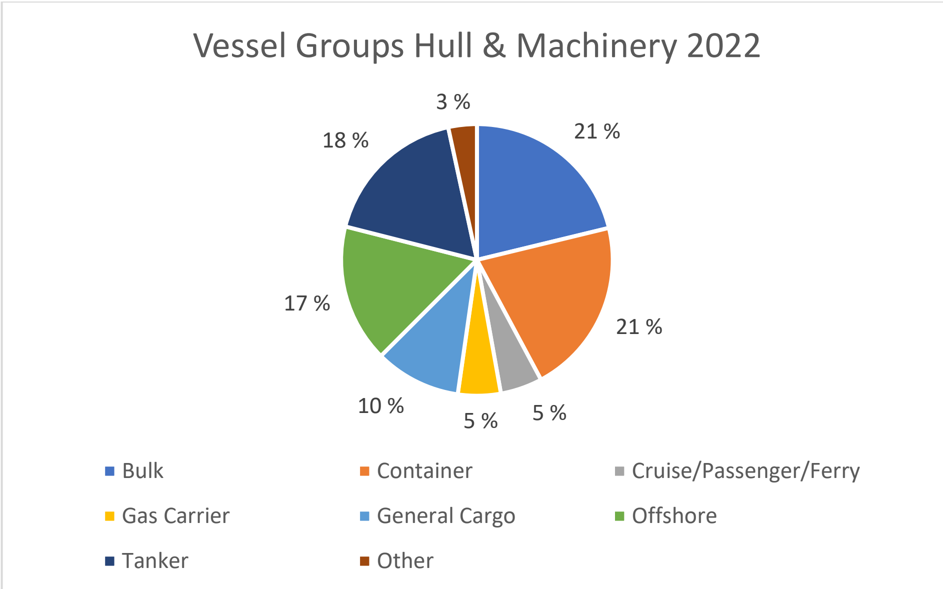


Figure 4: Vessel Groups by Type 2022 (Gard, 2022).

Claims Frequency and Engine Damages/Failure

To accurately portray the datasets collected in diagrams and figures it is imperative to investigate the possible sources of error when it comes to claims frequency within the Hull & Machinery segment. When examining the frequency of claims, there is no indication of what caused the claim in the first place. The causes can include human error, natural causes, or technical breakdown of equipment or machinery. The causes of failure/damage to marine engines have been delineated because of the influence by the SOx restrictions, as disclosed in the theory segment of this thesis.

2.0 Theory

2.1 MARPOL & SOx Regulations

MARPOL is the International Maritime Organizations (IMO) International Convention for Prevention of Pollution from Ships. This convention is the legal foundation restricting SOx emissions from ships, notably through Annex VI regulation fourteen as mentioned earlier. The annex came into force 19 of May 2005 (IMO, 2023), and defined the SOx limit for Sulfur Emission Control Areas (SECAs) and global sea areas not within the SECAs.

The annex was established to reduce air pollution from the marine industry. By restricting the SOx content in marine fuel oils, it was forcing ship owners, manufacturers, and distributors to create alternatives and substitutes for marine fuel oil with high sulfur content. This change in marine fuel oil composition led to uncertainty about the repercussions of changing fuel blends. Cat fines, handling, and lubrication were and are some of the factors the industry is concerned about.

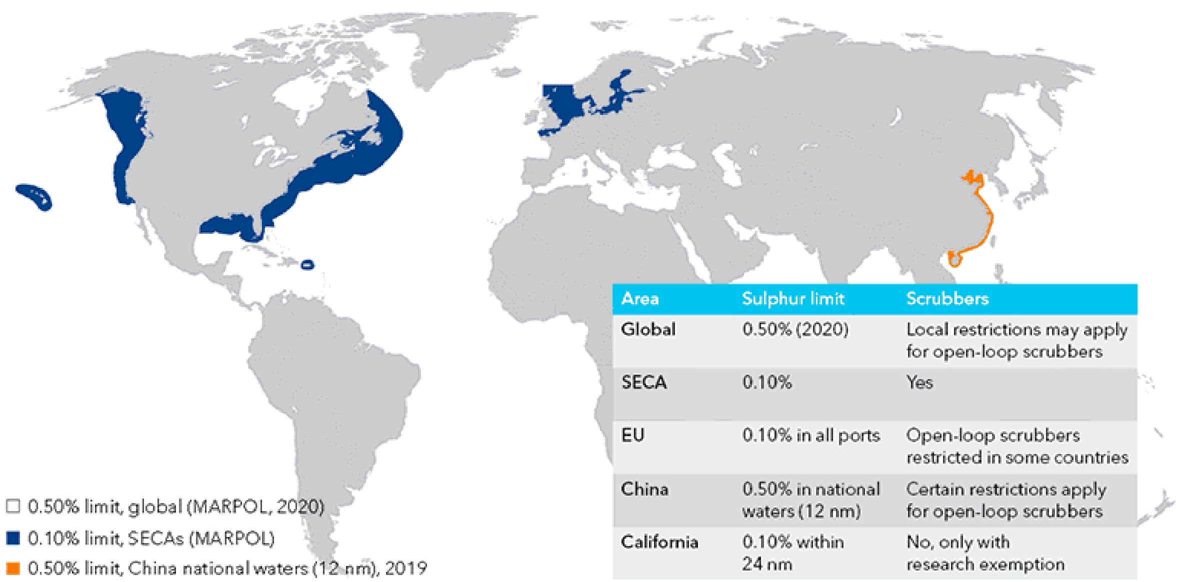
Statistics for the periods between the implementation of progressively stricter restrictions are important to examine. As discussed before, Annex VI of MARPOL has been in force since 2005. Additionally, the main stages of implementation of further restrictions on SOx content in marine fuel were for SECA in 2010 and 2015, and for the global sea areas 2012 and finally 2020 (IMO, 2023).

Table 1: Overview of SOx Limit Implementation in SECA and Globally.

<table>
<tr><th rowspan="2">Effective from</th><th colspan="2">Suplhur content Limit</th></tr>
<tr><th>SOx, ECA</th><th>Global</th></tr>
<tr><td>15 May 2005</td><td>1,5%</td><td rowspan="2">4,5%</td></tr>
<tr><td>01 July 2010</td><td rowspan="2">1,0%</td></tr>
<tr><td>01 January 2012</td><td rowspan="2">3,5%</td></tr>
<tr><td>01 January 2015</td><td rowspan="2">0,1%</td></tr>
<tr><td>01 January 2020</td><td>0,5%</td></tr>
</table>

2.1.1 SECA

SOx Emission Control Areas (SECAs) as depicted on figure 5, are the designated areas where the SOx content in fuel is limited to 0,10%. The regulations have been in place in the various SECAs since 2005, with the Baltic SECA being the first and The United States & Caribbean SECA being the last one implemented in 2013 (IMO, 2019). It is interesting to study the effect the restrictions have had on insurance claims with ships navigating within, to, and from these areas. The increasing number of scrubbers installed in vessels to be compliant with the restrictions also present an interesting aspect for further exploration. As it shows the possible short-term thinking the industry is influenced by.



Area	Sulphur limit	Scrubbers
Global	0.50% (2020)	Local restrictions may apply for open-loop scrubbers
SECA	0.10%	Yes
EU	0.10% in all ports	Open-loop scrubbers restricted in some countries
China	0.50% in national waters (12 nm)	Certain restrictions apply for open-loop scrubbers
California	0.10% within 24 nm	No, only with research exemption

Figure 5: Overview of SECAs in The World (DNV, 2019).

2.2 Limit on SOx

On January 1st, 2020, IMO implemented the strictest limit SOx in marine fuel as measure to combat toxic air, and pollution (IMO, 2021). This regulation, known as Regulation 14 of MARPOL Annex VI, mandated a reduction in the limit from 3.5% to 0.5% (EPA, 2023). The IMO provided regulation guidance in November of 2018, to support the transition to the new 0,5% limit of SOx (IMO, 2018). The implementation has thus far demonstrated a high success rate with only twenty-two vessels filing a FONAR by the 5th of December 2023 (IMO, 2023)

In 2013, the European Geoscience Union published a research article highlighting the hazardous health effects of SOx emissions from marine fuel. According to the article, the reduction of SOx in the global air, would improve the annual mortality rate, and save lives. (Partanen, et al., 2013). The dual concerns health hazards and environmental pollution attributed to SOx within marine fuel prompted IMO to implement and enforce these significant restrictions.

2.3 ISO Regulation

ISO is an organization that delivers standards across various industry sectors such as technology, manufacturing, and management (ISO, 2023). ISO sets the standards for marine fuel oil, also known as residual fuel oil. In response to the restrictions implemented by IMO in relation to SOx in marine fuel, ISO has published specifications for fuel standards aligning with MARPOL annex VI regulations. As of 2021, ISO 8754:2003 is the standard prevailing standard for marine fuel oil (ISO, 2003). The standard includes the processes of verifying SOx content and provides the framework to determine the compliance of vessels operating on marine fuel oil.

The most essential ISO regulations when it comes to marine fuel oil are ISO 8216 and 8217. These regulations specify manufacturing, refining, machine characteristics, and compliance with, international, national, and regional standards (ICCT , DieselNet, 2018). ISO is crucial in defining the types of marine fuel oils ships can use whilst remaining compliant with IMO standards, therefore playing an important role in the industry adherence to international regulations and environmental standards.

2.4 Marine Fuel Types

Given the nature of the SOx restrictions, it is important to disclose the types of compliant marine fuel ships can operate with. The compliant marine fuel oils are Very Low Sulfur Fuel Oil (VLSFO), Marine Gas Oil (MGO) and Liquified Natural Gas (LNG) (IMO, 2021).

VLSFO is a marine fuel type where the SOx content does not exceed 0,5%. In comparison to HFO, VLSFO is a distillate blended with varying degrees of viscosity and density to meet the specifications set in the ISO 8217 standard (Einemo, 2021).

MGO is a crude oil product, usually made from a blend of distillates and possessing a higher density than diesel(gasoil). An advantage of MGO is that it does not require heating during storage. Additionally, operating on MGO results in reduced amount of particle pollution in emissions compared with HFO. However, MGO tends to have a higher average price when compared with VLSFO (Oiltanking GmbH, 2023).

The third compliant fuel type is LNG, this type of fuel is used by a small but growing segment of the world fleet, with 641 active ships in August of 2022 (Maritime Cyprus, 2022). LNG is compliant with the SOx restrictions implemented by IMO. As a fuel it boasts a favorable price compared with MGO and has environmental advantages, leading to an increase in newbuilds being outfitted with LNG-operated engines (DNV, 2023).

2.5 Scrubbers

Regulation 14 (MARPOL Annex VI) provides an alternative method for addressing the SOX limit by allowing the utilization of Exhaust Gas Cleaning System (ECGS) while operating on HFO (IMO, 2017). ECGS commonly known as scrubbers, is a system designed to extract the Sulphur from the exhaust gas, and subsequently discharge it. There are two categories of ECGS: wet and dry. Within these categories four distinct designs exist: open loop, closed loop, hybrid, and dry system.

The first three designs – open loop, closed loop, and hybrid – utilize seawater or freshwater to remove SOx from the exhaust gas, with discharge options on either on land or at sea. The open loop system employs seawater, closed loop uses freshwater, hybrid systems have the flexibility to use either seawater or freshwater. In contrast, dry units work with calcium hydroxide to clean exhaust gases (OCIMF, 2016).

With the implementation of the global SOx cap in 2020 the increase in vessels operating with scrubber systems (ECGS) has increased dramatically from 2007 to 2023. The number of vessels with ECGS has surged from 1 in 2007 to over 4300 having either installed or ordered scrubber systems in 2023 (Statista, 2023). Showing the potential impact, the SOx regulations have on the maritime industry.

In 2020, Peter Smith, a safety4sea author, published an article on the impact of scrubbers on marine claims from the P&I club perspective (Smith, 2020). Smith detailed various types of scrubbers, number of that were installed in 2020, and, most importantly, the predictions and outcomes of the 2020 SOx regulation limit. Safety4sea is a leading publicist company on new, safer, smarter, and greener shipping. (Safety4sea, 2023), and according to the Safety4sea IMO 2020 team's predictions, there was expected to be a substantial increase in scrubber-related claims (Smith, 2020).

However, at the time of the article publication, the number of claims were significantly lower than anticipated. Smith suggests multiple possible explanations, including fewer vessels being equipped with scrubbers, a balancing on price point of low and high SOx fuels, adherence to industry guidance, and actors' preparedness for the new SOx cap. This observation aligns with the notion that the maritime industry has seen an increase in quality procedures and guidelines for operating vessels since the initial implementation of the SOx restrictions.

2.6 Marine Propulsion

To further understand the research problem, it essential to explain the marine propulsion system and the specific impact of the SOx regulations within this system. A marine propulsion system is the technology used to thrust water-borne craft on water (Nautilus Shipping, 2022). In Gard's vessel portfolio, the marine propulsion system is typically a marine diesel engine consisting of multiple components. However, for the purpose of this thesis, the focus will be on the components of the main engine and auxiliary engines affected by the regulations.

According to the World Wide Journal of Multidisciplinary Research and Development there are four main elements of risk with operation on VLSFO: Low viscosity, low lubrication, acidity and flash point (Troung, Le, & Dong, 2019). Understanding how these elements affect the risk picture of marine propulsion systems are crucial to understand the occurrences of breakdowns and failures of marine fuel engines.

Low viscosity in marine fuel poses a potential risk to the operation of the engine fuel pumps. Firstly, it may disrupt and cause the failure of the hydrodynamic film, which will result in seizures, manifesting as locking or freezing of the engine. Secondly, it can result in unsatisfactory pressure in the fuel injection, consequently leading to complications when starting and doing low-load operation of the engine. Lastly, low viscosity might contribute to an inadequate fuel index margin, thereby limiting the achievability of the engine accelerating (Vos, 2022).

Low lubrication poses an increased risk of damage to the engine, as it directly impacts the essential mitigations lubrication delivers to an engine. Lubrication serves crucial roles in the propulsion system, including reduced friction, prevents machine wear, protection from corrosion, sealing, transport of contaminants to filters, and colling by circulation of heat between components in the engine (Graco). In the context of marine engines, low lubrication has been identified as the primary cause of engine damage and has been researched extensively by marine insurance companies. Notably, as seen in table 2, the most prevalent damage claims involve cylinder/liner and crank shaft/bearing issues. The Swedish Club contributes the issues to low lubrication (Stålberg, 2023).

Table 2: Damage Parts in Engines (Stålberg, 2023).

Damaged parts	No. of claims	Average cost (USD)
Crank shaft/bearing	28	1,194,092
Camshaft	4	880,114
Cylinder/liner	32	543,623
Bearing	17	588,168
Piston	7	391,419
Fuel pumps	19	227,940
Cylinder cover	4	195,699

Every marine fuel type contains naturally occurring levels off acid. This can potentially cause damage in the fuel injection equipment given the corrosive nature of the acidic compounds. However, according to Chevron marine, no conclusive correlation has been found between acid level number in marine fuel and corrosiveness (Vermeire, 2021).

2.6.1 Cat Fines

IMOs restrictions on the SOx content in marine fuel oil have led to concerns within the maritime insurance community, particularly regarding cat fines in marine fuel oil, especially for VLSFO compared to HFO. Cat fines are defined as small particles in the marine fuel oil with critical hardness that can damage the engine systems, causing typical damages to the fuel pump, piston system, injectors etc (Alfa Laval, 2018).

A collaborative study between the Joint Hull Committee (Lloyd's/(IUA)) and Braemar (The Salvage Association) in 2013 analyzed reported engine claims data caused by cat fines in marine fuel. The study found a correlation between the increase in cat fine claims and the demand for VLSFO. Moreover, the main argument for the rise in engine claims is not necessarily the fuel itself but rather the crews lack of experience and maintenance procedures (JHC, 2013). This opinion is shared by several actors within the marine insurance industry, and the likely solution to avoid engine failures by cat fines is, training and implementing proper maintenance procedures. These procedures include sampling, regular testing, usage of purifiers, appropriate fuel storage, and equipment (Gard, 2014).

2.7 Hull & Machinery Claims

In marine shipping, claims are categorized into segments, and for this thesis, a particular emphasis will be placed on the Hull & Machinery segment. The Hull & Machinery claims cover encompasses insurance for physical damage to the ship, salvage, collision liability, damages to fixed and floating objects and recovery actions. Coverage is highly relevant to the thesis as it forms the basis for the later data analysis, focusing specifically on engine and sub-engine breakdowns and failures. The presence of cat fines in fuel poses a significant concern within the marine fuel industry, along with the improper equipment maintenance aboard vessels that often leads to claims.

2.7.1 Claim Frequency

Claim frequency is commonly used in the marine insurance market as one of the factors to assess future premiums. It refers to the number of claims the insurer has had or expects to have during a given time period. This prediction is based historical claims data, comparing of patterns and trends, while considering both internal and external factors that can influence the frequency.

CEFOR, engaged in significant research on marine claims since 1954, has been a key participant to the insight into claims frequency. In 1992, CEFOR compared their members' claim data to the total world pool an effort that has continued to the present day (CEFOR, 2011, s. 137). The data collected from members focuses on two areas: total loss trends and claim frequency. As claim frequency is an integral part of the analysis segment of this thesis, attention will be given to this focus area.

2.8 Human Error

Human factors play an important role in marine insurance claims, and the factors become significant when examining the impact of the SOx restrictions. This is due to the importance of maintenance checks and protocols, especially when operating on different blends of marine fuel, with many checks and inspections being recommended on a monthly or weekly basis (Jensen & Jakobsen, 2019).

Human error is often identified as the common cause in most claim cases, prompting discussions about the importance of the human factor in the Hull & Machinery claims segment. Studies suggest that the implication of the human error factor can range from 50-90% (Kuo, 1998, p. 107). Understanding the impact of the human error factor and its role is vital, especially in the context of new regulations.

Newer research, contributing 80 % of the causes to maritime accidents worldwide, emphasizes that maritime accidents comprise failures and breakdowns beyond those involving only the Hull & Machinery segment (Anantharaman, Islam, Khan, & Garaniya, 2020). Human error, operationalized as human decisions and design solutions leading to accidents, is a common factor in marine accidents (Kuo, 1998, p. 108). Hull & machinery claims can be the result of decisions like neglecting maintenance protocols relying on intuition rather than knowledge. Whereas engine design may cause claims in the long run, human error will continue to influence Hull & Machinery claims as long as the operation of vessels involves humans. Recognizing the human factor and its dynamics, is crucial for an understanding of causes of claims in the marine industry.

3.0 Method

3.1 Thematic

The selection of the theme for this bachelor thesis was restricted to align with the study course of Shipping Management in a broad context. The research problem has been sufficiently narrowed down to provide a comprehension of the maritime industry. Additionally, the chosen theme is relevant to the ongoing green transition of the global marine fleet, making it directly relevant to the Shipping Management study course. This alignment of the theme ensures that the contributed research not only assists further academic understanding but also contributes to the practical considerations within the maritime industry.

My internship this semester was with Gard AS, one of the largest players within the marine insurance industry with a worldwide market share of 17% (Thorbjörn Emanuelsson, 2023). Gard operates primarily in the P&I and Hull & Machinery segments. Throughout my internship, I have acquired an interest for environmental restrictions and their effect on marine insurance. Deliberation with my company supervisor and the Gard team highlighted the significance of examining claims frequency in the Hull & Machinery segment.

To effectively examine the research problem, acquiring historical data spanning several years was crucial. The implementation of SOx restrictions since 2005, provided considerable available information and data to be investigated and correlated against the data from the Hull & Machinery claims. Consequently, my research focuses on understanding the impact of SOx restrictions on insurance claims in the Hull & Machinery segment, an important area within the marine insurance industry.

Building on earlier research and theory is essential for the relevance and prominence of the research results (Larsen, 2020, p. 35). The research problem centralizes the theme of the thesis and must be accurately defined. Meeting essential requirements, such as the research problem should be compelling to the student, the research problem should be based on existing research and theory, and the research problem should be able to support multiple viewpoints. This is vital to formulating a compelling and satisfactory research problem.

The research problem serves as the cornerstone of the thesis, and has an instrumental influence on research design, analysis targets, and the overarching theme. The research problem, "*How does the IMO restrictions on sulfur oxide affect insurance claims on marine fuel engines?*" is central, highlighting the need for an understanding of how the marine industry adapts to implemented restrictions. This also contributes to my knowledge of the shipping industry. As my work with the thesis has progressed, I have gained some insight to the intricacies of the shipping industry and the vital role of marine insurance, making the investigation both compelling and rewarding.

Based on earlier research and development, the research problem has given me the opportunity to delve deeper into the overall theme of the thesis. The combination of a compelling theme, well-defined research problem and existing research and theory in the field has made working on this thesis exciting and stimulating. The research problem is open to interpretation, providing the opportunity for both negatively and positively angled viewpoints. This flexibility gives way for the research problem to be researched differently than my own interpretation and opens for critical awareness and encouraging reflection (Grennes, 2019, p. 210).

The research problem can be seen as explanatory, as the variables researched are interlinked. The claims frequency is affected by numerous parameters, and it is therefore difficult to narrow down claim causes when only looking at the overall claim frequency. Focusing on the claim frequency of Hull & Machinery claims in the context of the SOx restrictions was the most viable approach to untangle variables and parameters that seemed unfeasible.

Defining variables is an essential part of the thesis, as it clarifies concretely what is researched (Larsen, 2020, p. 41). The research problem is formulated as to illuminate the context and comprehension, rather than provide definitive answers or solutions (Larsen, 2020, p. 27). As stated before, the research problem is open for further research and reflection, making it well suited in a student thesis.

3.2 Methodical Approach

Essential to the research conducted in this thesis is the selection of method used to acquire and analyze data imperative to the research problem. This is crucial because in the process of collecting the data, by gathering, grouping, and structuring, it might become disorganized even if the impressions of the data in the process are answers to the study questions already presented (Grennes, 2019, p. 113). To convert these impressions into meaningful knowledge, we must arrange the acquired data correctly, the tool for doing this correction is called methodology.

In methodology the terms “quantitative” and “qualitative” methods, whether combined or used individually, are regarded as fundamental for scientific studies. However, before these terms can be clarified, the design of the research itself holds essential importance.

3.2.1 Explorative, Descriptive, and Causal Design

The research design is a detailed plan explaining how to reach the scientific goals of the study (Grennes, 2019, p. 102). Every plan is exposed to revisions and variables that can change the original plan, and it is vital to acknowledge that all research designs that are unique. However, there are certain designs looked upon as ideal, Gilbert A. Churchill outlines three ideal research designs: explorative, descriptive, and causal (Churchill, 1991). The research design for the methodology used in this thesis will be descriptive. Within a descriptive research design, the focus will be on the variables associated with the research problem and the contextual relationships between these variables.

3.2.2 Deductive or Inductive Approach

The methodology is further characterized by the choice of a deductive or inductive approach. The deductive approach will focus on the theory related to the research problem and established research (Larsen, 2020, p. 24). Employing this approach involves the gathering of data during examinations based on hypothesis or research questions, ensuring that the research is conducted in a way that has theory and established research in mind.

In contrast, the inductive approach will have a more open procedure where the research problem is typically established after the data collection has been completed (Larsen, 2020, p. 24). This method of approach is usually chosen when the researcher wants to base their study theories on their findings, allowing for the development of theories during the examination and data collecting phase.

In the research processes, it is often impractical to separate the two method approaches completely. The pragmatic approach also known as the abduction approach, is more appropriate as the exchange between empiricism and theory is fluent and unfettered. This interchange initiating new questions that need to be answered arising from findings during research (Larsen, 2020, p. 25). A deductive approach was chosen as a starting point for this thesis. The choice was influenced by established theorem and research that had already been conducted on the theme, enabling a stronger focus on the nuances of the research problem.

3.2.3 Qualitative vs Quantitative

To collect the data crucial for answering the thesis research problem, there is need for a qualitative or quantitative approach. The quantitative approach involves conversion of the collected data into numerical propositions, making them quantifiable and suitable for statistical analysis (Grennes, 2019, p. 115). In contrast, the qualitative approach seeks to gather data relating to the feelings and opinions the units examined have about the theme of the study.

Within the quantitative approach, examinations are often descriptive, comparative, or relational, whilst a qualitative approach aims for the examinations to be descriptive, phenomenological, or ethnographic (Larsen, 2020, p. 26). Quantitative examinations are therefore characterized by inequality and distance, whilst qualitative examinations are characterized by closeness and equality (Grennes, 2019, p. 192).

3.3 Quantitative Method

The chosen scientific method for this thesis was quantitative, as this method emphasizes the use of statistical analysis of the data collected to explain phenomena such as the research problem (Larsen, 2020, p. 27). The quantitative method for this thesis is based on secondary data collected from Gard AS and CEFOR, aligning with the descriptive nature of the research problem. The goal being, illuminating context between the SOx restrictions and the claims frequency in the Hull & Machinery segment. A primary data collection was seen as unnecessary, as the data for claims within the Hull & Machinery segments had already been collected. Instead, the focus was on collecting the correct segments from the abundant available data.

Data collected from secondary sources will usually be found within two segments.

1. Data collected especially for the research examination and that would not have existed without collection.
2. Data independent of the research examination (Grennes, 2019, p. 154).

For the quantitative method, the data collected falls within the second segment, as the information is from Gard and CEFOR databases. In comparison to primary data collection, the secondary method is less costly and labor intensive. Given the amount of data available in Hull & Machinery claims, claims frequency numbers, and SOx restriction data, the assessment was that secondary data would be sufficient for the thesis.

The reliability of the secondary data used in the analysis is strengthened by its source, as the data has been collected from Gard and CEFOR members. This data is collected from direct reporting from the members regarding their claims within the Hull & Machinery segment. While this method might pose a limitation by the possibility that certain or minor claims are not reported by members, steps were taken to remedy this limitation. I put a limitation on minor claims that had insignificant payouts, and further deliberation with Gard AS also confirmed the notion that these minor claims that were supposedly not reported, would have little effect on the claim frequency.

Secondary data has its downsides, and as research is done with secondary sources there are limitations and possible drawbacks. One concern is the potential of misinformation or data that is not relevant for the research problem (Grennes, 2019, p. 154) To remedy these possible risks, I made sure to collect data form secondary sources that were relevant to the theme of the thesis, according to my understanding of the research problem and its implications. To evaluate the data selected from the secondary sources, I focused on earlier theories and research where the data had been used, validating the data relevance.

Another problem with using secondary data is the inherent distance between the examined participants and the researcher. Information gathered from secondary sources may provide insight into behaviors and not the attitudes of the participants (Larsen, 2020, p. 50). However, given that this thesis is based on a research design that has a descriptive design that focuses on explanation and contextualizing the research problem, rather than finding specific answers and solutions.

I had limited prior knowledge about the theme of the thesis and saw it as important to study earlier theories and research. As such, I concluded that secondary collection was the most desirable approach for obtaining information relevant to the research problem. The data, collected by experts in their respective fields within the Hull & Machinery claims segment, can be seen as valid and relevant to the research problem and theme of the thesis.

3.3.1 Study Population

The study population chosen for this thesis was based on the secondary data. To analyze the data correctly the population examined must be defined. In this thesis, the population is defined as vessels registered at Gard affected by the sulfur restrictions from 2005 to 2022. Furthermore, a subset selection within the population was determined to examine the research problem closer. This selection was chosen to be insured vessels of Gard within the Hull & Machinery claims segment. The main problem in choosing this type of selection, is selection error whereas using the entire study population opens for measurement errors that are usually qualified as random and systematic (Grennes, 2019, p. 161).

When a subset selection has been done in the study population, one has to designate whether the selection is probable or non-probable. Probable selection is reserved for generalizing statistics where all units in the study population could be identified and selected for the examination (Grennes, 2019, p. 164). Non-probable selection is characterized by being chosen by the researcher. Consequently, the selection cannot be used to generalize, and the units within a non-probable selection are only delineative for themselves. As such, a selection of the ships within the Hull & Machinery claims segment was chosen, as any of the study population units could have claims during the period between 2005 to 2022.

3.3.2 Processing of Data

Effective organization and simplification of the collected data is crucial to properly analyze, understand, and discuss the findings (Larsen, 2020, p. 59). In this thesis, the data were organized in time intervals based on the implementations of the SOx restrictions. This classification was done to create distinct categories to the values and variables under examination. The processing of data into classifications are a crucial procedure to verify the validity and reliability of the thesis (Larsen, 2020, p. 111).

3.3.4 Data Analysis

The data analysis is the next step after processing the collected data, characterized by systematically organizing, designating, and structuring of the processed data. This structuring makes the interpretation of the data material accessible, achieved by coding and categorizing the different variables and values while eliminating irrelevant information regarding the research problem. This process heightens the probability of drawing correct interpretations from the available data.

The initial step in data analysis involves reducing the amount of information that has been collected by categorizing or employing other processes that will give us transparency and knowledge of the data material (Grennes, 2019, p. 204). Quantitative analysis is used for this purpose and is often approached in two ways. The first is descriptive based quantitative analysis, focusing on how variables and values are distributed in the data material, giving a numerical overview of the data material researched (Grennes, 2019, p. 199). The second method of analysis is inductive, aiming to find relationships between variables by using bi- or multivariant analysis. The next step in the data analysis of this thesis is to actualize the deduced relationships. Using a tool such as the Chi-square is one way of doing just that. The Chi-Square will give us the significance level of the relationships thereby, actualizing the deduced relationships (Grennes, 2019, p. 201). In this thesis I will use the deductive quantitative analysis method.

3.4 Validity and Reliability

The three factors validity, reliability and transferability are considered crucial to the quality of a study, as these factors are required to assess the credibility of the research conducted. Critical assessment of the empirical study is necessary to evaluate these factors (Grennes, 2019, p. 141).

3.4.1 Validity

Validity is the relationship between what is researched and the research problem. Especially involving the assessment of the consistency between the theoretical and empirical segments of the study (Grennes, 2019, p. 142).The theoretical segment is often defined by the research problem, phenomena, and the framework of the study. The empirical segment is characterized by measurement of data through collection and analysis. Two types of validity stand central in the assessment of a study, internal and external. Internal is the consistency between the theoretical and empirical segments of the study. Internal validity is, therefore, what findings the study presents, and if the information given is consistent with the research problem (Grennes, 2019, p. 141). External validity is measured by what level of relevance the empirical measurements has compared to other sources. Nonetheless, it is important to consider validity in all segments of the study, such as the data collection, data analysis, and interpretation (Larsen, 2020, p. 94).

3.4.2 Reliability

Reliability is a factor of assessment that is based on whether the measurements that leads to the result of the study has been done in the most exact way possible (Grennes, 2019, p. 145). High reliability relies on the accuracy of the measurement tools used to collect data and the exactitude of the data analysis. In a quantitative study, credibility is achieved by other researchers being able to use the same data to reach the same conclusions. (Larsen, 2020, p. 94). Stability in the examination, collection of data and testing are therefore important to achieve high reliability in a quantitative study.

3.4.3 Limitations

Quantitative methods involve a more objective approach to the research problem than that of qualitative methods. The data is often controlled, used to compile facts, and derive causes of practices. Consequently, quantitative methods tend to be more focused on the statistical value of the research rather than the human factor. Furthermore, the conclusions found whilst conducting the statistical research are often explained as methodological and substantial with both having their limitations.

The methodological limitations I have focused on are low validity, low reliability, bias of sampling, and effect of the data analysis arrangement. Nonexistent consistency between the theoretical and empirical segments might give the misleading findings causing conclusions that are irrelevant to the original research problem (Larsen, 2020, p. 80). Additionally, measurement errors in the processing of data will lead to misgivings in the data patterns. Another limitation is bias of sampling where the units chosen to represent the population are inaccurate and will lead to a misconducted generalization of the population. Incorrect grouping of variables in the statistical research might lead to the wrong impression of the data collected (Larsen, 2020, p. 81).

I made sure the theoretical and empirical segments were consistent by basing my analysis on already established parameters. The data I have collected is available through Gard on request and publicly through CEFOR and enables data repetition. The sampling of the population chosen for this thesis is a good representative of the merchant vessels affected by the SOx restrictions, thereby being a satisfactory candidate for generalizability. Finally, I grouped the variables in a sensible way to ensure the correct impression of the data material.

Substantial conclusions provide insight about the reality we study (Larsen, 2020, p. 81), but are not without limitations. One limitation is the wrong interpretation of connections between variables, where one variable might appear to be affected by another variable, but is, in fact, affected by a third variable. To circumvent this limitation, I looked at the drawn conclusions in context with established theory and research. The other two limitations I considered associated with substantial conclusions, is based on the characterized groupings of variables, notably level and time fallacy. The level fallacy limitation was avoided by the selection of the sampling group as stated in the preceding paragraph. Time fallacy limitation is seen as an inapplicable limitation as the data material is collected spans over a period of 17 years, minimizing its impact.

The risk of limitations affecting the research process is prevalent in all studies. In quantitative studies, it is crucial to examine the possible effects these limitations might have on validity and reliability. The data material has been carefully selected and processed to justify the conclusions drawn, considering the theoretical and empirical segments. With data material that is collected from a time-period of two decades and are drawn from open sources, I assert the validity and reliability of this study to be high.

4.0 Results

In this segment, I will present the processed and analyzed data material. The data presented in this section is based on Hull & Machinery claim data. The material is organized into categories to present the empirical data in an orderly fashion. The data is compiled from the collected data and is presented in four sections. Section A is the SECA time periods, section B illustrates global sea areas time periods, section C depict the overall time period, and lastly, Section D will include tables of the peak claim years. ¨

4.1 Section A SECA

Section A includes the time periods of restriction implementation in the SECAs. This section covers the time periods of 2005-2010, 2010-2015 and 2015-2022 to illustrate the impact of the SOx restrictions.

In the first time period 2005-2010, the yearly claim distribution of claims compared to the amount of registered ships within each vessel type was as seen in figure 6 high for general cargo, cruise/passenger/ferry, and gas carrier at the start of 2005. The trend of yearly claims had a downturn until 2007-2008 where it rises for all segments except bulk, cruise/passenger/ferry and offshore. After 2008 there is a decrease in the yearly claim distribution, ending in what can be seen as a stagnation in 2010.

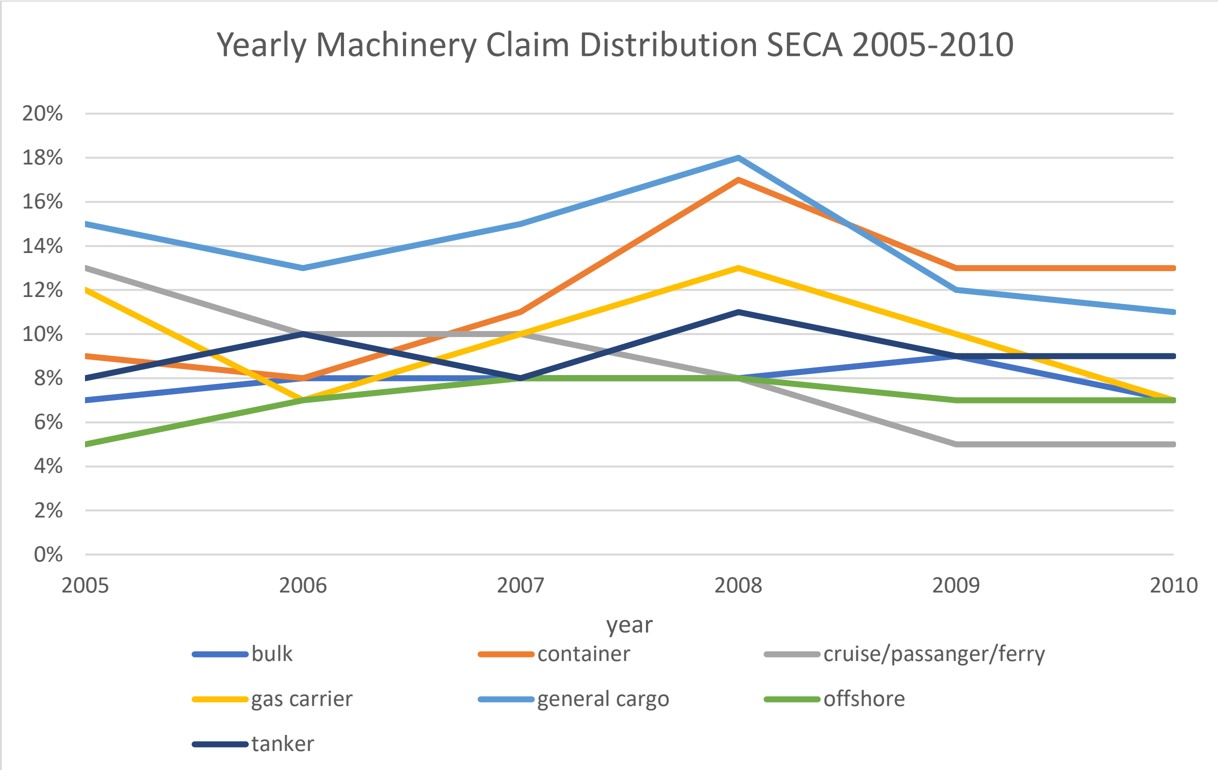


Figure 6: SECA Yearly Claim Distribution 2005-2010.

Spanning 2010-2015, the second time period is seemingly affected by fluctuations in the yearly claim distribution. figure 7 illustrates a rise in the percentage in the container, general cargo, and bulk segments after the stagnation in 2010. From 2012 to 2014 the yearly claim percentage has a falling trend. However, figure 7 depicts a steep rise in claim percentage for the container, offshore and cruise/passenger/ferry segments.

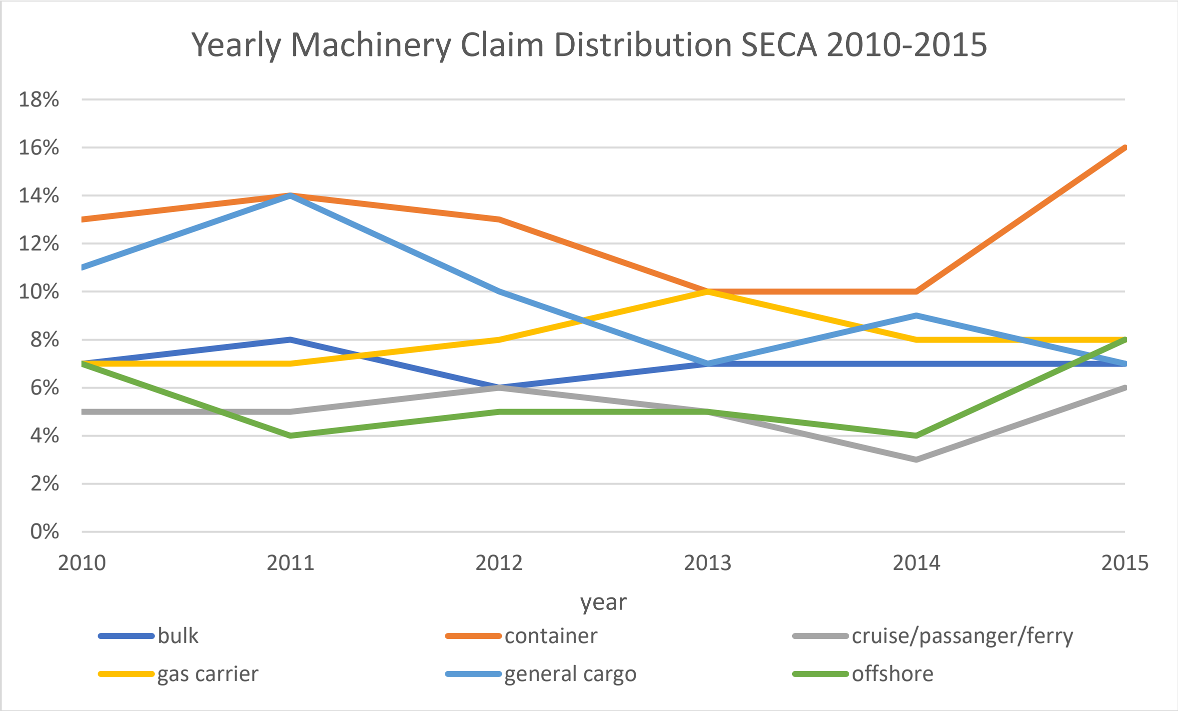


Figure 7: SECA Yearly Claims Distribution 2010-2015.

The last time period in Section A, continues to show the falling trend of the yearly claim distribution as seen in figure 8. The steep rise seen for container, offshore and cruise/passenger/ferry also see a drastic fall in the yearly claim distribution. A rise in the general cargo and tanker segment are seen between 2017 and 2018. Yet all segments have a falling trend in the yearly claim distribution. In 2022 it is illustrated that there is a small increase in most segments. However, compared with the starting yearly claim distribution in 2005 these numbers are lower.

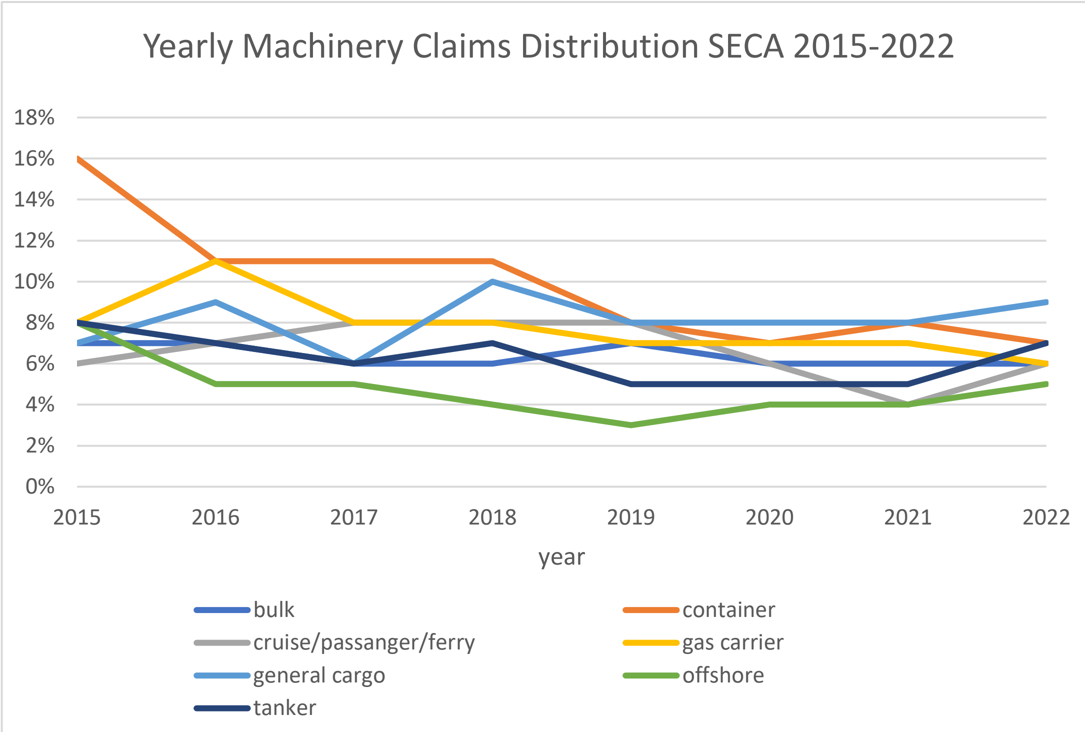


Figure 8: SECA Yearly Claims Distribution 2015-2022.

4.2 Section B All Sea Areas

Section B covers the time period of the SOx restrictions implementation on global sea areas. These include the implementation in 2005, 2012, and lastly, the implementation in 2020.

Figure 9 illuminates the trends not as clearly seen in the above time periods. All segments except tanker, bulk and offshore see a decrease in claim distribution from 2005 to 2006. The general cargo and container segments have two major fluctuations in 2008 and 2011. The most drastic decrease in claim distribution for the period is seen in the cruise/passenger/ferry segment. Whilst the container segment is the only segment that sees a firm increase in its claim distribution at the end of the period.

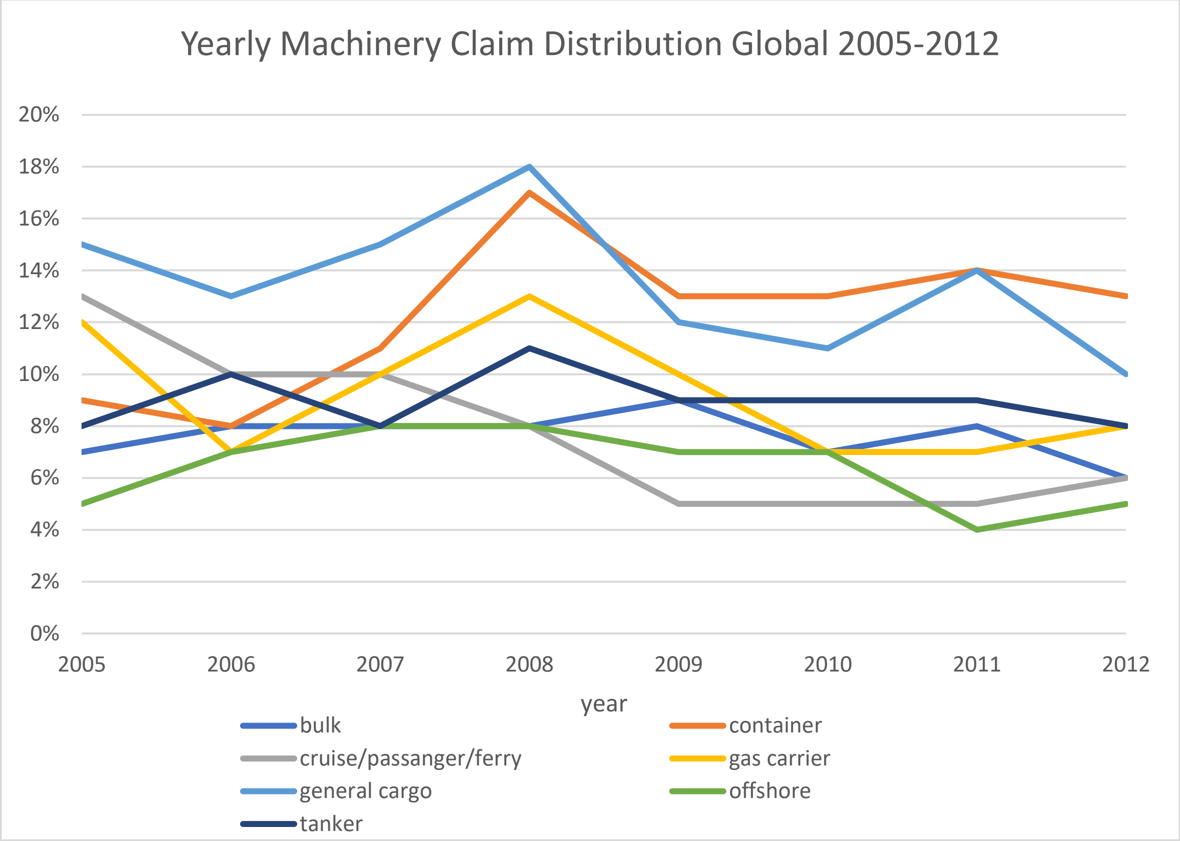


Figure 9: Global Yearly Claim Distribution 2005-2012.

In the 2012-2020 time period the fluctuations in container and general cargo are still prevalent as seen in figure 10. The container segment sees a major rise in claim distribution in 2015 and stagnates until 2018 where it sees a continuous fall. The general cargo segment is accompanied by consecutive fluctuations in the period. the falling trend or stagnation is also prevailing in most segments except for offshore at the end of 2020.

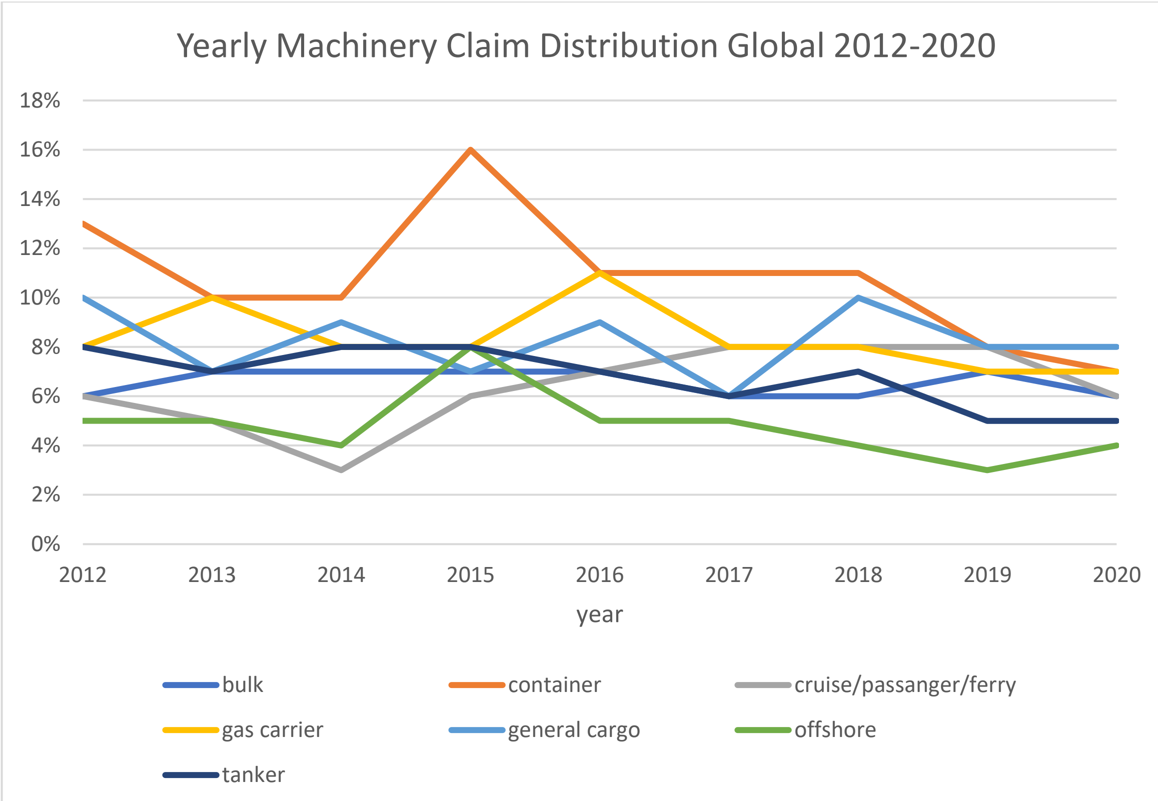


Figure 10: Global Yearly Claim Distribution 2012-2020.

The last time-period encompasses 2020-2022. This period covers the last SOx restriction that has so far been implemented. As seen in figure 11 there is a small increase in the yearly claim distribution for the container segment that falls in the consecutive year. 2021 to 2022 sees an increase in percentage in general cargo, tanker, cruise/passenger/ferry, and offshore segments. At the same time, there is a decrease in container and gas carrier segments. The bulk segment keeps a stagnating trend during the period.

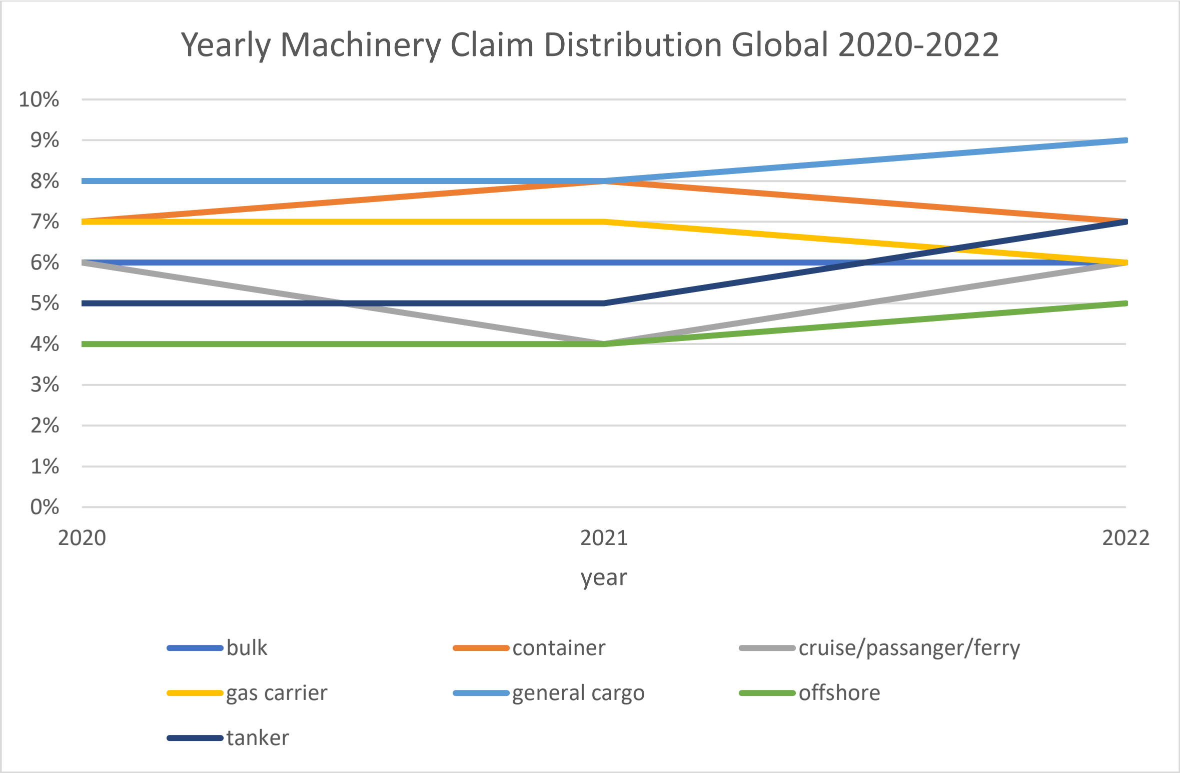


Figure 11: Global Yearly Claim Distribution 2020-2022.

4.3 Section C Whole Time Period

The last section covers the entirety of the studied time period from 2005-2022. This section covers the trends and yearly claim percentages of all segments from 2005 to 2022 to demonstrate an overlook of all fluctuations, falls, rises, and trends in the segments. There is also an overall claim percentage graph to show the trend for all claims of the vessels registered.

Figure 12 is as aforementioned the whole time period from the first SOx restriction implementation in 2005 until 2022 after the last implementation in 2020. As seen in the other figures both general cargo and container segments have major fluctuations in claim distribution. With container having considerable increases in 2008 and 2015, and decreases in 2009, 2013, 2016 and lastly in 2019. General cargo fluctuates with increases and downturns from 2008-2011 and 20011-2014. From there general cargo continues its fluctuation trend in the form of a two-year period as seen in the years 2014-2016 and 2016-

2018 until stagnation in the later years of the period with only a small increase in 2022. Other major fluctuations in the overall period are in the gas carrier and offshore segments. Gas carrier is affected by the increase in 2008, but steadily the claim distribution steadily decreases until. 2013 and 2016 where there are increases. The offshore segment sees a steadier downward trend in claim distribution, except for 2015 where there is a major increase. Mostly all segments have decreased their yearly claim distribution from 2005 at the end of 2022, with the exception of the offshore segment.

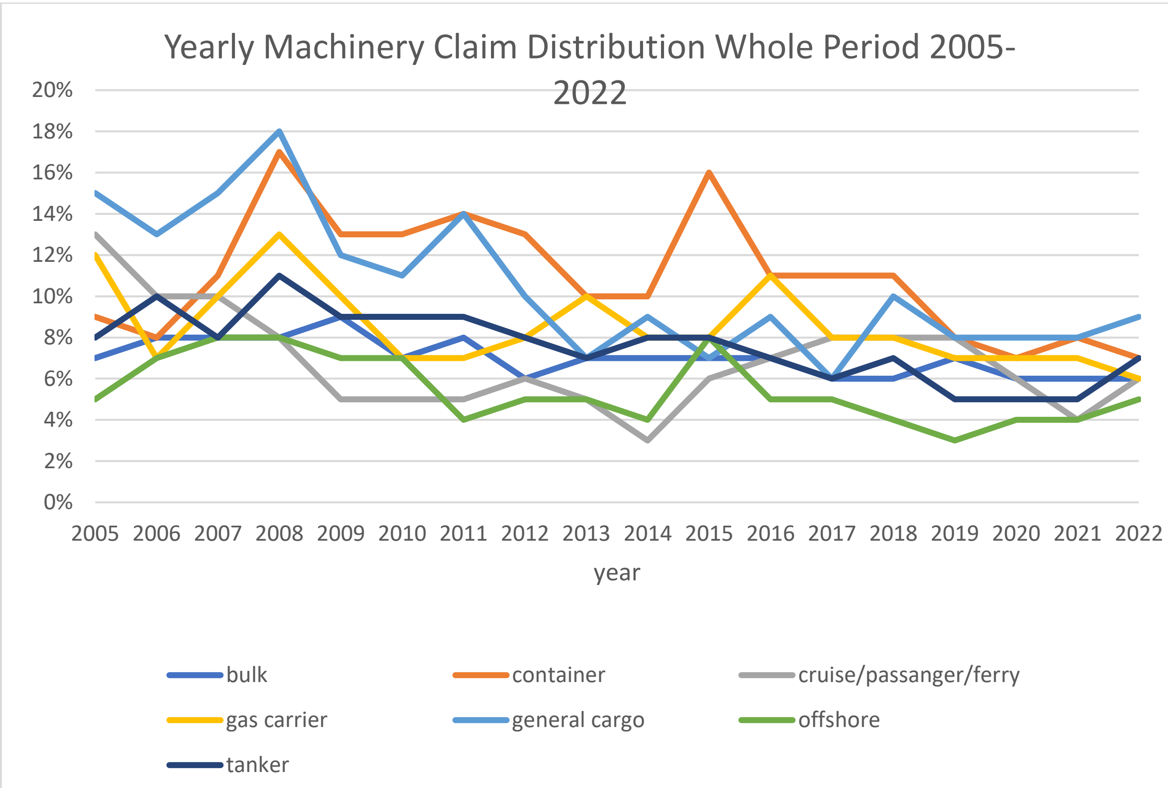


Figure 12: Whole Period Yearly Claim Distribution 2005-2022.

Figure 13 illustrates the overall claim distribution of all vessels registered combined over the period of 2005-2022. There is an overall falling trend with major fluctuations in 2008, 2013 and 2015 and smaller fluctuations in 2011, and 2018. The claim distribution starts at approximately 9% and ends in 6%, highlighting an overall decrease by 3% in the overall yearly claim distribution.

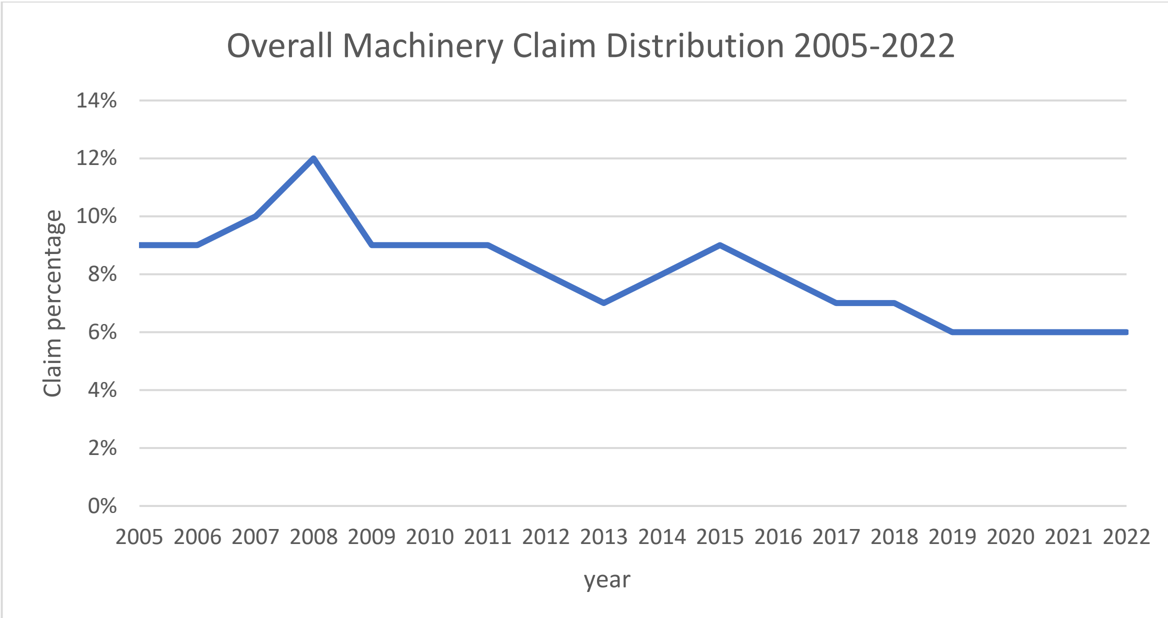


Figure 13: Overall Claim Distribution 2005-2022.

The claims frequency of 2005-2022 as shown in figure 14 display the falling trend of machinery insurance claims after the peak in 2005. Machinery has multiple fluctuations in the period. with 2005, 2010, 2013,2015 and 2017 seeing prominent increases in claims frequency. The figure also portrays that even if the total claims have gone down in the machinery segment, the claims frequency is at almost the same level as in 2005.

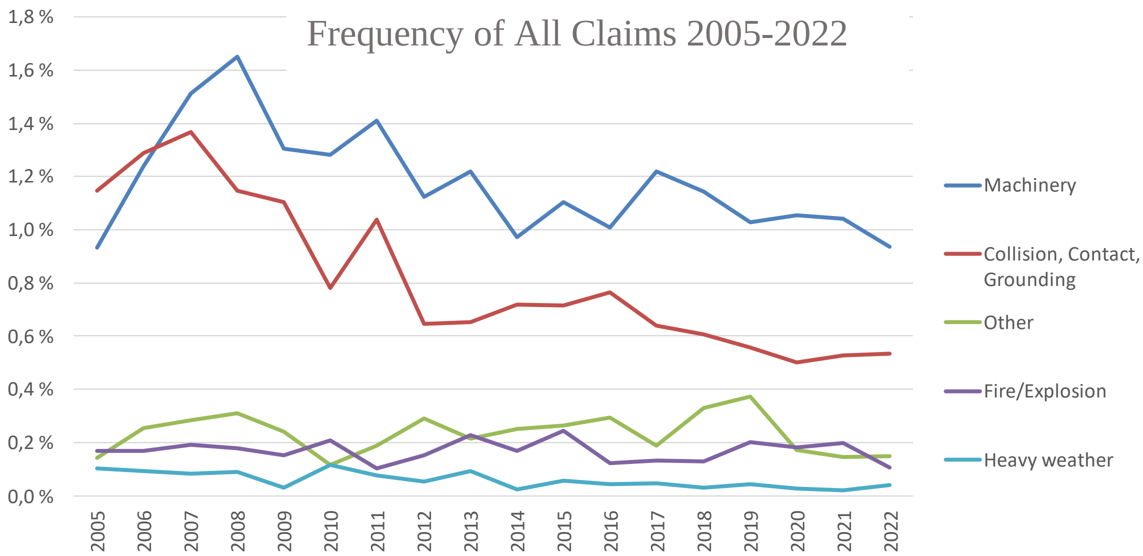


Figure 14: Frequency of Claims 2005-2022 (CEFOR, 2022).

Figure 15 shows the frequency of machinery claims by intervals of claim cost, by accident year between 2005 to 2022 of the CEFOR registered vessels. Same as with the other figures there are fluctuations in 2008, 2011 and 2015. There is a major increase in all segments from 2005 to 2008 and from 2008 there is a falling trend beginning to stabilize by the end of the period. Claims below 1 million USD are the major contributors, whilst higher claims have considerably lower percentage of occurrences.

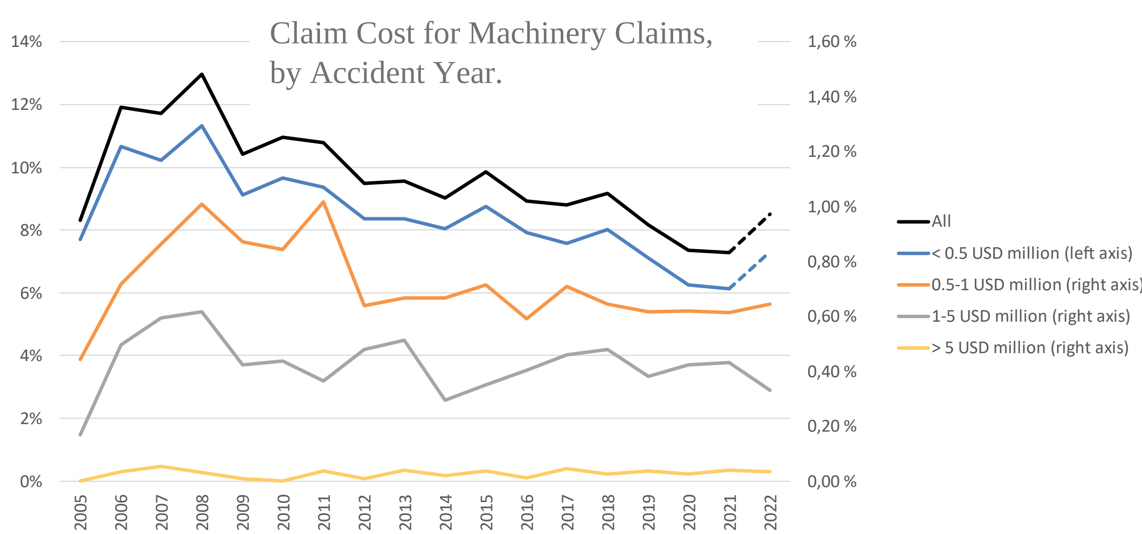


Figure 15: Claim Cost for Machinery Claims, by Accident Year (CEFOR, 2022).

4.4 Section D Peak Years

Section D deals with the Peak years of the yearly machinery claim percentage and shows what type of error lead to the claim. These peak years include 2008, 2011 and 2015.

Human error is the greatest contributor to errors in 2008 as shown in table 3 With only 330 of the claims stemming from technical errors. Natural and other causes had a low impact in 2008.

Table 3: Causes of Machinery Claims 2008.

Type of error	Sum of Claims 2008
Human error/omission - Officers/crew	431
Technical	329
Human error/omission/other	67
Natural cause - Heavy weather	11
Other immediate cause	6
Natural cause - wave action/swell	4
Technical - machinery	1
Grand Total	**849**

2011 sees an increase in the technical error claims cause as seen in table 4. Whilst human error is declining from the previous peak year in 2008. Natural and other causes are still low in the influencing part of the claims in 2011. The number of claims is lower than in 2008.

Table 4: Causes of Machinery Claims 2011.

Type of Error	Sum of Claims 2011
Technical - other	473
Human error/omission - Officers/crew	262
Human error/omission/other	51
Natural cause - ice	11
Technical - machinery	9
Natural cause - Heavy weather	7
Technical - equipment	6
Natural cause - wave action/swell	5
Other immediate cause	3
Human error/omission - Shoreside personnel	2
Technical - structural	1
Human error/omission - Pilot/other third	1
Grand Total	**831**

Human error has decreased significantly in 2015 compared with the other peak years. Whilst technical errors have continued to increase as shown in table 5. Natural and other causes had a larger impact on the claims this year, and there are sixty-nine claims that have causes that are yet to be determined.

Table 5: Causes of Machinery Claims 2015.

Type of Error	Sum of Claim 2015
Technical - machinery	425
Technical - equipment	332
Human error/omission - Officers/crew	79
Not Yet Known	69
Technical - other	37
Technical - structural	20
Human error/omission - Pilot/other third	18
Other immediate cause	11
Human error/omission - Shoreside personnel	11
Natural cause - Heavy weather	11
Unknown	10
Human error/omission/other	4
Natural cause - wave action/swell	3
Natural cause - ice	2
Hostile activity - other	1
Grand Total	**1033**

5.0 Discussion

In this segment of the thesis, I will discuss the research problem "*How does the IMO restrictions on sulfur oxide affect insurance claims on marine fuel engines?"* I will discuss whether the effect of the SOx restrictions is negative or positive for the Hull & Machinery claim segment.

The results found in the data analysis illustrates a falling trend in the Hull and Machinery claim segment for the annual claim distribution. These findings differ slightly from the theory segment, as many stakeholders were concerned that the SOx restrictions would have an adverse effect on engines. However, the claims frequency indicates a probable negative effect of the restrictions as it only by 2022 had fallen back to the frequency of 2005.

The peak years of claims raises further questions, presenting a substantial number of causes of claims as human errors early in the period, while showing an increasing number being technical in the later years of the whole time period. Further discussion on how the marine industry has received and adapted to the restrictions on SOx is needed to gain an improved understanding.

5.1 Restrictions Implementation

Chapter 2.1 explains why and how IMOs SOx restrictions have been implemented. The implementation has been involving multiple actors within the maritime industry. The ISO, shipbuilders, fuel production companies, fuel testing companies, ship owners, crews, and, lastly, ship insurers are all industry stakeholders that must adapt and develop new solutions to accommodate restrictions imposed by IMO.

As mentioned in sub-chapter 2.1.1 the restrictions were implemented with the establishment of SECAs in 2005 and a 1,5% limit on SOx, while global sea areas had a limit of 4,5%. This limit led to the transition from HFO to fuel oils permitted by the restrictions. New blends and other fuel types were produced and delivered to the market, with the players being skeptical to the consequences of these new blends and their potential negative effects on marine engines.

The results in figure 6 provide information regarding the upwards trend to the peak of yearly claims percentage in 2008, suggesting that the reaction from the players in the market was limited due to lack of knowledge about longer-term effects of the SOx restrictions on marine fuel engines. Furthermore, table 3 shows that the largest contributor for claims was human error, as presented in chapter 2.8. This factor can be viewed as the result of the crews not having proper maintenance routines when operating on other fuel oils than HFO.

The Worldwide Journal of Multidisciplinary Research and Development advises caution in respect of the probable consequences of using Low SOx fuels, citing concerns about low lubrication, low viscosity, acidity, and flash point (Troung, Le, & Dong, 2019). According to the paper there have not been any major incidences or damages by using low SOx fuels. The results in figure 15 also indicate that high-cost claims are less prevalent in the Hull & Machinery claim segment. The reason for fewer incidences and damages, might be that the crew on the vessels have adopted better procedures and have improved their competence operating with the new fuel types. This improvement is also indicated in section D in the result segment, with declining claims caused by human error, whilst technical errors contribute to machinery claims in a much more significant way than earlier.

IMOs SOx restrictions have increased in severity since 2005 and, as of the end of 2023 are at a 0,1% limit for SECA and 0,5% globally. When looking at the results there appears to be a correlation between the first implementation of IMOs restrictions and the sudden rise in Hull & Machinery claims. The trend of the Hull & Machinery annual claim distribution has been slowly falling and is only by 2022 at the same level as the claim’s percentage in 2005.

It is possible that the first restriction implementation led to the major increase in claims by the crews not being prepared for maintenance and procedures needed for operating vessels on lower SOx. This increase is further supported by the engine and fuel producers issuing regular circulars on the specifications of using fuel types with different engines as mentioned in chapter 2.8. Seeing a decrease in human error causing claims, table 4 and 5 also supports this increase.

The fluctuations in 2008 and in 2011 are preceded by restriction implementations, as already discussed reactions, and impact the first SOx limit regulation. There appears to be improvements on the human error side of the claims in table 5, suggesting that the initial shock of the new fuel oil operation has subsided on the crew's side. However, the increase in technical errors even if small in cost and scale figure 15 were becoming more prevalent.

2011 does not follow the same pattern as the other fluctuation years, as it is directly the year after a new regulation limit on SOx. Compared with 2008, 2015, and 2018, that only reaches a peak after three years after a new restriction. However, there seems to be a sequence of increases and decreases in a three-year period. These fluctuations could be the effect of the fuel blends and sailing routes that need time to be properly optimized for new restriction limits both in SECAs and globally.

5.2 Effect on Engines and Equipment

The effect the SOx restrictions have had on marine engines and equipment are an important aspect of the thesis. Chapter 2.6 explains how marine propulsion operates on vessels, and the causes that were predicted to be the most plausible for claims, including low lubrication, low viscosity, acidity, and flash point. In table 2 The Swedish Club presents low lubrication as the main cause of claims in the engines in 2023. It is probable that this coincides with the increase in technical errors as seen in table 4 and 5. This probability is further supported by the previously discussed fluctuations, as there is a pattern of increases in yearly claims distribution each third year. An increase in the yearly claim percentage of 2023 can indicate that the restrictions have led to additional technical errors following the three-year pattern.

The introduction of scrubbers as an important substitute in the marine fuel industry likely occurred as a response to the SOx restrictions as mentioned in chapter 2.5. This probable response is supported by the significant increase in scrubbers from 2007 to 2023, with over four thousand of the vessels in the mercantile fleet being outfitted with them (Statista, 2023). showing the potential effect IMOs SOx restrictions have on the equipment side of marine vessels. Following up on the three-year pattern, both scrubbers and cat fines chapter 2.6.1 have seen drastic improvement to both procedures and guidance in form of circulars, maintenance checks and articles published to help the marine industry. All of these seeing improvements over the years on how to handle the new blends. A positive note for insurance is after the 2020 SOx restriction implantation, as the yearly claim distribution has seen a decreasing trend in 2021 and 2022 figure 12. Suggesting that the marine industry have after several limit increases, found a balance by adapting new procedures.

5.3 Effect on Insurance Claims

The two preceding sub-chapters indicates that IMOs restrictions have influenced the marine industry, both in terms of claim distribution and the engines themselves. To understand if this influence has had a negative or positive effect on Hull & Machinery claims it is important to look at the possible observational correlations between variables from the result segment.

The trend pattern of yearly claim distribution is the first possible correlations that can be observed. The pattern follows an increase until a peak then falling with a couple of years gap between as seen in figure 12. The main trend periods are 2005-2008 following the first implementation, 2009-2011, 2012-2015, 2016-2018. The trend is following the same pattern from 2019-2022 and seem to be stretching for another peak in 2023. Each peak is preceded by the SOx limit being lowered, thus giving the assumption that there is a correlation between the pattern of increasing claims peaks and the restrictions implementation. Yet, the peak year of 2011 does not follow the same pattern as the other peaks as it is only a year after a major restriction implementation. The 2011 peak is deviating from the pattern when looked at solely, as the nearest other restriction that could have triggered it is in 2005.

The peaks do come with a couple of years in between them, and often following a restriction implementation. However, the peak year of 2011 does not follow the exact same pattern as the other peak years, consequently it is not necessarily the increasing restrictions that causes the pattern, but there is an observable fluctuation cycle in the Hull & Machinery claims segment, with a falling trend overall.

The claims frequency results follow the same pattern as that of the yearly claim distribution results, as seen in figures 12 and 14. Claims frequency as explained in chapter 2.7.1 is illustrating the expected premiums to be settled by the amount of claims anticipated. Figure 12 presents an increase in the claim distribution following the decline in frequency since 2018. This decline supports the trend pattern seen in the yearly claim distribution. Anticipated frequency claims are based on earlier trends and with the implementation of the newest restriction in 2020 there seems to be an observable correlation between the restriction implementation and anticipated pattern peaks.

Figure 14 portrays a different possibility to a peak year in the pattern with firstly both machinery and collision claim frequency seeing a drastic rise. This leads to the probability that these two segments have affected each other negatively. Secondly, in figure 15 there is a significant increase in the 0,5-1 million USD claims within machinery that coincides with the drastic damages that can come from collisions. With these two elements included, there is a probable cause that the peak year of 2011 was not affected by the restriction implementation in 2010 (IMO, 2023). Yet, there is the peak year for claim frequency in 2013 that suggests that the restrictions had an effect. Though, it is not a peak year when looking at the yearly claim percentage. Implying that the restrictions have a correlation with the pattern but are not showing an observable causality.

The increase of technical errors and the decline of human errors as causes for Hull & Machinery claims seems to have a connection with the learning curve of the industry. Human errors as explained in chapter 2.8 are fronted as the reason behind 80-90% of all damages to engines. However, this argument is not supported by the results shown in table 4 and 5 as the human errors as the reason for claims are shown to be declining. One possibility is that the way that claims causes are reported has shifted, as crews have learned to report a human error as a technical error. Another possibility is the fuel composition of vessels having changed over time, with blends of VLSFO, MGO and LNG being more taxing on the components inside the engines as fronted by the Swedish Club in 2.5. Another aspect that supports this possibility is that the crews have developed measures and procedures to mitigate mistakes and failures based on their decisions whilst operating a vessel.

A summation of the last paragraph would be that the type of error has changed, but not necessarily in a constructive manner. An increase in technical errors could indicate a need for upgraded equipment, more repairs, more maintenance etc. whilst the decrease in human error can have developed from the crews being unwilling to take the blame for the claim cause. Thus, potentially leading to an incorrect result of the claim causes, especially with the notion that human errors are theorized to be the origin of most claims in the marine insurance industry (Kuo, 1998, s. 107).

6.0 Closing

In this thesis I have strived to answer the following research problem *"How does the IMO restrictions on sulfur affect insurance claims on marine fuel engines?"*

To accurately explain and answer this question there were three key elements to elaborate upon. The effect of the SOx restrictions, the effect of the SOx limits on marine engines and the effect on marine insurance.

The theory segment of this thesis explained the restriction implementation, marine engine propulsion, marine insurance theorem relevant to the thesis and how the human factor has an influence on the theme.

The methodology segment reinforces a quantitative research method for gathering and analyzing data, as there were considerable secondary data available to explain the trends of Hull & Machinery claims.

Lastly, in the discussion segment I combined the results with theory to investigate if IMOs SOx restrictions had any effect on the insurance claims involving marine fuel engines and if these eventual effects were positive or negative.

6.1 Conclusion

The results show an increase in the yearly claims percentages and claims frequencies compared to 2005 when the first SOx restrictions were implemented. The increase coincides with the player's skepticism to new fuel blends and the human factor deliberated on in the theory segment.

The discussion segment elaborates on the possible correlations between the implementation of the SOx restrictions and the pattern of yearly claims peaks. These peaks coincide with the application of stricter limits on SOx in marine fuel preluding a couple of years increase in claims before decreasing again until a new restriction is implemented.

However, the discussion segment also illustrated one that the figures of the peak year 2011 did not seem as correlated with the restrictions as the other increases. There seems to be a connection between the restrictions and the effect it has had on engines. This connection is prevalent in the number of technical errors compared to human errors seen in the results.

It is possible to assume that improved processes and guidelines have led to better decision making from the crew. However, it is also possible that the reporting of causes has changed.

Nonetheless, the impact of fuel blends on the wear of components in engines and improved processes for crews shows a decrease of claims over the years. Thus, it is presumable to assume that the restrictions have had an impact on engine health. The restrictions seem to have had a negative impact on machinery claims from their first implementation, with a significant increase in both annual claim percentage and frequency.

Theat number of technical errors has also been rising, can be presumed to be caused by new fuel blends that the components are not designed for. The falling trend supports this rise by presenting the reaction and action that the marine industry has taken to manage the restrictions. This leads to the most probable conclusion that IMOs restrictions on SOx have affected the insurance claims on engines in a negative way.

6.2 Proposal for Further Research

The time-period chosen for this thesis covers the years from implementation in 2005 until the year 2022. This includes all implementations and years after both in SECA and global areas. There is a fluctuation pattern that is consistent during this period. It is possible to assume that this pattern either follows a trend that happened before the restriction's implementation, or it is a new pattern that might have been caused by the restrictions.

To properly study this pattern the suggestion for further research would be to look at earlier claims data dating back before 2005. This type of research would give the opportunity to explain the pattern, and se the development of Hull & Machinery claims more clearly.

Another point of suggestion for further research involves other factors that could have contributed to the increases during the time-period. The thesis has only discussed the claims numbers and human and technical errors.

Further research revolving around potential economic recessions and rises as contributors to the fluctuations could help explain both the pattern and falling trend seen. As well, as the age groups of the vessels included in the results to deem if the restrictions have contributed to a negative impact on marine engine claims.

7.0 Bibliography

Alfa Laval. (2018, January 26). *Industries: Alfa Laval*. Retrieved from alfalaval.com: https://www.alfalaval.com/industries/marine-transportation/marine/fuel-oil-treatment/fuel-line/the-daily-grind-cat-fines-and-engine-wear-part-1/

Anantharaman, M., Islam, R., Khan, F., & Garaniya, V. (2020). A Review of Human Error in Marine Engine. *the International Journal on Marine Navigation and Safety of Sea Transportation*, 44-46.

CEFOR. (2011). *globalassets: CEFOR.* Retrieved from cefor.no: https://cefor.no/globalassets/documents/about-cefor/history-pdf/cefor-centennial-book.pdf

CEFOR. (2022). *Annual Report 2022.* CEFOR.

Churchill, G. A. (1991). *Marketing Research.* Chicago: The Dryden Press.

DNV. (2019, March 12). *News: Det Norske Veritas*. Retrieved from dnv.com: https://www.dnv.com/news/sulphur-limit-in-ecas-increased-risk-of-psc-deficiencies-and-detentions-142911

DNV. (2023). *Maritime Insights*. Retrieved from dnv.com: https://www.dnv.com/maritime/insights/topics/lng-as-marine-fuel/index.html

Einemo, U. (2021, March 18). VLSFO: Fact Versus Fiction. *Ship&Bunker*.

EPA. (2023, August 29). *enforcement: United States Environmental protection Agency*. Retrieved from epa.gov: https://www.epa.gov/enforcement/marpol-annex-vi-and-act-prevent-pollution-ships-apps

Gard. (2014, February). *Content: Gard.* Retrieved from gard.no: https://www.gard.no/Content/20738794/LPC%2001-14%20Prevention%20of%20engine%20damage%20due%20to%20catalytic%20fines.pdf

Gard. (2022). *gard.no*. Retrieved from gard.no: https://www.gard.no/web/frontpage

Gold, E. (2006). *Gard Handbook on Protection of the Marine Environment.* London: Gard AS.

Graco. (n.d.). *Vechicle Service*. Retrieved from graco.com: https://www.graco.com/gb/en/vehicle-service/solutions/articles/what-is-lubrication-and-why-is-it-important.html

Grennes, T. (2019). *Innføring i vitenskapksteri og metode.* Oslo: Universitetsforlaget.

Grynspan, R. (2022). *Review of Martime Transport 2022.* UNCTAD.

ICCT , DieselNet. (2018). *Standard: Transportpolicy*. Retrieved from transportpolicy.net: https://www.transportpolicy.net/standard/international-fuels-iso-petroleum-marine-fuels/

IMO. (2017). *Marpol Annex VI: International Maritime Organisation.* Retrieved from maproltraning.com: http://www.marpoltraining.com/MMSKOREAN/MARPOL/Annex_VI/r14.htm

IMO. (2018, November 9). *Our Work: International Maritime Organization.* Retrieved from imo.org: https://wwwcdn.imo.org/localresources/en/OurWork/Environment/Documents/MEPC.1-Circ.878.pdf

IMO. (2019). *Our Work: International Maritime Organization*. Retrieved from imo.org: https://www.imo.org/en/OurWork/Environment/Pages/Special-Areas-Marpol.aspx

IMO. (2021, January 28). *mediacenter, Press breifings: International Maritime Organization*. Retrieved from imo.org: https://www.imo.org/en/MediaCentre/PressBriefings/pages/02-IMO-2020.aspx

IMO. (2023). *Conventions: International Maritime Organisation*. Retrieved from imo.org: https://www.imo.org/en/about/Conventions/Pages/International-Convention-for-the-Prevention-of-Pollution-from-Ships-(MARPOL).aspx

IMO. (2023). *Gisis : International Maritme Organization*. Retrieved from gisis.imo.org: https://gisis.imo.org/Public/MARPOL6/Notifications.aspx?Reg=18.2.5

IMO. (2023). *Our Work: international Maritime Organization*. Retrieved from Imo.org: https://www.imo.org/en/OurWork/Environment/Pages/Sulphur-oxides-(SOx)-%E2%80%93-Regulation-14.aspx

ISO. (2003). *ISO 8754:2003: Internatinal Organization of Standarization.* Retrieved from iso.org: https://www.iso.org/obp/ui/en/#iso:std:iso:8754:ed-2:v1:en

ISO. (2023). *About Us: International Organization for Standardization*. Retrieved from iso.org: https://www.iso.org/about-us.html

Jensen, M. C., & Jakobsen, S. B. (2019, April). *docs: Man Energy Solutions.* Retrieved from man-es.com: https://www.man-es.com/docs/default-source/service-letters/sl2019-671.pdf

JHC. (2013, September). *Global Assests: CEFOR.* Retrieved from cefor.no: https://cefor.no/globalassets/documents/education/seminars/archive/training-course-for-surveyors-oct-13/catfines-jhc-13-09.pdf

Kuo, C. (1998). *Managing Ship Safety.* London: LLP Reference Publishing.

Larsen, A. K. (2020). *En enklere metode.* Bergen: Fagbokforlaget.

Maritime Cyprus. (2022). *World LNG Report 2022.* Maritime Cyprus.

Nautilus Shipping. (2022, December 16). *Marine Propulsion Systems: Nautilus Shipping*. Retrieved from natuilusshipping.com: https://www.nautilusshipping.com/marine-propulsion-systems

OCIMF. (2016). *Document libary: Oil Companies International Marine Forum.* Retrieved from ocifm.org: https://www.ocimf.org/document-libary/98-guide-for-implementation-of-sulphur-oxide-exhaust-gas-cleaning-systems-final/file.

Oiltanking GmbH. (2023). *News Info: Oiltanking*. Retrieved from oiltanking.com: https://www.oiltanking.com/en/news-info/glossary/marine-gasoil-mgo.html

Partanen, A. I., Laakso, A., Schmidt, A., Kokkola, H., Kuokkanen, T., Pietikäinen, J.-P., . . . Korhonen, H. (2013, December 12). Climate and air quality trade-offs in altering ship fuel sulfur content. *European Science Union*, pp. 1-2.

Safety4sea. (2023). *Contact. Safety 4 sea*. Retrieved from about.safety4sea.com: https://about.safety4sea.com/contact/

Sjøfartsdirektoratet. (n.d.). *Shipping vessels sdir.no*. Retrieved from sdir.no: https://www.sdir.no/en/shipping/vessels/vessel-types/

Smith, P. (2020, August 4). *Scrubber Claims: Safety4sea*. Retrieved from safety4sea.com: https://safety4sea.com/scrubber-claims-a-pi-club-perspective/

Statista. (2023, October 24). *Statistics: Statista*. Retrieved from statista.com: https://www.statista.com/statistics/1099286/number-of-scrubbers-in-vessels/

Stålberg, P. (2023). *Main Engine Damage.* Gothenburg: The Swedish Club.

Thorbjörn Emanuelsson, B. K. (2023). *Membership Directory. Norwegian Chamber of Commerce Hong Kong*. Retrieved from norchamhk.com: https://www.norchamhk.com/membership-directory/corporate/188271

Troung, T. H., Le, V. V., & Dong, T. M. (2019). *An Overview of Low Sulfur Fuel for Marine Engines: World Wide Journal of Multidisciplinary Research and Development.* Retrieved from wwjmrd.com: https://wwjmrd.com/upload/an-overview-on-low-sulfur-fuel-for-marine-engines_1558948792.pdf

UNCTAD. (2023). *Review of Maritime Transport 2023 Chapter 2: World Shipping Fleet, Services, and Freight Rates.* UNCTAD.

Vermeire, M. B. (2021, August). *Content: Chevron Marine.* Retrieved from chevronmarineproducts.com: https://www.chevronmarineproducts.com/content/dam/chevron-marine/fuels-brochure/Chevron_Everything%20You%20Need%20To%20Know%20About%20Marine%20Fuels_v8-21_DESKTOP.pdf

Vos, J. d. (2022, May 27). *News: Ship&Bunker*. Retrieved from shipandbunker.com: https://shipandbunker.com/news/world/177237-peninsula-low-viscosity-vs-lubricity-in-fuel-quality-analysis

NTNU

Norwegian University of
Science and Technology

gard