DOCTORAL THESIS

# Investment Risk Management in Sustainable Maritime Operations

Sina Atari Jabar Zadeh

TALLINNA TEHNIKAÜLIKOOL
TALLINN UNIVERSITY OF TECHNOLOGY
TALLINN 2025

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25/2025

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TALTECH PRESS

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This dissertation was accepted for the defence of the degree of Doctor of Philosophy in Business & Economics on 25/03/2025

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**Defence of the thesis** 15/05/2025, Tallinn

**Declaration:**
Hereby I declare that this doctoral thesis, my original investigation and achievement, submitted for the doctoral degree at Tallinn University of Technology, has not been previously submitted for doctoral or equivalent academic degree.

Sina Atari

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ISSN 2585-6898 (publication)
ISBN 978-9916-80-285-4 (publication)
ISBN 2585-6901 (PDF)
ISBN 978-9916-80-286-1 (PDF)
DOI https://doi.org/10.23658/taltech.25/2025
Printed by Koopia Niini & Rauam

Atari, S. (2025). *Investment Risk Management in Sustainable Maritime Operations* [TalTech Press]. https://doi.org/10.23658/taltech.25/2025

TALLINNA TEHNIKAÜLIKOOL
DOKTORITÖÖ
25/2025

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# Contents

## List of publications

The list of author's publications, based on which the thesis has been prepared:

I **Atari, S.** (2021). Sustainable maritime fleet management in the context of global sulphur cap 2020, *Transport and Telecommunication Journal*, Volume 19, Issue 1, 53–66. DOI: 10.2478/ttj-2021-0005 (ETIS Classification 1.1).

II **Atari, S.,** Bakkar, Y., Olaniyi, E. O., & Prause, G. (2019). Real options analysis of abatement investments for sulphur emission control compliance. *Entrepreneurship and Sustainability Issues*, Volume 6, Issue 3, 1062–1087. DOI: 10.9770/jesi.2019.6.3(1) (ETIS Classification 1.1).

III **Atari, S.**, & Prause, G. (2018). Risk assessment of emission abatement technologies for clean shipping. In *Reliability and Statistics in Transportation and Communication: Selected Papers from the 17th International Conference on Reliability and Statistics in Transportation and Communication, RelStat'17, 18-21 October, 2017, Riga, Latvia* (pp. 93–101). Springer International Publishing. (ETIS Classification 3.1).

IV Olaniyi, E. O., **Atari, S.,** & Prause, G. (2018). Maritime energy contracting for clean shipping, *Transport and Telecommunication Journal*, Volume 19, Issue 1, 31–44, ISSN (Online) 1407-6179, DOI: 10.2478/ttj-2018-0004. (ETIS Classification 1.1).

**Additional paper:**

V **Atari, S**.; Gerstlberger, W.; Prause, G. (2023) Maritime Supply and the optimal maritime Operations. In *Reliability and Statistics in Transportation and Communication: Selected Papers from the 24th International Conference on Reliability and Statistics in Transportation and Communication, RelStat'24, 15-18 September, 2024, Riga, Latvia*, forthcoming in a Springer conference book in 2025. (ETIS Classification 3.1).

## Author’s contribution to the publications

The author is the primary contributor to three of the published articles. The key contributions of the author to each paper are:

I As the sole author, the thesis author was responsible for all research activities, including the conceptualization and structure of the article.

II As the first author, the thesis author led the idea generation, research design, data collection, data analysis, model development, and manuscript preparation. The findings and conclusions were collaboratively developed with the co-author.

III The thesis author contributed to idea generation, study design, the preparation of the theoretical framework, data collection, and the analysis of both quantitative and qualitative data, including bunker fuels, ship information, and shipping line strategies. The thesis author had primary responsibility for the analyses, with the findings and conclusions jointly discussed and prepared with the co-author.

IV The thesis author played a secondary role, focusing on the development, testing, and validation of a risk assessment model for fuel companies.

V Atari contributed to the conceptualization and data analysis.

# Abbreviations

| | |
|---|---|
| BSR | Baltic Sea Region |
| CO2 | Carbon Dioxide |
| EnviSuM | Environmental Impact of Low Emission Shipping Measurements and Modelling Strategies |
| ECA | Emission control area |
| CAPM | Capital asset pricing model |
| CML | Capital market line |
| IMO | International Maritime Organisation |
| IRR | Internal rate of return |
| PV | Present value |
| NPV | Net present value |
| ROV | Real option valuation |
| ROT | Real option theory |
| ROA | Real option analysis |
| SECA | Sulphur emission control area |
| HFO | Heavy Fuel Oil |
| MGO | Marine Gas Oil |
| MDO | Marine Diesel Oil |
| NOx | Nitrogen Oxides |
| SOx | Sulphur Oxides |

Explanations of abbreviations used in the thesis.

# Terms

| | |
|---|---|
| CAPEX | Capital expenditure |
| Opex | Operating expenditure |
| ROT | Return on time |
| ROA | Return on asset |
| ROI | Return on investment |

Explanations of terms used in the thesis.

# Introduction

The shipping industry is critical to the movement of essential goods to economies around the world and plays an essential role in facilitating global trade. It is also the main driver of global economic growth (Brancaccio, 2017). With the expansion of the sector and the transportation of more goods, cargoes, and passengers, there is a need to increase financial investment. However, this presents a significant challenge in achieving development while maintaining environmental sustainability. Although conventional marine activities and operations are essential for economic growth, they have a significant impact on pollution, environmental disturbances, and greenhouse gas (GHG) emissions. To address these issues and reduce their ecological footprint, industrial players should gradually emphasize the use of greener technologies and practices. Strategies that have been implemented include using environmentally friendly fuels, increasing energy efficiency, and enforcing stricter controls on greenhouse gas emissions. These developments have made significant progress in reducing the ecological consequences of maritime operations in the Baltic Sea and North Sea regions. An important regulatory step in this area is the establishment of Sulphur Emission Control Areas (SECA). Currently, the most widely used approaches to address this issue include low-sulphur fuel oil (LSFO), high-sulphur fuel oil (HFO) with scrubbers, and liquefied natural gas (LNG) (Wang et al., 2023; Olaniyi & Prause, 2020; Krantz et al., 2023).

To address the stringent sulphur emission guidelines, scientists and industry professionals have explored various new and innovative solutions (Wang et al., 2023) derived from both academic research and practical applications. Some distinct examples include studies by Fan et al. (2023) and Arias et al. (2023). These studies detailed experimental technologies or modified processes aimed at reducing sulphur emissions from marine vessels. The methods range from advanced scrubber systems that remove sulphur from exhaust gases to new fuel formulations that inherently contain less sulphur. Many of them are costly and make decisions in affected organizations very tedious and fraught with financial risks.

According to BSR findings after 2015 (i.e., Rotoli et al., 2020; Prause & Olaniyi, 2019), the drop in fuel prices has lessened the economic impact of SECA regulations, prompting many shipowners to delay their investment decisions. While postponing the adoption of emission reduction technologies may have lowered the cost of SECA compliance, it did not however improve shipowners' competitive standing. Therefore, new policy instruments are required to promote innovation, enhance competitiveness, and meet the environmental regulations. Although managing fuel price fluctuations and offering more affordable maritime logistics services would have been simpler, maritime stakeholders must develop smart strategies to secure long-term sustainable advantages (Hassellöv, 2023). Due to the complex and capital-intensive nature of maritime projects, specialized pre-investment analysis and risk assessments are obligatory for safeguarding the success of these initiatives while also learning innovative ways to comply with such laws in the face of possible additional regulatory laws to ensure a reduction in compliance costs (Prause et al., 2023).

Yet, despite the clear economic implications of environmental regulations such as SECA and the 2020 Global Sulphur Cap, there is a notable lack of quantitative academic research focusing on maritime finance and economics, particularly in addressing these stringent regulations. In 2021, Bai et al. performed an extensive examination of more than 3,000 articles published in the last twenty years, with a primary emphasis on maritime transport. Their research shows significant focus of most studies on port management, container operations, and liner shipping management, with relatively limited investigations into the more recent regulatory influences.

The author of this thesis, like many other researchers believes that the study of maritime economic and financial affairs is inherently interdisciplinary. Conducting such research requires the collection of extensive information on finance, maritime industry practices, environmental factors, and emerging technologies, followed by a comprehensive analysis of associated risks (Mızrak, 2024). By understanding these risks, investors can implement strategies to mitigate potential downsides and enhance the likelihood of a successful investment decision (Jeffers et al., 2024). However, conventional quantitative research methods popular in business management are insufficient to address the complexities of the risks associated with the maritime industry (Prause et al., 2023). Most financial assessments of investment decisions lack the depth in responding to changing conditions such as fuel price fluctuations or regulatory compliance associated with the shipping industry, which invariably increases the risk rate of large investments (Savchuk, 2023). Many do not take into consideration these factors and many others that influence the shipping and bunker fuel industries, both directly and indirectly, in their evaluations. Thus, a significant gap in traditional methodologies that can tackle investment risk is evident within the industry. This represents the first gap **(Research Gap 1)** identified in the context of this research.

A further comprehensive review of the current financial literature reveals a predominant focus on mostly capital markets, primarily addressing investment strategies and associated risks related to intangible assets such as intellectual property valuation, market valuation, and brand valuation, etc. (Meira, 2023; Salamah, 2023). Many of these analyses rely heavily on secondary information about financial markets. This represents a significant gap when considering other critical aspects and strategic factors related to investing in physical assets, particularly managerial flexibility in the context of abatement technologies for maritime regulatory compliance. This might arguably be largely because regulatory instruments for green shipping and sustainability can be considered relatively new and still in their growth phase (Dzwigol, 2023). However, in their work, Cao et al. (2024) argue that topics such as capital budgeting and investment appraisal, which are crucial for evaluating investments and the procurement of assets like ships, trucks, and aircraft, have received less attention in literature regardless of the timeline. Moreover, most of the investment evaluations usually assume an immediate project start and continuous operation when there are predictable cash flows until the end of the investment lifetime, which does not allow for a flexible evaluation approach (Zhang & Yin, 2023). This lapse highlights the second gap **(Research Gap 2)** identified by the author. By using abatement technologies, this work will attempt to explore effective and strategic evaluations of investment in capital projects in the maritime sector using key investment factors.

Also concerning is the fact that the volume of publications focusing on maritime economics in the context of green shipping and sustainable transportation has been strikingly limited. Despite the growing global urgency to address environmental challenges within the maritime sector, academic and industry, research has not kept pace, leaving significant gaps in knowledge and innovation. Many studies in the shipping industry focus mostly on discussions that revolve around freight rates, engineering components, and maritime economics (Alexandridis et al., 2018). There is still a notable gap in the literature regarding the economic impact of greening efforts on the sector.

Discussing the "challenges of green innovation," Nordhaus (2024) inferred that this lack of comprehensive, forward-looking studies on the economic implications of greener shipping hinders the development of effective strategies to meet environmental goals while maintaining economic viability in the industry.

Critical to this study is risk management, which is very important to the current shipping industry, where managers must balance the financial risks associated with environmental regulation compliance and operating different types of ships or routes against potential returns. For example, they must figure out how investing in abatement technologies (like scrubbers), which involve upfront costs, can result in long-term savings and regulatory compliance benefits.

So far, shipping companies face both external risks (e.g., fuel price volatility, regulatory changes) and internal risks (e.g., maintenance and crew management), and the investment decisions that include selecting these influencing factors remain complex and challenging when determining the most effective emission reduction solution (like abatement technology) for green and sustainable shipping (Meng & Shaikh, 2023). Reasoning within the context of this study, and from an economic standpoint, while conventional solutions have been frequently explored, the introduction of the Global Sulphur Cap 2020 presents a significant economic challenge for fleets worldwide. It has become important to identify the most effective strategy optimization models for the best mix of investments that offer the highest returns for the least risk (Zhou et al., 2023).

To effectively tackle risks associated with both external and internal factors, it is essential to use a risk assessment methodology similar to those employed in managing portfolios in financial markets. However, the existing research highlights a notable deficiency in the application of these financial theories to investments in marine fleets. Thus, the third gap **(Research Gap 3)** identified in this study centers on the lack of comprehensive frameworks for optimal investment management to address the systematic risks (global fleet and external) and unsystematic risks (specific to individual ships) to mitigate the risk associated with maritime environmental regulations such as the SECA and Global Sulphur Cap 2020. This critical area remains largely underexplored, leaving a significant void in the literature on how to navigate these regulatory challenges effectively.

Hence, taking a step beyond the evaluation of investment in capital projects in maritime, this study further addresses the management and diversification of risk across interconnected vessels while concurrently enabling the construction and optimization of a strategic investment portfolio tailored to the dynamic nature of SECA and Global Sulphur Cap 2020.

Accordingly, central to this thesis is the objective of clarifying the financial implications, associated risks, and strategic considerations that maritime companies must successfully navigate within the scope of environmental regulations, such as the Sulphur Cap. In doing so, this research addresses a significant gap in both academic discourse and practical application within the fields of Business Administration and Management.

Considering the vital role of the shipping industry in global trade, accounting for more than 80% of global trade (Wang et al., 2021), this PhD research, which explores how strict environmental regulations, such as the Sulphur Emission Control Areas (SECA) influence strategic decision-making processes within the marine sector – particularly in financial terms – is both important and timely. This research focuses on understanding the extent to which environmental regulations affect how maritime businesses plan, adapt, and make long-term decisions to comply with these standards while maintaining operational efficiency and profitability. This focus is crucial, as it drives maritime companies to align their operations with environmental requirements without compromising their economic sustainability, underscoring the importance of comprehensive strategic planning in response to environmental regulations. This emphasis places the research at the forefront of the debate on sustainable maritime business practices.

The objective has led to the development of novel mathematical models and the application of diverse statistical and probability-based financial instruments to advance scientific progress through substantial investment innovations. These innovations address regulatory investments in abatement technologies for compliance. The study further fills the three identified gaps by integrating real-life scenarios into the analysis, thereby enhancing the relevance and practicality of the research in tackling current challenges in the shipping industry.

In alignment with the study's objective and the three identified gaps, the author explores pivotal research questions concerning the financial optimization and impact of SECA compliance strategies and their integration into broader business strategies to enhance performance. Consequently, this thesis aims to address the following research questions (RQ1–3):

RQ1: What key factors can effectively reduce the risk of maritime investments, and how to apply them effectively?
RQ2: How can investment in marine abatement technology be more effectively evaluated using key influencing factors?
RQ3: How can the risks of abatement investments in maritime fleets be most effectively managed in light of SECA regulations?

These critical questions relates to the risks and evaluation of maritime investments, particularly in the context of sustainable shipping and emission control.

The first research question **(RQ1)** focuses on how the risks of maritime investments can be reduced and the key factors influencing this process. This RQ is addressed using an approach to risk management inspired by the conventional method of Value at Risk (VaR). As Alexandridis et al. (2009) pointed out, the use of the Value at Risk (VaR) method will increase investor confidence and enhanced risk management practices in the financial industry. Articles III and IV (Olaniyi et al., 2018, and Atari & Prause, 2018) address this question. Atari & Prause (2018) explore the risk assessment of emission abatement technologies, offering a framework for managing these risks in maritime operations. Meanwhile, Olaniyi et al. (2018) develop a maritime energy-contracting model, an investment tool designed to minimize investment and operational costs, as well as risks, during the implementation of abatement technologies and the adoption of new ships with cleaner fuels. Both studies concentrate on how to make better investment decisions, how and where these changes occur and the potential consequences of these actions to offer new insights for the maritime industry. The results integrate a novel business model and feedback from maritime stakeholders to optimize investments and risks, supporting sustainable, clean shipping.

The second research question **(RQ2)** investigates how investments in marine abatement technology can be more effectively evaluated, based on critical factors such as asset type, costing and financing, maintenance and operating costs, depreciation, and other economic conditions. The author adopts an advanced Real Option Theory model (ROT), a refined version of traditional option theory, to precisely analyze investment demands in the marine sector. This approach is informed by an extensive review of relevant literature and detailed consultations with experts from both the maritime and financial industries. Additionally, the author used the ROT method to adeptly integrate traditional financial evaluation methods like the net present value (NPV), return on equity, internal rate of return (IRR), and payback time calculations. This integration facilitates a more comprehensive evaluation of project expenditures, providing managerial flexibility. This topic is covered in Article II (Atari et al., 2019), which applies a real options analysis to abatement investments for Sulphur emission control compliance. While conventional financial instruments like bonds, stocks, futures, derivatives, and options are widely used in the financial industry for risk assessment, management, and investment evaluation, this work blends classical models with investments in capital-intensive physical assets, developing new models to better address investment evaluation in this context.

By focusing on operational problem management and optimizing green initiatives, while considering both controllable and uncontrollable variables in the maritime sector, the third research question **(RQ3)** explores how to effectively manage the risks associated with abatement investments in maritime fleets, particularly under SECA regulations. This thesis addresses this RQ by adapting the Portfolio Theory and diversification (1968, 1976) methods to optimize investment risks associated with different fuel types used by ships. This strategic approach facilitates the creation of a diversified investment portfolio tailored specifically to the unique risks inherent in various maritime fuels. In risk diversification, fleet management helps to balance between risk and return by constructing a portfolio that maximizes returns for a given level of risk (Morchio et al., 2024). Shipping companies typically manage multiple ships to expand their fleet, increase revenue, and meet customer and industry demands and as a result, their marine investment decisions impact a broader set of assets that includes the entire fleet (Stopford, 2008). This research question, therefore, helps in the diversification of risks across various assets while simultaneously constructing and optimizing an investment portfolio for shipping companies. Articles II–IV provide a comprehensive understanding of maritime investment risks and the strategies needed for effective risk mitigation and evaluation; however, Article I (Atari, 2021) specifically focuses on sustainable maritime fleet management in response to the Global Sulphur Cap 2020. This extension not only deepens our understanding of maritime economics and finance, but also paves the way for new model creation and applications in future research in the field.

The articles are interconnected through a common goal of mitigating investment risks while ensuring compliance with environmental. Each paper addresses different aspects of risk – ranging from risk identification (Articles III and IV) to a more sophisticated risk evaluation (Article II with real options theory) and comprehensive risk diversification across fleets (Article I).

As shown in Table 1, the articles progressively elaborate on the research, beginning with the identification and framing of the investment risk problem in maritime finance, particularly the challenges associated with SECA and Global Cap 2020 compliance. The research first explores key factors influencing risk reduction in maritime investments, addressing uncertainties in fuel price volatility, regulatory shifts, and abatement technology adoption. It then advances to the development of innovative evaluation models, integrating real options analysis and capital budgeting techniques to enhance investment decision-making for marine abatement technologies. Finally, these models are incorporated into a structured, portfolio-based risk management framework, optimizing fleet investment strategies by balancing systematic and unsystematic risks under evolving environmental regulations.

*__Table 1.__ Overview of Gaps, RQs and Articles.*

| Research Gap | Research Question (RQ) | Article |
|---|---|---|
| **Gap 1:** -Traditional quantitative methods in maritime finance are insufficient to capture the complexities of investment risks. | **RQ1:** What key factors can effectively reduce the risk of maritime investments, and how can they be applied effectively? | - **Article III:** Olaniyi et al. (2018)<br>- **Article IV:** Atari & Prause (2018) |
| **Gap 2:** Conventional evaluation methods for investments in physical assets (like abatement technologies) do not account for the flexibility required by changing economic conditions seen in Maritime. | **RQ2:** How can investment in marine abatement technology be more effectively evaluated using key influencing factors? | - **Article II:** Atari et al. (2019) |
| **Gap 3:** There is a lack of comprehensive frameworks for optimal investment management that simultaneously address systematic risks (affecting the global fleet) and unsystematic risks (specific to individual ships) under strict environmental regulations. | **RQ3:** How can the risks of abatement investments in maritime fleets be most effectively managed in light of SECA regulations? | - **Article I:** Atari (2021) (focused on sustainable maritime fleet management in response to environmental regulations)<br>- Additional information are also provided across Articles II–IV to reinforce the comprehensive risk management approach |

*Source: Author's compilation.*

Consequently, this thesis with the goal to provide more practical and reliable methods for assessing shipping investments, particularly under market volatility, and to advance the evaluation of maritime innovation projects proposes the development of innovative models and methods designed to enhance the understanding and management of investment risks within the framework of strict environmental regulations. The research achieved significant progress in the field of investment risk management for sustainable marine operations. The new models developed aim to integrate theoretical constructs and empirical evidence, providing a comprehensive framework that addresses the complex dynamics of adaptation and economic sustainability in the maritime industry, with a focus on abatement technology.

In presenting a comprehensive framework that blends environmental compliance with strategic investment decision-making in the maritime sector, the study combines essential aspects such as financial risk assessment, strategic planning, and environmental stewardship. This integration not only broadens the scope of the discipline but also offers crucial insights for maritime industry professionals, helping them effectively manage the complexities of environmental regulations. Lastly, situated within the larger context of strategic management during regulatory uncertainty, the thesis significantly advances academic scholarship and offers a practical guide for sustainable business practices in the maritime industry.

The thesis structure continues with an exploration of the history and impact of SECA, the Global Cap, and other pertinent regulations and abatement technologies in the first chapter. This chapter further focuses on maritime economics, particularly the significance of bunker fuel prices, related financial issues, and the assessment of the economic implications of new environmental regulations, innovative green shipping initiatives, and investment risk considerations. A comprehensive review of the research gap, objectives, and methodologies sets the stage for a detailed analysis and discussion of the findings. The results highlight the viability of the proposed models, offering sustainable investment strategies that transcend traditional return-risk considerations. The thesis concludes with a summary of key insights, implications for the maritime industry, and suggestions for future research, marking a significant advancement in the pursuit of environmentally and economically sustainable maritime operations.

# 1 Background

## 1.1 SECA regulation and sulphur emission compliance solutions

The reduction of SOx is addressed in Regulation 14 of MARPOL Annex VI (Seddiek & Elgohary, 2014) and the emission criteria are related to the sulphur content in fuels. The global sulphur content cap in fuels was set at < 3.5 percent from 2012 and later reduced to < 0.5 percent from 2020 (DNV, 2018). However, for SECA, it was < 1 percent from 2010 in SOx Pollution Control Areas and further reduced to below 0.1 percent from 2015 (Trozzi, 2010). One can say that the SECA law is perhaps one of the most influential environmental regulations related to shipping and has arguably been discussed more than any other topic in shipping over the past ten years (Makkonen & Repka, 2016). Similarly, this same SECA law has had many practical implications for shipping (Blank, 2011).

Many countries' economies rely heavily on the shipping industry, making regulatory changes within the sector a subject of extensive research. The legislated sulphur cap introduced between 2005 and 2020 has been widely studied. Some studies focus on examining the best ways for shipping companies to comply with emission regulations, coming up with different options for dealing with emissions issues, as well as economic cost-benefit assessments (see Bengtsson et al., 2011; Lindstad et al., 2015; Olaniyi et al., 2018). While some like the post-SECA studies evaluate the decisions of stakeholders. In particular, economic research on SECA has considered broader consequences of the SECA law; see, for example, Lähteenmäki-Uutela et al. (2017) and Olaniyi et al. (2017). Difficult decisions must be made to ensure compliance which is not a straightforward process, as many calculations are required regarding current and future fuel prices and company budgets. Below, the most favorable solutions identified between 2005 and 2015 regarding SECA regulations and compliance with the new sulphur emission rules are presented.

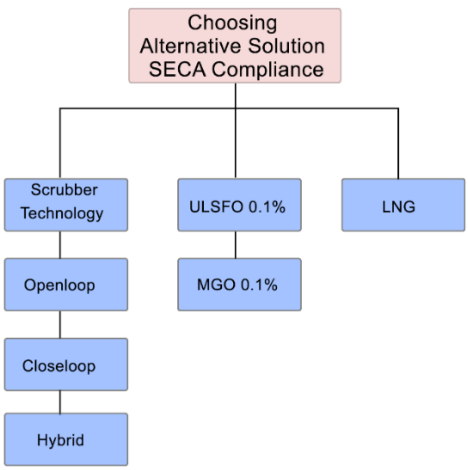


***Figure 1**. Major SECA compliance solutions.*
*Source: Author's compilation.*

Hämäläinen & Inkinen's (2019) research revealed that SECA had a greater influence than the industry expected, indirectly affecting a range of shipping activities, including bulk cargo, freight transportation, and the bunker fuel market. Although possible solutions are limited and typically come with high risks, the optimal solution is determined by the ship type and shipping lines as there is no single definitive answer for all cases. Each ship, depending on its lifetime, sailing distance, and speed, may have specific investment capabilities and potential (Atari & Prause, 2017). In the decision-making process, the strategic direction and future planning for a full business cycle are primarily taken into account.

However, discussions have emerged about various new fuels, fuel management, fuel economy, and several studies on the current state of LNG, scrubbers, and high-sulphur fuel use after SECA regulation. The debates are gradually moving away from SECA, and discussions surrounding the Global Cap 2020 have become even more intense than those on SECA. Solutions have not changed significantly from SECA to Global Cap 2020, so shipowners are still dealing with the same possible solutions (Olaniyi & Prause, 2021). However, some of the new fuels and solutions discussed in the industry are making serious strides into the market.

After the full implementation of SECA, fuel prices fluctuated as fuel demand changed. These fluctuations led to increased attention on new fuels, therefore, Holmgren et al. (2014) examined fuel management outcomes and proposed a new model for alternative fuels compatible with the work process in Northern Europe. Like Holmgren et al., since the SECA regulation, industry experts have paid more attention to alternative solutions beyond the three most popular ones. In any case, restrictions have led to the growing use of emerging fuels in the industry. Key issues in promoting alternative fuels in marine transportation include increasing the price competitiveness of marine-grade fuels by reducing manufacturing costs, providing tax cuts, exemptions, and government support (Kesieme et al., 2019).

## 1.2 Investment challenges and regulatory impacts in the SECA era

Obtaining and installing scrubbers was observed during and before the implementation of SECA. However, it has been difficult to established a clear investment strategy for scrubbers even though the technical and environmental aspects of scrubbers have been examined extensively (Olaniyi et al., 2018). In fact, it is difficult to find the right scrubber for ships at the right operational price. As Jiang et al. (2014) point out, retrofitting an existing ship generally costs more than installing a scrubber on a new ship, requiring a shorter payback period for the investment to be viable. Furthermore, they stress that installing scrubbers is not cost-effective if a ship's remaining lifespan is short. This is why the benefits of scrubbers highly depend on the price difference between the fuels used. For example, the payback time depends on the price spread between high-sulphur fuel and low-sulphur or ultra-low-sulphur fuel (Panasiuk & Turkina, 2015; Zhu et al., 2020).

Although the use of scrubbers has tremendous potential for major social and environmental benefits, as they can reduce SOx emissions by at least 95% and particulate matter (PM) by at least 60%, there are limitations regarding their use in the waters of some countries, which adds to the difficulties beyond IMO regulations (IMO, 2016). Many countries have released the most recent ship emission management documents, banning ships from discharging wastewater and burning residue from open-loop scrubbers along their coastal and river ECAs. Ships are required to record the particulars of wastewater and residue disposal (Honniball, 2019).

Many studies show that after the SECA regulation, most shipowners switched from HFO to LSFO or ULSFO and preferred these fuels over others (Zhu et al., 2020). LSFO has always been costlier than any other available fuel on the market. The use of this fuel is favorable for shipowners when the price spread between LSFO and HFO narrows (Atari & Prause, 2018). When the price spread is low, using a scrubber is not rational, as it will not generate much revenue (Olaniyi, 2017). Figure 2 shows the historical prices of different fuels.


***Figure 2.*** *Historical bunker fuel price.*
*Source: Current price development oil and gas, DNV GL (2019).*

Price values are calculated based on mm/BTU. In LNG, liquefaction costs need to be added if it is not in the EU market (DNV GL, 2019). The prices of liquefaction and natural gas do not differ significantly in the EU. However, a more serious concern is whether future prices are predictable, whether a similar correlation will exist in the future, and whether the variance or covariance of the current data will remain similar. These are all questions that may arise in the minds of researchers and economic analysts at the initial stage of data analysis.

One possibility is that the price of most oil derivatives is derived from the price of crude oil (Alizadeh et al., 2004), thereby establishing a historical price correlation between different fuels. Even in the international market, gas pricing was traditionally determined through a formula based on crude oil values. Many scholars have been surprisingly inattentive to analyzing bunker prices.

## 1.3 Maritime economics, investments and risk management

Over the last two decades, the world GDP increased by approximately 73%, compared to a 112% increase in sea trade over the same period (Low et al., 1998). Maritime economics encompasses industries such as shipping, fishing, ports and infrastructure, offshore wind, and marine biotechnology. It is also a natural asset and ecosystem, whether for fish, shipping lanes, or carbon dioxide absorption. The total contribution to the global economy was valued at 1.5 trillion USD, and the industry created more than 31 million jobs by 2010 (Soares & Santos, 2018). The contribution of the entire industry to the northern European economy has exceeded 160 billion euros (Statista, 2020). In 2019, around 53,000 merchant ships traded globally. Of these, 12,290 ships were sailing in the

European SECA (about 23% of the world fleet), according to the Statista Research Department (2020).

The SECA regulation has had a significant impact on several macroeconomic factors, most notably oil and ship bunker fuel prices (Olaniyi & Prause, 2019). Since maritime transport is a capital-intensive industry (Atari & Prause, 2017), a sudden increase or decline in prices may have a significant impact on investment decisions. Investments in new ferry ships with a capacity of 2,500 passengers require more than 200 million euros (in 2020). Typically, ships are built in Chinese, Korean, or Bangladeshi shipyards, and engines are supplied by one of the European conglomerate engine designers and manufacturers (Atari et al., 2019).

## 1.4 Maritime investment risk management

Maritime business activities involve a mixture of risks. Risk is typically defined as the uncertainty of results, and the best way to evaluate it in terms of probability distribution is to analyze historical risk events (Jorion, 2007). For convenience, this work distinguishes between different categories of risk: market risk, credit risk, liquidity risk, etc. Risk itself is the probability that an event with significant unknown impact will occur in the future (Atari, 2021). A standard risk assessment and management framework may include the following four phases: recognition, evaluation, administration (mitigation and risk decision-making), and monitoring (Al-Thani & Merna, 2005).

Although the shipping industry has always been considered one of the most volatile industries, most risk management frameworks in the maritime sector have focused on freight rates (Alizadeh, 2013). Contrary to the focus of existing literature, shipping risk is not limited to freight rates but also includes the high volatility of important cost categories. Stopford (2008) differentiates between five categories of shipping costs: operating costs, voyage costs, cargo handling, capital costs, and maintenance costs. In capital budgeting, these cost categories can be classified into costs that stem from investment in equipment, including tentative abatement technologies (CAPEX), and those that represent costs for running the vessel (OPEX). Since CAPEX represents the initial investment costs in the vessel's hardware, the related shipping cost category is capital cost, which primarily includes interest and depreciation. OPEX comprises the costs of operating the vessel, including operating costs, voyage costs, cargo handling, and maintenance costs.

As Stopford (2008) pointed out, the main economic parameters affecting CAPEX and OPEX in the shipping sector are fuel prices (f), interest rates (i), maintenance costs (m), and other costs (o), leading to the following equation for the running cost (RC) of a vessel:

$$RC = RC\ (CAPEX,\ Opex) = RC\ (f, i, m, o).$$

There are major shortcomings in the existing literature on risk management (both CAPEX and OPEX risk) in the context of ship finance and investment (Alexandridis et al., 2018). Fluctuating raw material prices can have a profound effect on corporations' cash flows and earnings. The undesirability of volatility gives businesses an opportunity to collect advanced information on market fluctuations and monitor their exposure to price volatility (Kavussanos & Visvikis, 2016).

The risk of fuel rate instability has a direct impact on a ship's operating costs (Atari & Prause, 2017). Most importantly, historically, bunker fuel has accounted for about 50% of a vessel's total cost (Stopford, 2002). For a ship whose operational costs are heavily dependent on fuel, studies have shown that this percentage might decrease to 40% or sometimes rise to 60% of the running operating costs (Hämäläinen & Inkinen, 2018; Notteboom, 2011). The high volatility in bunker fuel prices makes predicting operational costs challenging (Atari et al., 2019; Atari & Prause, 2017). While fluctuations in other operating costs are more or less predictable, bunker costs continuously rise and fall in an unforeseeable manner. As a result, achieving proper risk control and maintaining a healthy cash flow status makes bunker costs the single most important variable to manage (Harwood, 2006). This represents a dangerous pitfall that may diminish potential operational profits during good times (Giovannini & Psaraftis, 2019).

As a result, the emphasis of this research is on investigating the risk evaluation of fuel prices in abatement technology investments, which already presents a difficult challenge when considering the nominal lifespan of ships, typically around 20 years. In the case of risk management for marine abatement investments, the spread – i.e., the price differential between several fuel types – is at the center of attention, so all investments must be compared to alternative investments using different fuel types.

## 1.5 Value at risk

Parties involved in this business – shipowners, charterers, and cargo owners – constantly face substantial operational, business, financial, and market risks. Apart from frequent changes in freight rates and vessel prices, fluctuations in operating costs also contribute to shipping viability (Syriopoulos, 2010). The major risk of purchasing equipment related to SECA is the market risk of raw materials. Shipowners will therefore benefit from protection against fluctuating bunker fuel prices (Alizadeh & Nomikos, 2009). This thesis will not delve deeply into the effects of rising and falling fuel prices or study their causes. Instead, it will focus solely on the effects of SECA and Global Cap 2020, which have naturally had a significant impact on fuel prices.

In general, standard finance theory is developed to provide mathematically sophisticated explanations for financial questions that, when posed in real life, are often complicated by imprecise and inelegant conditions (Pompian, 2012). Therefore, to control and manage business and market risk as a subset of investment risk, the concept of Value at Risk (VaR) is used, which is one of the most widely used risk measures. VaR assessment has been widely accepted since the 1990s. It was first introduced by JP Morgan and later refined by the RiskMetrics Group in their risk management software (Marshall & Siegel, 1996). VaR indicates the likelihood of losses at a high level, specifying that over a holding period, losses will exceed a pre-specified threshold depending on the confidence level (Atari & Prause, 2018). To link classical VaR with **Maritime VaR** and thereby create a new model, the following steps were taken:

- The period determination,
- The Gaussian bunker fuel distribution test = Yes or No,
- The Gaussian spread values of bunker fuels distribution test = Yes or No,
- The Gaussian income value distribution test = Yes or No,
- If yes, then the historical MaritimeVaR could be created,
- MaritimeVaR = Confidence interval (CI) of bunker fuel or PV of asset return,
- MaritimeVaR = CI, Bunker fuel can reveal the greatest likelihood of profit or loss.

In the mentioned process, classical VaR is first transformed into Capital Budgeting VaR (CBVaR). Looking into past research related to capital budgeting and VaR, a previous study by Ye & Tiong (2000) failed to address future cash flow or probability density, as the new NPV-at-risk model was designed based on BOT infrastructure projects, where cash flow might not depend on variable costs. Linsmeier & Pearson (2000) draw attention to Cash Flow at Risk (CFaR) and reconsider the need for CFaR as potentially more sophisticated than VaR. Although CFaR is conceptually similar to VaR, estimating the risk of loss in cash flows generated by a random variable in a Monte Carlo model can be more complex than estimating VaR. To some extent, these difficulties are mitigated by the fact that the model of financial market factors can be relatively crude, as there is no point in refining it beyond the precision of the operating cash flow model. Nonetheless, developing a CFaR measurement system is likely to be a significant undertaking.

To calculate cash flow, expenditure, or confidence levels of the dataset, the random variable represents C, given an asset or portfolio f(C), the probability density function **dC**, and CI as the confidence level. Finally, the probability of yielding less than C* is expressed as follows. The following model does not follow a Gaussian distribution:

$$Prob\,[C< C^*] = \int_{-\infty}^{C^*} f(C)dC = 1 - CI$$

After transforming VaR into CBVaR, it is time to shift to MaritimeVaR. For MaritimeVaR validation, the work examined quantum data over a recent five-year period to observe the distribution of bunker fuel prices. This allows for the use of parametric and non-parametric VaR methods. The normality test follows the composite hypothesis assumed by Yap & Sim (2011) in data evaluation:

$$H_0 = f(x, \Theta) \in N(\mu, \sigma^2) \text{ against } H_1: f(x,\Theta) \notin N(\mu, \sigma^2)$$

This hypothesis is formulated based on normality testing, and the null hypothesis is rejected when appropriate. To test the normality of historical prices, the first test employed is that developed by Shapiro and Wilk (1965). The test is based on the G (Gaussian) statistic:

$$G = \frac{\left[\sum_{i=1}^{n} a_i \left( C_{(n-i+1)} - C_{(i)} \right)\right]^2}{\sum_{i=1}^{n} \left( C_{(i)} - \bar{c} \right)^2}$$

Where $C_n$ represents the ordered values of cash flows and $a_i$ are the given constants. Normality is rejected for small values of G. The fuel spread or OPEX is given by:

Ci = C1+C2+C3+...+Cn, where C1<C2<C3<...<Cn. The Kolmogorov-Smirnov test (Lilliefors, 1967; Dodge, 2008) is used as a second test of normality, justifying the choice of VaR methodology. In theory, the Kolmogorov–Smirnov statistic for testing normality belongs to the subcategory of goodness-of-fit statistics, specifically EDF (Empirical Distribution Function) statistics, which compare the population cumulative distribution function $F_n(C)$ with the empirical cumulative distribution function. The Kolmogorov–Smirnov KS statistic is defined as follows:

$$KS = \max_{1 \le i \le n} \{ | F(Ci) - \frac{i-1}{n} | , | F(Ci) - \frac{i}{n} | \}$$

where:

$$F(C_i) = W\left(\frac{C_i - \mu}{\sigma}\right)^n$$

W is the cumulative distribution function of the standard normal distribution. Normality is rejected for large values of KS, and critical values (percentage points of the distribution) are required for different sample sizes. Once the statistical population (data) is selected, the appropriate method can be determined.

In VaR analysis, three standard models are widely used in financial markets: historical data, Monte Carlo simulations, and parametric models. Choosing the correct method enables faster achievement of VaR objectives, providing results that inform investment managers about the maximum or minimum capital loss expected for a single investment or a portfolio over a given period, with a specified confidence level (Best, 1998).

Since shipbuilding raw material price fluctuations lead to volatility at different stages whether in operating expenses, cash flow, or income (Atari & Prause, 2017), the new MaritimeVaR methodology is used to hedge against risks related to OPEX. This helps investors manage investment risks in the bunker fuel market, specifically hedging against fuel price risks and the financial impact of changing or not changing the type of bunker fuel used. When cash flows are variable, it is difficult for investors to accurately attribute deviations in cash flows to corporate management decisions or external factors beyond management's control (Bradley et al., 1998).

The parametric VaR method, also known as the variance-covariance method, is best suited to risk measurement problems where distributions are known, tested, and reliably estimated. However, the result can be unreliable when the sample size is very small (Saita, 2010). This method assumes a normal distribution of returns, requiring the estimation of two factors: expected return and standard deviation (Atari & Prause, 2017).

The implemented volatility must be specified over a given time period. To identify population, sample, or general discrete data, finite days and their daily prices are required. Market data is gathered over the last $n$ working days. The following formula provides a simplified approach to calculating price volatility:

$$\sigma_{day} = \frac{\sigma_{year}}{\sqrt{n\ days}}$$

Alternatively, if daily returns or spread values on specific days are of interest, the variance of the bunker fuel spread can be measured annually as follows:

$$\sigma_H^2 = \sum_{n=1}^{n} \frac{(X_t - \overline{X_t})^2}{n-1}$$

For each scenario, the portfolio is valued using full nonlinear pricing models. The worst days selected are determined by the VaR historical confidence interval. The number of variables on day I is denoted as $C_i$, while $m$ represents the number of days from which historical data is taken:

$$C_m \frac{C_i}{C_{i-1}}$$

VaR is associated with a degree of probability; lowering the probability increases the confidence interval. Investment VaR and its corresponding confidence interval are shown in Table 2.

***Table 2.*** *Investment VaR and its confidence interval.*

| MaritimeVaR Confidence level | Probability Level | The amount of loss (Max or Min) – below the expected or average return. Function of standard deviation (σ) and time(T) |
|---|---|---|
| 99% Confidence | 1% | $-2.33(\sigma) \times \sqrt{T}$ |
| 95% Confidence | 5% | $-1.65(\sigma) \times \sqrt{T}$ |
| 90% Confidence | 10% | $-1.28(\sigma) \times \sqrt{T}$ |

*Source: Author's compilation.*

The employed VaR model and the results obtained from the proposed model, in accordance with the marine industry, answer research question number one presented in this thesis. The novelty of this section lies in the fact that the developed risk-based models extend into two major branches: the first is capital budgeting, and the second is marine economics. These subfields are categorized as 'MaritimeVaR' and 'Capital Budgeting VaR (CBVaR),' both of which create a new branch in financial modeling.

In the next chapter, the author briefly describes the theory behind maritime investment valuation and focus on how a practicing professional involved in real project valuation can use these new models to calculate the value of different types of project investments.

## 1.6 Investment theory

The models and theories discussed here all stem from and are based on original investment theory, which is why it is been mentioned. The theory of investment has been well developed in the field of economics over the last century. General investment theory arguably originates from John Maynard Keynes' (1936) work, in which he described the relationship between capital and interest rates, or in other words, the efficiency of investment. Based on the "internal rate of return (IRR)," firms are assumed to compare different projects after a complete evaluation process (Atari et al., 2019). This theory is useful in the investment decision-making process.

All of this occurred after Irving Fisher's capital and investment theories were presented in his papers on the existence of capital and profits (Fisher, 1906) and the rate of interest (Fisher, 1907). Both ideas are best expressed in Fisher's book The Theory of Interest (Fisher, 1930), which treats a firm's investment decision as an intertemporal issue. Fisher believed that all capital was circulating capital in his theory. In other words, the entire capital stock is depleted during the manufacturing process; instead, all "capital" is actually investment.

Investment theories have been developed in many aspects, but the most common models across industries rely on the value of discounted future cash flows. The most frequently used model is the Net Present Value (NPV) Model. NPV represents the amount of cash an organization values today for a project. The main issue is that it double-counts investment risk by first discounting at the risk-adjusted discount rate and then indicating NPV as a distribution.

Investments in financial assets are divided into two major categories: capital markets and capital budgeting. In capital markets, the investor allocates wealth (investment) into financial securities (Merton, 1990). On the other hand, capital budgeting is a method used by management to determine which capital investments would yield the highest return on investment for the funds invested (Peterson & Fabozzi, 2002).

Ho & Liao (2011) pointed out the deficiencies of DCF-based approaches, which exhibit two major pitfalls. The first is that in volatile decision-making situations, DCF factors such as cash flows cannot be accurately measured. The second is that the value of managerial flexibility in investment projects cannot be fully revealed through DCF evaluation analysis. Both would lead to improper results in strategic investment project valuation.

On the other hand, IRR has a strong position in investment evaluation. Many decision-makers believe that NPV has more advantages than disadvantages over IRR (Gaspars-Wieloch, 2019). The function of the IRR model is quite similar to NPV, except that the discount rate here is replaced by the IRR. If the IRR is greater than the discounted cash flow, then the manager can accept the investment. If the IRR is lower than the discounted cash flow, then the investment should be rejected.

The chart below shows the path of investment theory, which is usually divided into two major branches. After comparing the weight of research in both branches, it was observed that investment in real assets has not been well researched. Most of the research surprisingly focuses on capital market issues; therefore, most new methodologies and models are proposed for financial securities.

Figure 3 depicts the relationship and the complete investment process.

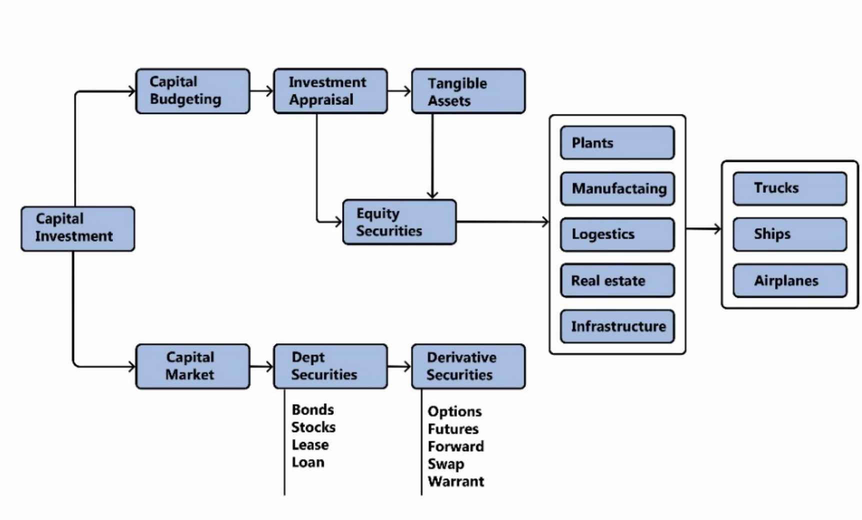


***Figure 3**. Capital investment.*
*Source: Author's compilation.*

### 1.6.1 A real option approach to maritime investments

Traditional financial industry strategies are not always capable of accurately pricing businesses following major acquisitions. Since conventional models have failed to predict outcomes in many situations, new investments by companies can result in dramatic changes in their valuation. Recent research on financial valuation moves beyond traditional literature to achieve more accurate methods. These investment models and theories are typically more mathematically complex.

In fact, with a deeper look into Real Options Theory (ROT), it is easily realized that options in the financial market have been created as a form of hedging and investment facilitation. However, from a historical perspective, as mentioned in the book by Brach (2003), this concept dates back to ancient civilizations. Historically, it replaced the trading of commodities and pricing of options instead of assets.

With the later development of financial options, they became widely used in financial markets, offering investors more freedom and less obligation when trading stock options. Gradually, options began to be used in investment evaluation. The term Real Option was first introduced by Stewart Myers in 1977, four years after Black and Scholes developed the option-pricing model. This model is used to determine the value of a call option. Real options allow us to evaluate different commodities, real assets, or project investments. However, our focus is on the type of real option applied to large-scale investment projects. In this context, ships and new technologies related to them are considered as these projects.

Several early studies in this area focused primarily on the gap between NPV, IRR, and real options. Abel et al. (1996) further explained that real options perform well where NPV or DCF methods fail. Dixit and Pindyck (1995) elaborated on investment under uncertainty, recognizing the costs of irreversibility, opportunity cost, and the cost of giving up flexibility. Atari et al. (2019) and Carbonara & Pellegrino (2018) provide a detailed analysis of scenarios where high price volatility of raw materials or total OPEX creates significant future uncertainty, making real options superior to other evaluation methods.

Considering real options as a method for evaluating real investment projects, very little research has been conducted in the maritime sector. Hypothetically, since this model is more suitable for solving environmental investment problems, it is applied to analyze and evaluate capital investments in new technologies, including ship scrubbing systems. The methods and models used in this research are illustrated in the diagram below.

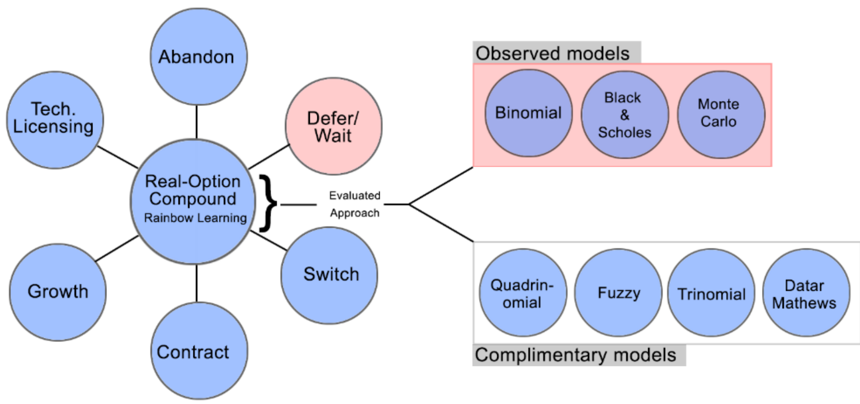


***Figure 4.*** *Real option approach to investment.*
*Source: Author's compilation.*

In recent years, the real options approach has been applied as a valuable tool for addressing several complex financial questions. The method is expanding rapidly as a new valuation framework. One of its roots, which has been considered a surprising development, is Lotfi Zadeh's (1956) state-of-the-art advancements in fuzzy mathematics and its applications. Fuzzy logic plays a crucial role in financial theory by helping to predict trends, remove ambiguities, and reduce uncertainties. It has influenced two primary investment areas: (1) conventional investment theories like NPV, DCF, and PV, and (2) real options.

Since the focus of this thesis is on valuation methods based on real options, other models like fuzzy NPV, DCF, and additional capital budgeting extensions are not included in the diagram.

Carlsson & Fullér (2000) and Collan et al. (2009) applied new methods such as the expanded Fuzzy Real Option approach in evaluating investment cases. Later, Attarzadeh (2017) and Islam (2017) tested new, complex real option methods on civil projects, primarily focusing on the evaluation of large-scale projects with high capital budgets. Their results demonstrated that real options produced significant insights for investment valuation.

Bendall & Stent (2010) proposed a new approach to real options by integrating real option theory with risk management, treating ships as commodity options to mitigate risks. In parallel, Huang (2007) and Kuchta (2000) developed NPV methods based on classical fuzzy logic and general capital budgeting models. Kahraman et al. (2002) further expanded this by setting up the Fuzzy Cash Flow model and calculating the payback period for projects. Sari & Kahraman (2015) introduced the idea of applying type-two fuzzy intervals to capital budgeting.

Forecasting is an interdisciplinary field with applications in economics, finance, and computer-based decision-making, and it continues to expand daily. However, financial forecasting relies on future cash flow estimates, and there remains a gap in accurately predicting returns on investment. While different analytical methods and financial software offer partial solutions, predicting future cash flows remains challenging.

Triantis & Borison (2001) and many other scholars working with real options have argued that the Black & Scholes models are not always reliable. They contended that Black & Scholes alone is insufficient for evaluating complex economic activities. However, others believe that the Black & Scholes (1973) model is not only the strongest valuation method for call options but also the most influential financial option pricing model in the history of financial engineering.

The model is expressed in continuous time as:

$$C\,(S, \tau, E) = S\ x\ N(d_1) - E\ x\ e^{-r x \tau}\ x\ N(d_2)$$

Where for $d_1$ and $d_2$:

$$d_1 = x = \frac{ln\left(\frac{S}{E}\right) + \left(r + \frac{1}{2}\,x\,\sigma^2\right) x\ \tau}{\sigma\ x\ \sqrt{\tau}}$$

$$d_2 = d_1 - \sigma\ x\ \sqrt{\tau}$$

where:

$\tau$ = time until the decision must be made or, in the case of deferment, the length of time the decision can be deferred.

$N(d_1)$ = cumulative probability of a normal distribution.

$C$ represents the expected value of the underlying asset, comparable to NPV, to determine whether the current value exceeds the investment cost at expiration.

$N(d2)$ represents the risk-neutral probability that the underlying asset's value will exceed the investment cost at expiration.

$E \times e^{-r \times \tau}$ represents the present value of the investment cost, where

$E$ is the expenditure required to acquire the project's assets,

$e$ is the base of natural logarithms, and

$r$ is the risk-free rate of return.

Financial option theory provides a structured approach to valuing a company's strategic investment options, bridging the gap between financial and strategic analysis. The main benefit of using real options is the connection to managerial flexibility. Since capital budgeting is a broad field and real-option models often require customization, this research specifically focuses on the real-options theory of company investment.

The second approach examined in this thesis is the Binomial Option-Pricing Model, proposed by Cox et al. (1979). The first-time step of the binomial tree has two nodes, representing possible asset values ($S_{ou}$, $S_{od}$) at the end of the first period ($T$ = 1). The last nodes at the end of the binomial tree represent the range of possible asset values at the end of the option lifespan ($T$ = n).

$$Sn = e^{-\sigma\Delta t}[(p \times Su) + ((1-p) \times Sd)]$$

where:

- $Sn$ = present value of the underlying asset.
- σ = volatility factor.
- T = life of the option.
- Δt = time step for calculations.

The up and down factors, u and d depend on the volatility of the underlying asset:

$$\begin{cases} \text{Su} = \text{ up factor} \\ \text{Sd} = \text{down factor} \end{cases}$$

$$Su = e^{\sigma.\sqrt{dt}}$$
$$Sd = e^{-\sigma.\sqrt{dt}}$$

Dixit & Pindyck (1994) emphasized the advantages of the binomial option-pricing tree model using risk-neutral probabilities over a risk-adjusted approach. The risk-neutral probability $p$is defined as:

$$P\ (\textit{risk neutral probability of moving up}) = \frac{e^{\sigma.\Delta t} - d}{u - d}$$
$$q = 1 - p\ (\textit{probability of moving down})$$

Risk-neutral probabilities are mathematical intermediates that allow for discounting cash flows using a risk-free interest rate. Experts recommend evaluating options using multiple approaches, so in addition to the Black-Scholes and binomial models, this research also applies the Monte Carlo simulation model, leveraging Black-Scholes for further analysis.

In this extended model, the underlying asset value is first calculated using the DCF method with a risk-adjusted discount rate. The risks are defined based on **CAPEX, OPEX,** and maritime industry factors, placing this model within multiple financial subcategories.

$$S_t = S_{t-1} + S_{t-1}\,(r \times dt + \sigma\, \varepsilon \sqrt{dt})$$

Where $St$ and $St - 1$ are the underlying asset values at time $t$ and time $t - 1$, respectively; $\sigma$ is the volatility of the underlying asset value; and $\epsilon$ is the simulated value from a standard normal distribution with a mean of zero and a variance of one (Mun, 2002). Since our CAPEX, OPEX, and risks are defined in the maritime industry, the extended model can be placed in different sub-branches. If we use only a single financial valuation model, i.e., Monte Carlo, it can be categorized under the Monte Carlo model subcategory in financial risk or evaluation models. Otherwise, it falls under the category of capital budgeting and real options, which can be referred to as "Maritime Real Option: Binomial, Monte Carlo, or Black & Scholes."

### 1.6.2 Investment risk management

The portfolio approach considers sets of investments and yields deeper insights into portfolio returns and risks. Most of the fundamental models were developed through the contributions of Fama, Sharpe, and primarily Markowitz (1991), who discussed and later contributed to investment theory. With their contributions, they introduced CAPM, the efficient market portfolio, and the Sharpe ratio. In most economic risk models, the volatility of the asset price or the market is considered the major risk of investment, whether in a portfolio or a single asset (Atari, 2021).

The results of previous research revealed that due to risk control, investors are keen to have a diversified basket of assets. As a result, Markowitz's Modern Portfolio Theory (1952) became a focal point for managing risk and diversifying the investment basket. The Markowitz theory has recently been applied to address financial security issues and has significantly expanded in that category.

Extensive and useful diversification models are surprisingly lacking in capital budgeting, investment appraisal, and real asset management. However, due to SECA regulations and the Global Cap 2020, fleet investment and management have become more complex than before. In response to research question number three of this thesis, solving this problem and finding the proper solution for shipping lines, Modern Portfolio Theory has been applied to manage maritime investment risks. This requires work in two areas like 1) the type and size of the ship and 2) the type of fuel used.

Note that the focus of the study was on ship fuel type and its diversification model. Markowitz's model is thus a theoretical framework for analyzing risk, return, and their interrelationships.

To achieve the desired results, the model first had to be adapted from financial security applications to real asset diversification. This process involved converting daily log returns and daily-portion expected returns to integer form and calculating the standard deviation. As a consequence, the expected return is the first and most critical factor to consider when building a diversified portfolio. The expected return of a portfolio is the weighted average of the expected returns for each asset in the portfolio:

$$E\,(R_P)=\sum_{j=1}^{m} w_j E(R_j)$$

where:

$R_p$ = expected return of the portfolio

$R_j$ = Expected return on security j

$W_j$ = Proportion of total portfolio invested in security j

m = total number of securities in the portfolio

Diversification and basket-making continue to be heavily dependent on accurate investment return assessment. However, while Markowitz's diversification and portfolio optimization model is strong and complex on its own, it has flaws as well. The model is not adaptive to time intervals and is limited to two fair standard deviations and returns, which is one of its listed flaws. After measuring the return, the standard deviation of the portfolio return at the desired point must be determined. The following formula presents the calculation of the standard deviation for a portfolio with multiple assets:

$$\sigma_p^2 = \sum_{i=1}^{n} \sum_{j=1}^{n} w_i w_j \, Cov\,(r_i, r_j)$$

where:

$W_{ij}$ = the weights of the portfolio's individual securities, where the weights are calculated by the proportion of capital in the portfolio

$\sigma_p^2$ = the variance rate of return, asset i

$Cov_{ij}$ = the covariance between the rates, return for assets i and j

The Covariance of portfolio return can be computed by summing up all the entries to the following table:

$$\sigma_p^2 = (W_1\ W_2 \ldots W_N) \begin{bmatrix} \sigma_{11} & \cdots & \sigma_{1n} \\ \vdots & \ddots & \vdots \\ \sigma_{n1} & \cdots & \sigma_{nn} \end{bmatrix} \begin{bmatrix} W_1 \\ \vdots \\ W_n \end{bmatrix}$$

However, Markowitz (1999) found that when there is a high degree of uncertainty about future returns, greater diversification of investments reduces risk. Many who are aware of potential returns with confidence will, in principle, invest in only one safe asset – the one with the highest expected future return. Both Fama and Markowitz proposed different diversification tests, but they did not determine the optimal number of assets in a portfolio, particularly when real or risk-free assets are added to the total market risky asset.

Sharpe (1970) extended the basic portfolio model by discussing SML vs. CML for determining the most efficient portfolio. He emphasized that the only portfolio that can be on both CML and SML is an efficient portfolio. Moreover, SML is expressed as:

$$E\,(R_i) = R_f + E(R_i) - R_f \quad \frac{Cov\ (R_i R_m)}{Var(R_m)}$$

While this work did not consider the beta of the market, and this was not possible, much effort was put into creating adequate models using the more complete Fama and Sharpe models. There were also constraints in constructing a portfolio and utilizing the market capital line. Assuming we have a portfolio of multiple assets with the same volatility ($\sigma$2) and Cov (covariance between these assets), we can deduct from the graph and our estimate of the cap that as $N$ (number of assets) approaches infinity, specific risk continues to diminish, leaving only market/systematic risk.

It is important to remember that if all asset returns are independently distributed, then Cov = 0 and = 0. For a portfolio of $N$ assets, there is a unique, diversifiable risk component.

$$\sigma_p^2 = \frac{1}{N}\sigma\ 2 + \frac{N-1}{N}.Cov$$

When the number of assets in the portfolio ($N$) is very large, the portfolio approaches the X-axis and tends toward ∞. We reduce portfolio risk by moving forward on the X-axis and increasing the number of assets.

$$\lim_{n\to\infty} \sigma_p^2 = Cov$$

The results obtained and the proposal are classified into two categories: systematic and unsystematic risks. Finally, a proposed model is presented. This justification is illustrated in Figure 5.

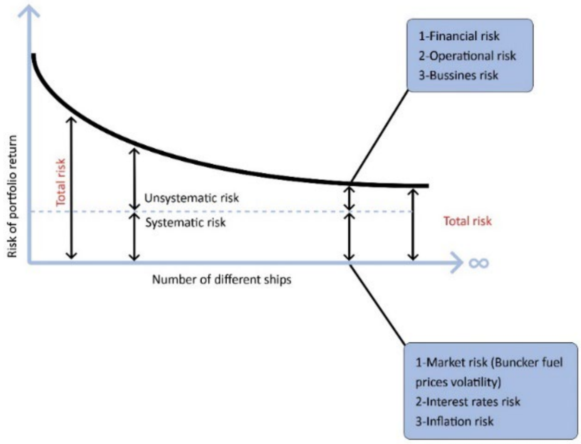


***Figure 5.*** *Risk of investment portfolio.*
*Source: Author's compilation.*

The chart explains the risk involved in investment portfolios. It shows that by adding more diverse investments (such as ships), the total risk decreases. The diagram also breaks down risk into unsystematic risks (specific to individual investments) and systematic risks (market-wide risks).

When discussing the optimal size of ships, the total number of ships in a fleet or in the global fleet, the type of ships, and the type of fuel they should use, the diversification question remains. This thesis presents a novel approach by focusing on risk management in the maritime industry. No one has yet paid attention to using the portfolio method to manage fleet investment risk. By applying this diversification strategy, we can manage the risk of investment in fleets.

Technically, this means that by combining assets into a portfolio, some risk is eliminated (mainly due to the covariance term), following Markowitz's emphasis on the correct selection of assets and proper diversification.

Diversification itself is a set of strategies designed to reduce risk by spreading the portfolio across appropriate investments (Atari, 2021). The diagram below presents an attempt to create a new model of an investment portfolio concerning real asset investment, based on both the classical Markowitz model and the modern investment model.

Figure 6 illustrates the steps involved in managing investments and portfolios. It starts with investment theories and progresses through steps such as assessing investments, managing risk, and diversifying assets. Then, it explains how to identify, select, form, update, evaluate, and optimize investment portfolios.

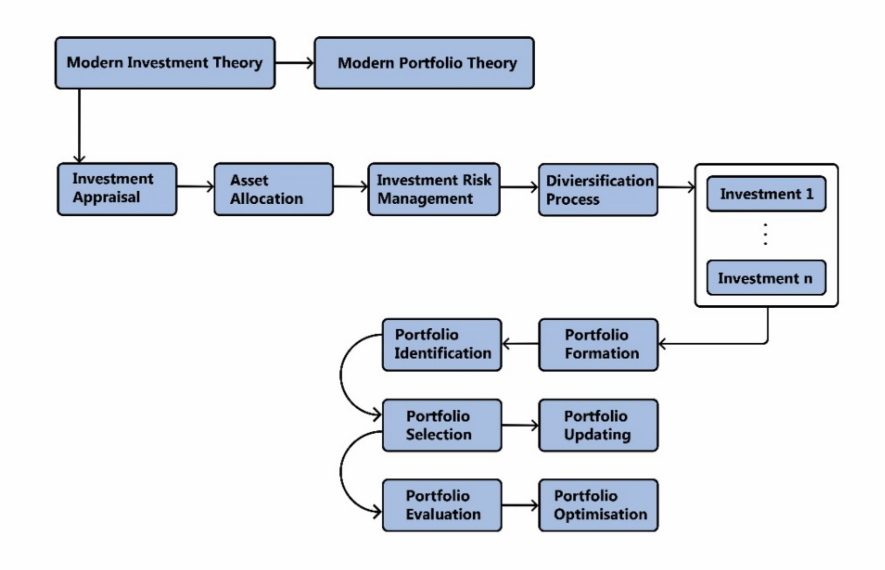


***Figure 6.*** *Investment appraisal, portfolio management.*
*Source: Author's compilation.*

A well-diversified portfolio requires constant optimization (Atari, 2021). The well-known mean-variance optimization considers the standard deviation of the returns for each asset. To complete the optimization process, it must visually demonstrate the position of each asset based on its expected return. Finally, this leads to constructing the efficient frontier, where the capital market line (CML) divides risky and risk-free portfolios.

To determine the best efficient frontier position, comprehensive studies on the correlation and covariance of returns between assets are required. Annualized data and information about the efficient frontier, optimal portfolio, or even the tangency point can help investors make investment decisions more quickly, accurately, and with reduced risk.

The results can be updated annually based on historical fuel data and the OPEX of ships. The entire process and its outcomes emphasize the importance of asset diversification in the maritime industry.

# 2 Methodology

In this section, the author discusses the research methodology of the thesis within the context of maritime operations. The methodology is strongly influenced by operations management (OM), particularly operations research (OR), which draws on financial and mathematical modeling to establish a robust analytical framework. A critical component of this approach is risk management, which is essential for evaluating uncertainties in maritime investment decisions, regulatory compliance, and operational strategies. Overall, this methodology is crucial for addressing the research questions centered around Sulphur Emission Control Areas (SECA), a key environmental regulation that has significantly influenced maritime discourse, as noted by Makkonen and Repka (2016).

Therefore, this research begins with a thorough review of the legal and environmental provisions governing SECA, transitioning into a comprehensive risk assessment. These steps are critical for framing the subsequent analytical processes, where the focus is on evaluating investments in these risk parameters.

Identifying the optimal solution for utilizing green fuels and solutions that comply with SECA regulations, while also maintaining a company's financial health, presents a multifaceted challenge that demands a complex and well-structured research approach. This integrated approach which is a combination of business research (BR), operations research (OR), and financial engineering methods introduces complexity to the evaluation of maritime investments due to the significant capital required.

By combining BR insights, which provide a contextual understanding of market dynamics and industry trends, with OR techniques for optimizing decision-making processes, and financial engineering methods for risk assessment and portfolio management, a comprehensive framework for evaluating maritime investments emerges. This combination allows for a holistic analysis that considers quantitatively finer factors and enables stakeholders to make informed investment decisions amid the complexities of the maritime industry.

As highlighted by Brady et al. (2012), evaluating investment decisions within business research (BR) involves a series of rigorous steps: designing the research framework, selecting suitable methodologies, gathering relevant data, and, crucially, refining and analyzing this data to derive meaningful conclusions. The complexity of such research tasks has prompted researchers to consistently innovate and exhibit resilience, often by adopting interdisciplinary approaches, as noted by Van Aken (2016).

The increasing prevalence of interdisciplinary research across various domains – such as supply chain management (SCM), logistics, maritime operations (MO), maritime economics (ME), and finance (MF) accentuates the necessity of integrating diverse perspectives and expertise to tackle complex issues effectively. In the context of maritime economics, blending financial engineering with operations research enables the development of sophisticated analytical frameworks and decision-support tools (Spronk et al., 2016). This integration empowers practitioners to address the unique challenges and opportunities within the maritime industry, leading to enhanced efficiency, profitability, and resilience in maritime operations and investments.

In collaborative efforts across multiple domains including business, operations, economics, engineering, and environmental science innovative solutions to pressing challenges are explored (Frodeman et al., 2017). These perspectives are pivotal in creating new methods for supply chain optimization, risk management in finance, and advancing sustainability in maritime industries (Gerlitz et al., 2022). By transcending traditional academic boundaries, such interdisciplinary and multidisciplinary research enables scholars and industry practitioners to leverage the collective strengths of various disciplines, thus facilitating a more effective approach to complex, multifaceted challenges in maritime finance and operations (Bakkar et al., 2019).

Modern research methodologies are streamlining the research process, allowing scholars to reach their objectives more efficiently. This doctoral thesis exemplifies this by adopting the aforementioned quantitative approaches. It utilizes advanced, novel scientific modeling techniques within the framework of Business Research (BR) and Operations Research (OR), applied to the business and management sciences. These quantitative methods, particularly effective for complex decision-making in maritime investment and risk management (a subfield of Maritime and Management Finance), ensure structured, repeatable, and objective data collection and analysis.

However, a continuing debate surrounds the limitations of quantitative methods in capturing the full picture of business phenomena. While these methods excel in statistical and mathematical analysis, they may oversimplify real-world business situations by neglecting the intricate relationships between variables. To overcome this limitation, scholars frequently integrate complementary methodologies, such as Operations Research (OR) with other quantitative methods in Business Research, including financial engineering (Jensen & Bard, 2002).

Furthermore, Management Science (MS), as a subfield of OR, is a discipline that applies analytical methods to improve business decision-making. It integrates smoothly into business administration. The ability of MS to optimize organizational processes, enhance decision-making, and improve operational efficiencies justifies its use in business administration studies (Anderson et al., 2019). It leverages statistical data and algorithmic models to solve complex problems in broad domains like maritime and ship finance, making it a vital part of modern business strategy and operations management (Taylor, 2002). This integration of MS enhances data-driven decision-making, which is crucial for gaining a competitive advantage in the business landscape.

Quantitative decision-making in business involves using mathematical models, statistics, and algorithms to analyze data and make informed decisions. This approach emphasizes objectivity and precision, relying on numerical data to predict outcomes and optimize strategies. Common applications include financial analysis, risk assessment, resource allocation, and strategic planning. While quantitative methods provide rigorous tools for decision-making, they may require supplementary qualitative insights to address factors such as investor behavior, morale, and other dynamic elements of business environments.

Decision analysis, Operations Research (OR), and Management Science (MS) each offer structured methodologies for addressing complex decision-making problems within organizations. Decision analysis encompasses probabilistic modeling, decision trees, influence diagrams, and sensitivity analysis, providing frameworks to analyze decisions and select optimal courses of action (Parnell, 2013). On the other hand, the OR research methodology involves problem formulation, model development, data collection and analysis, solution implementation, and performance evaluation. OR researchers frequently collaborate closely with practitioners to tackle real-world challenges and implement effective solutions (Petropoulos et al., 2024).

Similarly, research in Management Science involves formulating hypotheses, collecting data, conducting empirical analysis, and developing models or frameworks to support decision-making processes. This field emphasizes interdisciplinary collaboration and the integration of theoretical insights with practical applications (Jonker & Pennink, 2010). Therefore, by integrating these methodologies, researchers and organizations can enhance their decision-making capabilities and improve overall performance in dynamic and uncertain business and economic environments.

The debate regarding the preferred research method in Business Research (BR) continues. This thesis acknowledges the ongoing discussion between quantitative and qualitative approaches. While Simon (1979) champions qualitative methods for their ability to interpret complex and subjective factors, Kahneman and Tversky (2013) advocate for quantitative methods due to their ability to minimize bias through statistical models. Creswell, J. W., & Creswell, J. D. (2017) propose a more holistic approach, integrating both quantitative and qualitative methodologies for optimal decision-making. Venkatesh et al. (2013) further this argument, highlighting the need to combine advanced mathematical modeling with statistical methods while acknowledging the value of qualitative insights for a deeper understanding of behaviors and contexts. However, despite these arguments, this thesis will focus solely on quantitative modeling and informed decision-making (IDM).

Operations Research (OR) engages deeply with epistemological, ontological, and axiological considerations, shaping its approach to problem-solving in diverse contexts. Epistemologically, OR is rooted in positivism, emphasizing the acquisition and validation of knowledge through empirical data and mathematical modeling, suggesting that objective truths about systems can be discovered through observable phenomena (Brady et al., 2012). Ontologically, OR adopts a realist stance, believing that the systems it studies such as organizational structures and processes, have tangible characteristics that exist independently of perceptions and can be systematically analyzed and optimized (Birge & Louveaux, 2011). From an axiological perspective, OR prioritizes effectiveness and efficiency but is increasingly attentive to ethical considerations, balancing optimal solutions with fairness and societal welfare (Miser, 1991). These philosophical dimensions collectively guide OR's application across various sectors, ensuring that its methodologies not only address practical problems but also consider the broader impact of its solutions.

Finally, this thesis examines how different fields from management sciences, operations research, and business research to financial engineering, maritime economics, and maritime finance come together. These fields each have their own unique yet interconnected philosophical, ontological, epistemological, ethical, and axiological perspectives that influence decision-making and core values. The emphasis on analytical rigor, primarily underpinned by positivism and realism, unites these fields, guiding the application of both quantitative and qualitative methods to address practical and theoretical challenges (Ackoff, 1979; Leitch et al., 2010).

Ethical considerations are paramount, particularly in their focus on the socio-environmental impacts of decisions, reflecting a deep commitment to corporate social responsibility (CSR) and ethical financial practices (Crane et al., 2019). Furthermore, their axiological orientations prioritize values such as efficiency, effectiveness, innovation, and sustainability, driving these disciplines not merely toward profit maximization but also toward developing better societal and environmental outcomes (Porter & Kramer, 2006; Schaltegger & Burritt, 2018).

To facilitate an understanding of the methodology and its connection to the research questions, as well as their relationship with the articles in this thesis framework, Table 3 provides an easy reference for readers.

***Table 3***. *Research Design.*

| Research Question | Relevant Paper | Paper Focus | Methodology | Data Collection | Data Analysis |
|---|---|---|---|---|---|
| **RQ1: What key factors can effectively reduce the risk of maritime investments, and how to apply them effectively?** | Paper I: Risk assessment of emission abatement technologies for clean shipping (Atari & Prause, 2017) | This paper focuses on assessing risks related to abatement technologies, helping to identify key factors in reducing maritime investment risks | Quantitative | Quantitative data on bunker fuel use, ship info | Quantitative risk analysis, including statistical modeling, probability assessments, and trend analysis of risk factors affecting maritime operations |
| | Paper II: Maritime energy contracting for clean shipping (Olaniyi et al., 2018) | This paper evaluates risk assessment models for fuel choices in the maritime industry, addressing the risks of fuel-related investment decisions | | Secondary data on fuel contracts, maritime regulations, and industry reports | Risk assessment model development, validation using case studies |
| **RQ2: How can investment in marine abatement technology be more effectively evaluated using key influencing factors?** | Paper II: Real options analysis of abatement investments for sulphur emission control compliance (Atari et al., 2019) | This paper addresses the evaluation of abatement technologies using real options analysis, answering how to effectively evaluate such investments | Quantitative | Primary data from industry stakeholders, secondary data from shipping companies and environmental regulators | Real options analysis, risk assessment models |
| **RQ3: How can the risks of abatement investments in maritime fleets be most effectively managed in light of SECA regulations?** | Paper I: Sustainable maritime fleet management in the context of global sulphur cap 2020 (Atari, 2021) | This paper provides insights into managing the risks associated with maritime fleets in compliance with SECA regulations | Quantitative | Secondary data from industry reports, regulations, and shipping data | Descriptive statistics, optimization models for fleet management |

*Source: Author’s compilation.*

## 2.1 Research data collection

Research data were obtained from a variety of sources. The first set of data comprised ships' fuel prices over a ten-year period. These fuel prices and spreads were calculated at specific time intervals, obtained from a well-known Estonian oil and fuel producer company. They were valuable, and the data were critical to the research's initial success. In subsequent years, higher-quality and more accurate data were used. This data was obtained from companies specializing in collecting fuel prices and other commodity prices from ships and bunkers, such as the DNV GL online platform. Their raw data were of better quality and completeness.

Usually, large companies and research institutes benefit from such data because these specialized companies update their datasets daily and sometimes hourly. The data obtained were not subject to specific analysis, were not purchased for this research, and did not include any contractual restrictions regarding research use, publication, or republishing.

To advance research in the shipping industry, collecting detailed ship information was crucial. This data encompassed technical specifications such as engine power, number of engines, capacity, size, and fuel consumption. A more comprehensive dataset was compiled, including details such as ship weight, country of manufacture, passenger capacity, cargo capacity, and traffic routes. Additionally, data on accepted routes and ports were gathered to determine the amount of time ships spend inside or outside Sulphur Emission Control Areas (SECA) and fuel consumption in Emission Control Areas (ECA). This extensive dataset is vital for thoroughly assessing the applicability and accuracy of models in real-world scenarios.

When historical data is collected, it is used to validate and construct new models, and the remaining data is used to determine if the model is functioning properly. Model validation is performed in the first step by comparing the model's results with the corresponding processes or with the outcomes of other models run with the same input data. For each set of research conditions, confidence intervals and hypothesis tests are used to compare parameters, distributions, and time series results. These statistical tests aided in model development and assessing model appropriateness. During this process, the author conducted historical data validation, sensitivity analysis, and parameter heterogeneity testing.

On a related but significant note, the case study approach is not simply a form of qualitative analysis, even though it is often categorized within qualitative research methods (Creswell et al., 2007). The case study method incorporates multiple sources of data and various data collection techniques. Each source has advantages and disadvantages, and they complement one another, making it advisable to use several information sources (Yin, 1994). Merriam (1998) stated that a case study is an examination of a constrained system or cases over time, utilizing comprehensive, in-depth data collection from multiple sources to enrich contextual understanding. A case study may focus on any subject, but it must employ a structured methodological approach and include empirical (quantitative) data (Yin, 2002). Case study research has long been recognized as one of the most effective methodologies in operations management and operations research (Sadeghi et al., 2021). Seuring (2008) noted that case studies are particularly effective for analyzing multiple stages of a supply chain and operations, as they enable direct observation of sector-specific processes.

In case study-based empirical data collection, a structured protocol was followed, focusing on data acquisition within the context of the maritime industry, its social phenomena (investment and risk), cases (shipping lines), and sub-cases (ships). The primary data collection process began with structured, formal, and informal discussions with maritime experts, officials, and port affairs specialists working across various fields. These included captains, ship crews, ship engineers, maritime & energy consultants, engine technicians, scrubber engineers, and experts in ship equipment, raw materials, and chemical sales & marketing related to ship operations. Some of this data was obtained through participation in webinars and specialized conferences.

Additionally, numerous meetings with professionals experienced in other research fields and academics from IT, economics, business management, and finance contributed to the study. These engagements provided valuable insights into tools, data analysis, and financial theories, facilitating knowledge transfer that significantly enhanced the quality and rigor of this research.

Fieldwork, field trips, and industrial visits were embarked upon to validate and modify the designed models, and the optimized model is recommended for further research in other business environments within the operations research process (Lacono et al., 2011). The case study observation data collection included field trips, group studies, and discussions within the context of the project.

The main part of the empirical data was collected between November 2016 and September 2018 as part of the project "EnviSuM", an EU-funded project within the TalTech University project group, examining the economic and financial (investment & risk) impact of SECA. A portion of the data collection focused on the interactions between maritime stakeholders in the Baltic Sea Region (BSR) and their perspectives on financial concerns, compliance costs, the compliance process, and their overall perceptions of the impact of the new regulations.

The field trip study included data collected from visits to numerous ships, ports, bunker fuel and oil production and distribution facilities, green shipping communities, and international organizations active in various maritime fields across European countries. It was followed by several face-to-face, semi-structured expert interviews conducted across BSR workshops. By examining real cases from the maritime industry during and after the implementation of SECA in the Baltic Sea Region (BSR), the study provided insights into economic activities, operating income and costs, ship finance, ship investments, and profitability.

There were numerous possibilities for investment changes both prior to and following SECA. Green shipping regulations have significantly influenced investment patterns. Therefore, the case studies facilitated a review of investment decisions concerning ships and new technologies to ensure regulatory compliance. The objective of selecting this research approach was to develop, integrate, and substantiate the findings.

Operations analysis is the process of providing reliable statistics and analysis to address critical problems. One of the primary goals of this study is to determine how operations analysis can enhance management decision-making and flexibility. The managerial decision-making process is highly dynamic and closely linked to a business's viability, financial performance, and operational performance.

To maximize effectiveness, strategic choices must incorporate objective data and analysis to complement subjective data and decision-making. Achieving accurate decision-making required diligent and close communication with maritime stakeholders within the BSR, which was crucial for addressing the dynamics of the research questions. As a result, the case studies assisted in evaluating decisions on ship investments and new technologies to ensure compliance with SECA regulations.

All case studies mentioned in this thesis include holistic, embedded, and single or multiple case studies. The collected data were categorized, classified, and encoded in stages. The case studies were analyzed contextually, using an explanation-building approach, and their findings were integrated into the text.

## 2.2 Data analysis

Following the completion of the ships' (or shipping lines') information and consumption in relation to cost accounting, the analysis of bunker fuel data entails the spread prices of the most expensive bunker fuels present on the market. Capturing technological details and financial data regarding the new or used dismantled equipment's turns to be challenging in a data collection process. The prices and value of new equipment used on board or the retrofit equipment could help us to set the precise value as a CAPEX in our cases. Due to the high competition, the abatement technology manufacturers had difficulties on sharing commercial and financial data related. The values adjusted by the help of experienced maritime consultants and engineers to guess with the current market values. To complete the OPEX part, the total fuel consumption of each case was required in order to check the payback time, DCF, and NPV and lay the groundwork for new financial modelling. Fuel data analysis and investment valuations were performed by various statistical analyses, probability methods, and some machine learning techniques. The following software packages were used for modelling and data analyses: spreadsheets, IBM SPSS, Python, and R.

# 3 Results and discussion

## 3.1 Key factors for reducing maritime investment risks and their applications (RQ1)

RQ1 examines key factors that can effectively reduce the risk of maritime investments, and how can they be applied effectively. It focuses on understanding how shipowners can mitigate financial uncertainties and optimize their compliance strategies under regulatory frameworks such as SECA and the Global Cap 2020.

From SECA to Global Cap 2020, the main maritime compliance solutions to the new environmental legislation remained the same (Atari, 2021). LNG, LSFO, and HFO + Scrubbers were the most widely discussed SECA-related solutions (Olaniyi & Prause, 2020). In this thesis, all aspects of investment and related risks to comply with SECA and Global Cap 2020 were examined. However, Prause & Olaniyi (2021) pointed out that SECA imposed significant costs on the maritime industry. In practice, this obliges high costs on the industry, with profitable businesses bearing the brunt of the risk.

According to experts and nearly similar views, the most significant reason why scrubbers are not being widely used is the misconception that their equipment will become outdated in the near future. Newer regulations restrict their use, and most importantly, scrubbers take up significant space on the ship. Additionally, country-specific restrictions further limit their use, eliminating the possibility of installing scrubbers on many ships. Evidence shows that European companies are less interested in scrubbers compared to companies in other regions, including China. However, contrary to popular belief, this technology is unlikely to become obsolete in the near future.

The analysis of operating costs for different cases showed that scrubbers themselves increase the operating costs of a ship and increase fuel and electricity consumption on board. They also greatly increase maintenance costs, adding to labor costs required for maintaining this equipment. The additional cost comes from the need for a specialist engineer or technician who must always be on board during voyages to monitor and control the performance of the device.

In a way, consuming heavy fuel oil (HFO) itself presents many risks, which increases the risk of investing in a scrubber. Analysis revealed that high HFO prices reduce the economic costs of SECA compliance. It also showed that producers and refiners of heavy fuel will likely phase out this fuel from their production basket at a certain point in the future. With a declining production trend, its refining will likely shift to specific and smaller refineries. HFO is older than any other bunker fuel on the market, so it has more historical pricing data. The study of HFO historical prices revealed that it has experienced several major price variations over the years. As a result, the popularity of heavy fuel oil has declined.

The first striking observation to emerge from the analysis was that descriptive statistics and various test results illustrated the fuel price distribution following a normal distribution in many cases and across several time intervals. Based on the observation that, fuel prices and market spread values exhibit a standard distribution over a five-year cycle, both before and after SECA, the author was able to calculate the maximum expected loss (risk of investing in a scrubber using HFO) over that time period, given a confidence level (90%, 95%, 99%). The proposed MaritimeVaR methodology estimates the maximum potential loss on a maritime investment by assessing the probability of an investment outcome over a defined period with a specified level of confidence.

The expanded value at risk (VaR) in capital budgeting assisted in understanding returns on investment over the relevant time span, determining confidence levels, and monitoring and managing demand and ship fuel risks. The entire concept was adapted from financial engineering to maritime economics. It refers to the calculation of NPV, payback period, IRR, and DCF of scrubbers under various scenarios.

From a financial standpoint, all the findings were surprisingly compelling to investors. The primary goal of using and deploying a MaritimeVaR model was to utilize renewable marine fuels and abatement technologies. The author tested the outcomes of abatement technologies using the newly developed MaritimeVaR and CBVaR models, both of which used conventional NPV models and the results revealed that investing in scrubbers is objectively feasible in various cases. Only on a few occasions did the historical spread drop below the critical values, making the investment favorable and profitable.

However, discussions, uncertainties, and speculation surrounding the technology, future regulations, capital costs, investment timing (deferment), and the capital availability for investment remain key concerns.

The quantitative and case study data show that shipowners, especially in Northern Europe, often opt for low-Sulphur fuel to avoid the challenges associated with scrubbers. The findings align with the fact that, despite being the most expensive option, LSFO remains the most widely used fuel in Northern Europe. In meetings and discussions with industry experts, the author found that many are optimistic about the future of LSFO. They anticipate a higher market share for this fuel after SECA and Global Cap 2020. However, there is also opposition to this expectation, with some believing that LNG will dominate the market in the near future.

## 3.2 Evaluating marine abatement technology investments (RQ2)

RQ2 examines the factors influencing shipowners' investments in marine abatement technologies and their preferred compliance strategies under SECA regulations.

Engineers and technical experts emphasize the high performance of LSFO in engines, along with its easy accessibility. The findings further indicate that LSFO remains prevalent due to its greater availability compared to other bunker fuels. However, it also raises overhead costs for shipping companies. One major reason why most shipping companies continue to use this fuel under SECA regulations is the belief among ship engineers that advanced engine technologies have been well-developed and optimized for high efficiency and compatibility with LSFO.

Shipowners could drastically reduce operating costs by investing in abatement technologies such as scrubbers using lower-cost heavy fuel. In the reviewed cases, assuming shipowners installed scrubbers, the payback period ranged between 0.6 and 3 years, depending on the ship's size, engine number, and engine power. The payback period is largely influenced by the price spread between LSFO and HFO, which fluctuates depending on market conditions. By using scrubbers, shipowners could control operating costs instead of directing cash flows to refineries and fuel producers. Olaniyi & Prause (2020) provide a detailed analysis comparing investment in desulphurization processes at refineries versus onboard scrubbers at a smaller scale.

The results from ROT analysis and modeling reinforce confidence in scrubber investments. However, the evaluation of investment challenges also reveals several risk factors. Fuel price volatility, regulatory uncertainty, potential restrictions on open-loop scrubbers in some waters, and the operational reliability and maintenance costs of scrubbers all contribute to the complexity of investment decisions.

The new modeling approach extends real option assessment to the maritime industry, focusing on investment decisions related to alternative fuels. Observations indicate that most ships operating in the Baltic Sea since 2005 have increasingly switched to low-Sulphur fuels. Between 2014 and 2017, discussions about suitable fuel alternatives for ships intensified. Using actual alternatives, the author investigated whether decision-makers intentionally postponed or continued investments, or if these decisions were based on uncertainty, imitation, or market speculation. The analysis suggests that shipowners must adopt a flexible approach, balancing short-term compliance costs with long-term operational savings, while carefully assessing regulatory risks, technological developments, and fuel price volatility.

## 3.3 Managing risks of abatement investments in maritime fleets (RQ3)

RQ3 explore how the risks of abatement investments in maritime fleets be most effectively managed in light of SECA regulations. It focuses on identifying risk management strategies that allow shipowners to navigate fuel price volatility, regulatory uncertainties, and market fluctuations when making abatement investment decisions.

Logically speaking, investing in abatement does not make sense when the price spread is narrow. High fuel price volatility and the spread between fuel types create significant ambiguity for investment decisions. Comparing the new model calculations with the Black & Scholes model and the NPV method validates the decisions made by shipping lines. In short, many shipping companies made the right choice by rejecting scrubber investments in 2014 and 2015.

Based on option deferment, a one-year delay in investment decisions allows companies to learn from the market. Historical data show high volatility, with a deep recession in 2007–2008 and significant price fluctuations between 2014 and 2016 (before and after SECA). These factors confirm that shipowners and shipping lines made the correct decision by adopting a wait-and-learn strategy.

After SECA regulations took effect, further stabilization of bunker fuel prices in 2018 (following Chinese SECA) and in 2020 (after Global Cap) allowed for a re-examination of economic feasibility. To assess market conditions between 2020 and 2025, the author created a binomial diagram of potential fuel alternatives, incorporating a higher-level perspective using Cox models. The results obtained from this model confirmed the findings of the Black & Scholes model, illustrating all possible investment scenarios during the first ten years (2015–2025) of a scrubber's total useful lifespan. This model provides valuable investment insights for those considering scrubber installations.

The objective findings reveal that, following the SECA rule, the majority of shipping lines concentrated their capital investment in one fuel type, running all their ships on low-sulphur diesel. This poses a high financial risk for companies. However, most shipping lines have diversified fleets, including cargo ships, ferries, tankers, and bulk carriers. The new model, based on Markowitz portfolio theory and related financial models, was used to address the third research question. This approach applies real asset allocation and diversification within the capital budgeting framework.

LNG has recently emerged as a new clean fuel in the maritime industry. It not only produces zero sulphur emissions but also reduces other greenhouse gases and is generally considered safe and environmentally friendly. The case study findings indicate that investors are concerned about LNG supply, as it is produced in only a limited number of countries. While HFO is derived from crude oil, LNG is sourced from natural gas.

LNG has historically been priced lower than other bunker fuels, and its price volatility is comparable to that of other fuels. While LNG prices are tied to natural gas prices, gas prices are strongly correlated with oil prices. Due to the optimism surrounding LNG, many companies are rapidly developing LNG-compatible equipment.

A limited number of LNG-fueled ships have entered the global fleet. However, the risk of supply limitations poses an investment challenge not only for ships but also for engine manufacturers, fuel storage tanks, terminals, and other related infrastructure. The lack of sufficient LNG infrastructure discourages enthusiastic investors.

To balance investment risks and reduce uncertainty, the author proposes a modern portfolio application for asset diversification. The optimal strategy involves splitting total fleet assets into three fuel categories: LSFO, HFO + Scrubber, and LNG. This approach aligns with Markowitz modern portfolio theory, recommending an equal asset allocation strategy that involves dividing total assets into 33.3% for each fuel type.

The risk model for diversification must be well-optimized. Based on case study results and the newly developed model, the optimal asset distribution suggests that 60% of assets should be HFO-fueled, while 40% should be LNG-fueled. These ratios were designed for shipping lines with a fleet of ten ships.

A well-diversified and optimized portfolio for maritime fleets can provide a practical solution to the third research question of this thesis. The study develops and introduces a portfolio concept for maritime fleet management, aligning with environmental regulations. While all research findings are based on classical investment and risk theory and financial engineering, traditional models alone are insufficient for maritime investment decisions.

Effectively managing abatement investment risks under SECA regulations necessitates a dynamic decision-making process that accounts for fuel price volatility, regulatory developments, and market behavior. The findings emphasize that adopting an option-based deferment strategy that allows shipowners to observe market signals before committing to costly abatement technologies enables more informed and resilient investment decisions, safeguarding both operational stability and financial performance.

All three research gaps have been addressed, and the findings have been empirically validated, ensuring that the research conclusions remain relevant and applicable to both science and the business world.

# 4 Conclusion

It is evident that financial data and the financial challenges faced by companies are inherently complex. However, substantial research has been conducted in these areas, providing valuable insights that can enhance the financial processes of large corporations. Scientific research and operations can drive new developments in the maritime industry to foster greater integration and progress. Theories developed by renowned scientists such as Marconi, Black, and Scholes have established robust foundations that, when leveraged effectively, can significantly contribute to the maritime scientific and industrial advancements.

The shipping industry is rapidly evolving, particularly in its efforts toward greening and environmental sustainability. Significant progress has been made in emission control, and this trend is likely to extend to other areas, including Sulphur and nitrogen emissions, particulate matter, and water quality regulations. Although ongoing debates and challenges persist, the high compliance rates with Sulphur control regulations in Baltic waters suggest that similar measures could be adopted globally. Shipping companies must adhere to stringent environmental laws to avoid hefty fines, necessitating substantial investments to comply with new legislation.

Regrettably, the maritime industry has lagged behind in terms of innovation and environmental sustainability, primarily due to low investment in research and development (R&D). Addressing this issue requires concerted efforts from governments and organizations, particularly in the field of green finance. Rational investment involves significant risks, making it crucial for companies to adopt well-defined and optimized investment strategies. Incorrect investment decisions can result in substantial financial losses.

New models and enhancements to existing theories, such as MaritimeVaR, CBVaR, Maritime Real Options, and Maritime Investment Diversification based on Markowitz Portfolio Theory, can improve risk management and investment decision-making. These advancements can accelerate the decision-making process for financial experts in the shipping industry and beyond.

## 4.1 Contributions

### 4.1.1 Theoretical contributions

This thesis makes several key theoretical contributions to the body of knowledge in the field of investment risk management, specifically within the maritime sector, and extends the literature on sustainable operations and compliance with environmental regulations such as SECA and the Global Cap 2020. These contributions include:

1. Integration of Maritime Economics with Financial Economics (Addresses Gap 1).

This research bridges maritime economics with financial economics by incorporating post-modern portfolio theory, investment theories, and decision theory, providing a new analytical framework that allows maritime companies to better assess investment risks under market volatility and regulatory pressures. This integration extends the literature by offering a comprehensive approach to investment decisions in uncertain environments.

2. Novel Models for Risk Management (Addresses Gap 1)

This study introduces Maritime Value at Risk (MaritimeVaR) and Capital Budgeting VaR (CBVaR), which adapt existing financial risk models to maritime investment scenarios. By tailoring established risk assessment techniques to fuel price volatility and regulatory challenges, these models offer a structured approach to risk measurement and mitigation in maritime finance.

3. Extension of Real Option Theory in Maritime Investments (Addresses Gap 2)

The research extends the use of Real Option Theory (ROT) in maritime investments, particularly in evaluating abatement technologies and alternative fuels (e.g., scrubbers). By applying financial market concepts to maritime economics, this study provides a more adaptable investment framework, allowing decision-makers to account for flexibility in capital investments when faced with changing regulatory conditions and market uncertainty.

4. Application of Modern Portfolio Theory in Maritime Finance (Addresses Gap 3)

By adapting Modern Portfolio Theory (MPT) to optimize investments in sustainable maritime technologies, this research provides a structured risk-balancing framework that allows maritime finance professionals to strategically allocate capital across different investment options, ensuring that systematic and unsystematic risks are simultaneously managed.

### 4.1.2 Practical contributions

The practical contributions of this thesis offer valuable insights and tools that extend beyond theoretical advancements, providing actionable outcomes for industry stakeholders and further expanding the body of knowledge on sustainable maritime investment practices. These contributions include:

1. Investment and Decision-Making Guidance (Addresses Gap 1 & 2)

This research provides practical investment models for maritime professionals – including investment managers, asset managers, and CFOs – to enhance investment strategies and risk management. By integrating quantitative risk analysis with decision-making frameworks, this research enables real-world applications that help industry professionals navigate regulatory uncertainties and optimize investment portfolios.

2. Regulatory and Policy Contributions (Addresses Gap 2 & 3)

By extending the literature on investment risk management strategies for pollution mitigation technologies, this research provides valuable insights for policymakers and government agencies. It helps shape regulatory frameworks that promote sustainable shipping technologies while ensuring financial feasibility for shipping companies.

3. Managerial Implications for Strategic Planning (Addresses Gap 3)

This thesis provides top-level management with insights into risk mitigation strategies, expenditure stability, and long-term investment planning. By offering tools for improving strategic decision-making, this research ensures that maritime organizations remain competitive while complying with environmental regulations.

4. Sustainability and Environmental Impact (Addresses Gap 3)

This research offers actionable insights into how maritime organizations can adopt cleaner fuels and green technologies to align with global environmental goals. By providing data-driven recommendations for sustainability, this study supports both regulatory compliance and environmental responsibility.

Overall, this thesis not only addresses critical gaps in the body of knowledge but also extends the literature in maritime finance, risk management, and sustainability, providing practical models and frameworks that can be directly applied to improve decision-making in maritime investments under environmental regulations.

## 4.2 Implications

The models, analyses, and results introduced in this research offer a range of implications for both theoretical development and practical application within the maritime industry. These implications extend across several domains, including technological innovation, regulatory solutions, financial decision-making, environmental sustainability, and public policy. The following sections outline the key implications for each of these areas:

1. Technological and Regulatory Implications

The newly introduced models and analyses in this thesis provide significant value for the acquisition of new technologies and the development of regulatory frameworks. Specifically, this research offers potential solutions for decision-making regarding the purchase of new or used ships, particularly under conditions of uncertainty and market volatility. The integration of post-modern portfolio and investment theories with decision theory enhances the ability of maritime stakeholders to navigate complex decision environments. This research has the potential to inform regulatory measures that promote the adoption of advanced technologies and support sustainable maritime operations.

2. Managerial Implications

The managerial implications of this research are particularly relevant to top-level management within maritime organizations. The insights gained into decision-making mechanisms, risk aversion, and expenditure stability offer valuable guidance for improving strategic planning and operational efficiency. Senior executives, such as CEOs, CFOs, and asset managers, can apply these findings to enhance decision-making processes, better manage risks, and maintain financial stability. These improvements contribute to the overall competitiveness and sustainability of their organizations in an increasingly dynamic and uncertain market environment.

3. Financial and Investment Implications

For financial practitioners in the maritime industry, such as investment managers and asset managers, the findings of this study provide a detailed analysis of economic conditions and technological advancements. This information offers a solid foundation for refining investment strategies and risk management practices. The integration of financial economics with maritime economics, using post-modern portfolio theory and decision theory, enables more informed decision-making under uncertainty. These insights are particularly valuable for those involved in the financial management of shipping lines and vessel ownership, as they address both current opportunities and future challenges in the sector.

4. Public Sector and Policy Implications

This research holds substantial relevance for stakeholders in the maritime-related public sector, including ministries, municipalities, customs, government departments, and civil society organizations. The study’s findings provide critical insights into investment and risk management strategies for pollution mitigation technologies, which can significantly enhance government efforts to promote cleaner maritime operations. Policymakers responsible for environmental protection, transport, and industry can use these findings to develop regulatory measures that incentivize or mandate the adoption of sustainable technologies. Municipalities managing local waterways and port operations may also apply these insights to reduce the environmental impact of shipping activities.

5. Environmental and Ethical Implications

The environmental implications of this research are far-reaching, particularly for stakeholders focused on reducing pollution and improving air and water quality.

Environmental activists, green organizations, and legislators can utilize the findings to advocate for stringent environmental standards in maritime operations. The research provides solid empirical evidence to support the development of policies that balance economic efficiency with environmental sustainability. Additionally, organizations concerned with seawater and air quality can use the detailed analysis of the environmental impacts of maritime activities to prioritize monitoring efforts and develop targeted conservation initiatives.

6. Academic and Educational Implications

This research contributes significantly to academic discourse and provides a valuable resource for educational institutions, research agencies, and higher education programs. The findings of this thesis can be integrated into curricula focused on maritime studies, environmental science, and economics, enriching the educational experience and fostering a deeper understanding of the sector's challenges. Moreover, this research offers a comprehensive foundation for future studies that seek to explore the intersection of financial economics and maritime operations under uncertain conditions.

8. Policy-Making Implications

At the state, local, national, and EU levels, policymakers stand to benefit from the research's insights into the financial and economic challenges specific to the maritime sector. The research highlights vulnerabilities related to market risks and emerging trends in maritime technology and equipment investment. These insights are critical for developing regulatory frameworks that support technological innovation while effectively managing economic risks. By understanding operational impacts and potential optimization strategies, policymakers can draft more informed and effective regulations that align with global environmental goals and promote sustainability in maritime operations.

In sum, the implications of this research extend across multiple domains, offering both theoretical advancements and practical solutions for a wide range of stakeholders within the maritime industry. The findings not only fill crucial gaps in academic literature but also provide actionable insights that can drive significant improvements in environmental sustainability, operational efficiency, and strategic decision-making. This research serves as a bridge between empirical findings and practical application, enhancing the knowledge base for maritime industry stakeholders and contributing to more informed decision-making across various levels of governance and management.

## 4.3 Study limitations

There are limitations to this study that must be considered when interpreting the findings.

First, there is a significant gap in historical data for newer fuels, such as LNG. Since these fuels have only been in use for a relatively short period, assessing their long-term effects and trends remains challenging. This limitation restricts our ability to thoroughly analyze long-term changes and impacts.

Additionally, the study relies on risk models that were originally validated using stock market data, where returns are often measured daily or through logarithmic calculations. However, applying these models to maritime fuel data may not always yield accurate results, as the behavior of fuel data differs significantly from that of stock market data.

Another major constraint is the limited diversity in the ship samples analyzed. All ships studied are similar in size and type, primarily operating within the Baltic Sea Region (BSR).

To enhance the validity and applicability of the findings, future studies should include a wider variety of ships in terms of size, type, and operational regions. Expanding the geographic scope to include areas outside traditional Sulphur Emission Control Areas (SECAs) such as the China SECA and Global Cap, would provide a more comprehensive perspective and strengthen the study's conclusions.

Moreover, data collection posed significant challenges due to market conditions and the nature of the shipping and fuel industries. Shipping lines and ports, which often operate under monopolistic or oligopolistic conditions, have stringent policies regarding the sharing of financial and strategic information, including investment plans and budgets. This made it extremely difficult to directly obtain financial data from these large organizations. Similarly, companies involved in the production and distribution of ship fuel are typically large entities with strict non-disclosure policies regarding financial and strategic data.

Lastly, the decision-making process within these industries is highly centralized, with final decisions on purchasing new or used ships typically made by senior management. This centralization made it nearly impossible to directly interview individuals from within the shipping lines. Furthermore, engaging with these companies required navigating multiple layers of authority, which was both time-consuming and, in some cases, unfruitful, particularly when attempting to gather specific information about their plans to comply with environmental regulations and their commitments to green shipping initiatives.

These challenges collectively limited the ability to obtain the desired depth of information, influencing the overall quality of the research. Addressing these issues in future studies will be crucial for advancing our understanding of the maritime industrys adaptation to environmental and regulatory changes.

## 4.4 Future research

This study lays the groundwork for extensive future research in maritime finance and investment, identifying several areas where additional work can enhance and build upon the current findings.

The investment evaluation models traditionally used in this thesis such as Internal Rate of Return (IRR), Discounted Cash Flow (DCF), Payback (PB), and Net Present Value (NPV) have provided a solid foundation. However, the shipping industry would greatly benefit from the development of new standard models. Future research could explore and validate alternative methods such as the Profitability Index (PI), Loan-to-Value (LTV) ratio, Systematic Investment Plan (SIP), Extended Internal Rate of Return (XIRR), and Accounting Rate of Return (ARR). Additionally, decision analysis tools such as decision trees and multi-criteria decision-making frameworks can support strategic decisions in the complex maritime environment, aligning investment choices with broader organizational goals. These methods could provide deeper insights into the feasibility of maritime investment projects, which often have unique risk profiles and financial dynamics.

Moreover, while NPV, IRR, and PB are commonly preferred for appraising capital investment projects in the shipping industry, there is a growing need to expand these models to incorporate advanced analytical techniques. Future models could integrate Markov chains, fuzzy logic, Bayesian statistics, Artificial Intelligence (AI), Deep Learning (DL), and Machine Learning (ML) approaches to enhance predictions and decision-making processes in project valuation, focusing on Net Present Value (NPV), Present Value (PV), Free Cash Flow (FCF), and Discounted Cash Flow (DCF). Advanced probability models, such as stochastic modeling, Monte Carlo simulations, and Markov Decision Processes, can offer profound ways to assess risks and forecast outcomes under varied market conditions. These models can help in understanding and managing the inherent uncertainties of maritime investments.

In addition, there is an urgent need to refine and expand the risk models used in this sector. The models discussed in this thesis were based on Value at Risk (VaR) and Modern Portfolio Theory (MPT). Future research could further develop these concepts by incorporating Marginal Value at Risk (MVaR), Conditional Value at Risk (CVaR), and Capital at Risk (CaR) models. These models would provide a more comprehensive framework for assessing risk both before and after investments are made, which is crucial for managing uncertainties in maritime economics.

The integration of operations research methods – such as linear and nonlinear programming, integer programming, network optimization, dynamic programming, and metaheuristic techniques (e.g., genetic algorithms and simulated annealing) – can substantially improve logistical efficiency and cost management. For example, linear programming can optimize fleet investment allocation and planning, while dynamic programming can enhance decision-making processes under uncertainty by breaking down complex decisions into simpler, sequential stages. This interdisciplinary approach will not only broaden analytical capabilities but also refine strategic decision-making processes in maritime finance, paving the way for more resilient and adaptive operations in the industry.

Advanced mathematical theories, including stochastic calculus, game theory, and advanced probability models, can provide deeper insights into the complex dynamics of maritime investments. For instance, stochastic calculus can help model the random behavior of market variables over time, while game theory can analyze strategic interactions between different market players, such as shipping companies and fuel suppliers.

Lastly, the evaluation of new fuels stands out as a pivotal area for future research, crucial for advancing sustainable practices within the maritime industry. This study has focused on three specific types of fuels: LNG, Scrubber + Heavy Fuel Oil (HFO), and Low Sulphur Fuel Oil (LSFO). While these fuels represent significant steps toward reducing maritime emissions, the evolving landscape of environmental regulations and technological advancements calls for a broader exploration of alternative fuels. Future research could extend its focus to include a wider variety of renewable and clean fuels, such as biofuels, hydrogen, ammonia, and methanol. Each of these fuels presents unique benefits and challenges in terms of production, storage, and impact on vessel design, all of which must be thoroughly assessed. Comprehensive analyses should examine the capital expenditures (CAPEX) involved in retrofitting or building new ships capable of utilizing these fuels, as well as the operational expenditures (OPEX) linked to their day-to-day use in maritime operations.

By addressing these areas, future research can significantly contribute to the optimization of financial strategies and risk management in the maritime industry, ultimately leading to more sustainable and profitable maritime operations.

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## References

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## Acknowledgements

I would like to express my deepest gratitude to everyone who has supported me throughout my PhD journey.

Firstly, I am immensely thankful to the wonderful people of Estonia and TalTech University for providing me with the opportunity and resources to pursue my research. The vibrant academic environment and the warm hospitality have been invaluable.

I extend my heartfelt thanks to my parents and my sister, whose unwavering support and encouragement have been my pillars of strength. I am also grateful to the Vaas family in Estonia for their kindness and assistance during my stay.

Special thanks goes to all my colleagues and friends from the research lab. Your cooperation, insights, and camaraderie have made this journey enjoyable and intellectually stimulating. I also appreciate the contributions and guidance from all the professors and lecturers involved in my PhD studies.

I am particularly indebted to my supervisor, Gunnar Prause, and my co-supervisor, Wolfgang Gerstlberger, for their expert guidance, invaluable feedback, and constant support throughout my research work.

Thank you all for being a part of this incredible journey.

Sincerely,
Sina Atari

## Abstract

## Investment Risk Management in Sustainable Maritime Operations

This thesis looks at how shipping companies can manage their investments while also following strict environmental rules. The main motivation behind this research is the need for the shipping industry to balance making money with protecting the environment. While past studies have looked at either the financial or the environmental side of maritime operations, this work brings both together to find the best strategies for investment and sustainability.

The main problem this thesis addresses is how shipping companies can comply with sulfur emission control area (SECA) regulations without hurting their financial stability. The research aims to identify the best ways for these companies to invest in technologies and fuels that meet environmental standards while also being cost-effective. To do this, the study uses advanced financial and mathematical methods to analyze risks and make informed investment decisions.

First, the research reviews the SECA regulations and their impact on the shipping industry. It then moves on to a detailed risk assessment, using data from case studies, historical fuel prices, and expert opinion. The analysis involves creating new models to evaluate investment risks and potential returns.

The results show that the new models can help shipping companies had better manage the risks related to environmental regulations. By using a mix of different fuels and technologies, companies can reduce their risks and improve their financial performance. The study finds that investing in scrubber technology and LNG-fueled ships can be both environmentally friendly and financially smart.

In conclusion, this thesis provides new ways for the shipping industry to handle investment risks while meeting environmental standards. The models developed in this research offer practical tools for decision-makers in the maritime sector, helping them to navigate the challenges of sustainability and profitability. This work not only adds to the academic field but also offers real-world solutions for sustainable maritime operations.

# Lühikokkuvõte

## Investeerimisriskide juhtimine jätkusuutlikus merendustegevuses

See doktoritöö uurib, kuidas laevandusettevõtted saavad hallata oma investeeringuid, järgides samal ajal rangeid keskkonnareegleid. Uuringu peamine motivatsioon tuleneb vajadusest, et laevandussektor leiaks tasakaalu kasumlikkuse ja keskkonnakaitse vahel. Varasemad uuringud on keskendunud kas laevanduse finantsilisele või keskkonnaaspektile, kuid käesolev töö ühendab mõlemad, et leida parimad strateegiad investeeringute ja jätkusuutlikkuse tagamiseks. Töö peamine probleem, mida käsitletakse, on see, kuidas laevandusettevõtted saavad järgida väävliheitmete kontrolliala (SECA) eeskirju, kahjustamata oma finantsstabiilsust. Uuringu eesmärk on tuvastada parimad viisid, kuidas ettevõtted saavad investeerida tehnoloogiatesse ja kütustesse, mis vastavad keskkonnastandarditele ja on samal ajal kulutõhusad. Selleks kasutatakse uuringus täiustatud finants- ja matemaatilisi meetodeid riskide analüüsimiseks ja teadlike investeerimisotsuste tegemiseks.

Esiteks vaatab uuring üle SECA eeskirjad ja nende mõju laevandussektorile. Seejärel viiakse läbi põhjalik riskianalüüs, kasutades juhtumiuuringute andmeid, ajaloolisi kütusehindu ja ekspertide hinnanguid. Analüüs hõlmab uute mudelite loomist, et hinnata investeerimisriske ja võimalikku tootlust.Tulemused näitavad, et uued mudelid aitavad laevandusettevõtetel paremini hallata keskkonnareeglitega seotud riske. Erinevate kütuste ja tehnoloogiate kombinatsiooni kasutades saavad ettevõtted vähendada riske ja parandada oma finantstulemusi. Uuringust selgub, et investeerimine puhastusseadmetesse ja veeldatud maagaasil (LNG) töötavatesse laevadesse võib olla nii keskkonnasõbralik kui ka finantsiliselt mõistlik. Kokkuvõttes pakub see doktoritöö uusi lahendusi laevandussektori investeerimisriskide käsitlemiseks keskkonnastandardite järgimise kõrval. Uuringus välja töötatud mudelid pakuvad praktilisi tööriistu merendussektori otsustajatele, aidates neil toime tulla jätkusuutlikkuse ja kasumlikkuse väljakutsetega. See töö mitte ainult ei lisa väärtust akadeemilisele valdkonnale, vaid pakub ka reaalseid lahendusi jätkusuutlikele merendusoperatsioonidele.

# Appendix

## Publication I

**Atari, S.** (2021). Sustainable maritime fleet management in the context of global sulphur cap 2020, *Transport and Telecommunication Journal*, Volume 19, Issue 1, 53–66. DOI: 10.2478/ttj-2021-0005

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*Transport and Telecommunication, 2021, volume 22, no. 1, 53–66*
*Transport and Telecommunication Institute, Lomonosova 1, Riga, LV-1019, Latvia*
*DOI 10.2478/ttj-2021-0005*

# SUSTAINABLE MARITIME FLEET MANAGEMENT IN THE CONTEXT OF GLOBAL SULPHUR CAP 2020

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Since the implementation of Emission Control Areas (ECA) in 2015, investment decisions related to abatement technologies represent a crucial task in the maritime industry. Currently, the focus in the maritime sector is on Sulphur reductions due to SECA regulations and the legislative of Global Sulphur Cap that started in 2020. A special challenge appears in maritime fleet management where sets of ships have to be considered, representing portfolios of assets that have to be equipped with a variety of different options of abatement technologies.

Modern portfolio theory has been applied to various economic decisions to achieve an optimal allocation of resources among different investment opportunities. The research investigates and discusses the application of the Markowitz´ optimization in the context of SECA regulations for maritime fleets. The optimal investment portfolios are taking into account the three most important compliance options based on the use of low Sulphur fuel, the use of LNG fuel and the use of HFO with a scrubber. The theoretical results are empirically validated by a case of a shipping line operating 10 vessels.

**Keywords:** SECA regulation, Global Sulphur Cap 2020, maritime fleet management, abatement technology, Modern Portfolio Theory

## 1. Introduction

Sustainable or green transportation is generally defined as logistics operations that intensify efforts to limit greenhouse and hazardous gases including Sulphur, carbon dioxide and nitrogen emissions (Hunke & Prause, 2013). Hence, shipping lines pay increasing attention to the reduction of their carbon footprint and to apply innovative abatement technologies as well as new ship designs. In recent years, the way towards clean and sustainable shipping has been accompanied by several regulations comprising the implementation of Emission Control Areas (ECA) and the Global Cap for Sulphur reductions in ship emissions.

Since 2015, within the ECA zones, the SECA regulations force ship operations to use Sulphur reduced fuel or to install special abatement technologies. These rules have been extended in a slightly softer version to all global ship operations by the Global Cap in 2020. Generally, the new rules make shipping greener, but they also have a huge economic impact on investments, the capital volume and capital risks on the whole shipping industry (Olaniyi & Prause, 2019). Companies that had the opportunity to operate since 2015 in the SECA zones have gained valuable experience to cope with compliance rules that might simplify the worldwide implementation of the Global Cap rules (Prause & Olaniyi, 2019). Shipping lines around the world could benefit from the gained knowledge and experiences. However, changes are happening quickly, and it is not just the laws changing the business environment. New and alternative technologies, fuels are all players in the Green shipping evolution. Being part of this change, shipping companies, ports and fuel refineries, production and distribution companies need to make quick major strategic decisions in order to improve compliance vision to the new laws and advance their economic goals.

More than 14,000 ships are participating in the SECA. About 2,200 of them operate 100% of the time, while more than half of the time 2,700 ships spend sailing in this district (Raza et al, 2019). Nearly all of them have already found a good solution to the new statute. Conventional solutions have been discussed and examined by many scholars. Solutions include Liquefied Natural Gas (LNG), Heavy Fuel Oil (HFO) & Scrubber, 0.1% Low sulphur fuel oil (LSFO) and Marine gasoil; LSMGO - Low-sulphur (<0.1%) Marine Gas Oil (Olaniyi, 2018). Considering that the Global Sulphur Cap 2020 will affect more than 70,000 ships (Veritas, 2018), this can be both a great opportunity for innovation and growth as well as a major economic threat to companies that have not found the right solution yet. Under the terms of the International Maritime Organization (IMO) maritime pollution (MARPOL) regulation, the 2020 date was subject to a review, to be executed by time in 2018, as to the availability of the required bunker fuel oil for ships. Depending on the outcome of the review, this date could be deferred to January 2025 (Hilmola, 2018).

However, from an economic point of view, the choice of vessel type and the choice of fuel type for the engine and equipment is still ambiguous and is not a question to be solved easily. Major factors and variables include the best abatement solution for managers and investors to decide on which ship type, model, size, capacity and at what speed considering the direction and sailing area.

Associating the literature part to the research question will lead to the development of a model for the optimal investment solution in green shipping transportation. The model can be generalized to help finding the best solution for next or current investment. This article should be of interest to several stakeholders in the shipping industry, e.g. hedge fund managers, ship-owners and others with a share of real investments. This article proceeds as follows. After reviewing the relevant literature on shipping and financial theory in the section, it shows how investors can recreate Markowitz's presentation of efficient portfolios as the tangencies between LNG ships and Ships running by HFO and scrubber. After the discussion of the data selection and methodology, the capital asset pricing model (CAPM) and portfolio optimization will be used to determine the efficient frontier and the optimized portfolio considering the portfolio weights. Finally, results and recommendations are presented followed by concluding remarks.

## 2. Theoretical Background

The importance of shipping over sea is widely documented, and most commercial goods are still carried out by this form of transport. The United Nations Conference on Trade and Development (UNCTAD) reports that around 80 percent of global trade is transported by sea in terms of volume. In terms of value, this equates to 70 percent. Of that number, 60 percent accounts for marine commerce passes through Asia, with an estimated one-third of global shipping carrying the South China Sea (see, e.g., Team, 2017). The increase in world-wide population and the increased economic activity in recent years have added to the increase in world trade.

With an increasing economic activity comes further economic investments. Investment managers' success depends on how they allocate capital. Creating long-term value and wealth to shareholders is one of the most important objectives of companies (Bezemer *et al.*, 2007). Investment decisions have a significant impact on companies' life cycles. In cases where the decision is important and the number of options is high, it is difficult for investors to make optimal decisions (Cox, 1985). Investors in the capital market face both risk and return factors. Returns are a positive parameter and fluctuations (risk) are a negative parameter in financial investment decision making. Therefore, every investor seeks to invest their capitals in a place where returns are highest and fluctuations (risk) are lowest (Mokhtar *et al.*, 2014).

The main investments in the marine industry are typically divided into two major categories: 1. Shipping companies and shipping lines, and 2. Ports. Shipping lines, like companies in most industries, have a serious need to invest in expanding market share and customer needs, investing in new technologies to stay ahead of competitors as well to reduce costs and stay competitive. Above all, it is crucial to optimally deal with new laws and adhere to international commitments. This paper links two streams of literature: the seminal theoretical works of Markowitz and the green shipping industry.

## 3. Green shipping and abatement technologies

The policy of launching a green transport system is, in fact, an immediate and obvious solution to reducing pollution from the transportation and shows that any environmentally friendly means of transport does not emit toxic gases or liquid. Launching such a system requires public awareness, public participation, private management as well as innovation and production of ships that use renewable energies such as wind, solar, biofuels and hydroelectricity. These sustainable methods will be a new challenge for the whole industry after SECA regulations (Allwright, 2018). Temporary green shipping will cost a lot and there will be new investments for the respective industries. It also has many benefits, from reducing environmental budgets to improving health, economics and more (Rahm, 2015). In green shipping plans, which aim to reduce environmental pollution, transition to the green transport systems should eliminate Sulphur Oxides emission (SOx) and Nitrogen oxides emission (NOx) as toxic gas. Any action in this regard is a step towards the reduction of Carbon dioxide (CO2), which makes up the vast majority of greenhouse gas emissions from the maritime sector.

Green shipping and the whole transport sector in general are main elements in creating a sustainable economy. The production and distribution of green ships will lead to the creation and application of new technologies. This will lead to the creation of more jobs in the maritime transport sector and will contribute to a sustainable economy (Gibbs, 2009). The finance of green projects by introducing new supportive mechanisms has been discussed in the literature. Instruments such as green bonds, green equity and stocks are specifically constructed for this. Sachs *et al.* (2019) argue that these green finance tools are a promising way to finance or refinance green projects.

Energy sources such as fossil fuels have devastating effects on health and lead to increased incidences of cancer, cardiovascular diseases and lung diseases. Green shipping will have a great positive impact on health, and it will be beneficial to health and quality of life (Reinhold *et al.*, 2019). This paper reviews two dimensions of green shipping. First everything related to the ships and technologies and second all relevant things related to the green fuels.

Since the 1960s, heavy fuel oil (HFO) has been the main fuel among all marine fuels. While HFO is cheap and available worldwide, it has high viscosity and comes with high degree of pollution (Wang, 2014). Effective in 2015, ships operating within the ECA covering the Economic Exclusive Zone of North America (EEZ), the Baltic Sea Region (BSR), the North Sea, and the English Channel were forced to give up high sulphur fuel. It resulted in the use of Marine Gas Oil (MGO) with allowable sulphur content up to 1,000 ppm (Thomas, 2020). From 2020 onwards, ships sailing beyond ECAs will have to turn to Marine Diesel Oil (MDO) with a sulphur content of up to 5,000 ppm (Mohseni *et al.*, 2019). Enabling the burning of HSFO through the fitment of a scrubber is an attractive and effective alternative.

The uncertainty around fuel prices after the first of January 2020 has been the principal driver of slow decision making by operators. With fuel accounting for up to 40-60% of a ship's operating costs, choosing the right fuel to run under IMO's new SOx standards will be critical to success next year onwards (Atari & Prause, 2017). Operators using High Sulphur Fuel Oil (HSFO) have a few options: switch to Low Sulphur Fuel Oil (LSFO) if the engine performance do not drop or invest in upgrading the engine, continue using HSFO with an exhaust scrubber, or convert to alternative fuels such as LNG.

While LNG as fuel is very competitive in term of prices compared to the other available fuels, the use of this kind of fuel is quite limited. The worldwide LNG terminals and distribution stations are not very well established to make it a widely used bunker fuel. This trend is quickly changing however. Its favorable emissions profile makes it an increasingly popular fuel for continental use and, as a result, new reserves of natural gas are being explored aggressively.

LNG's success on affordability was highlighted in new research by Sharples (2019). LNG bunker fuel in Scandinavian markets have historically sold to replace the main competitor (LSFO) at a substantial discount. A shipping classification society expects LNG to take 11 percent of the total bunker fuel market share in 2030 (Shenoi, 2015). The risk for any type of low sulphur fuel remain a higher demand than the supply of it. If the investments in LNG terminals and port tankers do not adjust fast enough it may cause an LNG price explosion (Olaniyi & Gerlitz, 2019). The export of LNG in 2019 is still not expanded and distributed like the oil market. Qatar and Australia have nearly 45 percent of the world LNG export supply market share (Danilov *et al.*, 2019). Due to the high supply risk, the LNG fuel is not yet reliable as an alternative solution. Albrecht (2015) pointed out that mainly ship owners concern about the supply facility of LNG. The SECA area and far east countries have a superior establishment of LNG facilities and infrastructures; Europe is lagging. Olaniyi *et al.* (2019) investigated the marine LNG energy market. The developed model promotes a cycle of economically sustainable LNG production and distribution. The study states that to meet the global need for low sulphur fuel for the year 2020 and beyond, low sulphur fuel supply must be increased and expanded. At the present, the world market is divided between different solutions to meet the increasing demand for sulphur-friendly fuels.

On the other hand, as for scrubbers, because they are low-cost to install relative to a whole new propulsion system, the payback comes about three times faster (Olaniyi *et al.*, 2018). Before 2020, the numbers were far less favorable for vessels that spend, say, only half their time in an ECA. The large capital investment required in a retrofit is a major limitation for ship owners. The economic factor changes significantly in favor of new builds rather than retrofits installment (Atari *et al.*, 2019). It seems more economical and more attractive for ship owners to install scrubbers, while LNG propulsion is more feasible on new builds than retrofitting. In several cases it proved to be the case that the payback period is shorter for new LNG equipment. Although LNG still attracts the biggest attention as a Sulphur-free fuel, methanol and biofuels has proven to be a strong alternative and can be a future solution as well (Hansson et al, 2019, Moreira, 2019).

## 4. Maritime investment and risks

Financing and leasing ships have been the center of the attention to ship owners in past decades. Two main decision always have been essential to ship owners: when to buy, and when to sell, similar to capital trade markets (Stopford, 2008). Todd (2019) found that on average, the ship price depends for 30 percent of the total cost on hot rolled steel. Labor force productivity as a crucial factor accounts for 13 percent of total ship value. The trade market for vessels are in many ways similar to freight markets. It can be divided into a primary and secondary market (Wijnolst & Wergeland, 1996). In fact, the new build ships add to larger capacity to the overall worldwide fleets. On the other hand, the second-hand market offers a transfer of risks. However, the reality is that investing in a new or second-hand ship or any changes to the ship's system requires financial capital. Kavussanos & Marcoulis (2005) concluded that both micro (i.e. company level) and macroeconomic factors contribute to illuminate the shipping capitals return on investment. Kavussanos *et al.* (2002) studied macroeconomic factors and their models on whole maritime industry. The decision of buying (and investing) new or second-hand vessels is a key investment decision.

Most research on investment topics have been done on capital markets. In fact, few research is focused on maritime economics and investment related issues in maritime industry. Hence, focusing on capital budgeting investment research might solve issues in the maritime industry. Incidentally, the results of valuable research work on classical investment methods in order to criticize the inefficiency have been examined by Bendall & Stent (2003). Real option and fuzzy methods, replacing the classical net present value (NPV) and internal rate of return (IRR), have recently been applied to model prices in the maritime industry (Atari *et al.*, 2019, Metzger & Schinas, 2019). Acciaro (2014) has proposed new models by applying the real option investment evaluation theory into smaller ships with different fuel types and propulsions.

Considering the above, where should investors put their allocated capital? Should ship owners invest in a new fleet or simply turn to the shipping capital market investments? Should they invest in shipping industry stocks or raise the necessary capital by active participation in capital market? These questions make the study on shipping stocks more relevant and crucial than before. Concentrating more on the shipping industry investment, Westgaard *et al.* (2007) specifically studied the commercial ships market and proposed a framework for explaining stock returns based on the capital raising and investment with attention on historical data. Previous studies of risk factors in shipping have concentrated on the returns of shipping stocks. Drobetz *et al.* (2010) and Grammenos & Arkoulis (2002) have found betas with lower volatility than the market in the shipping industry in a simple asset pricing model. While the variance of shipping stocks generally is greater than the market, the model shows that stocks typically have betas of less than one.

Apart from investments risks other risks pointing to the financialization of shipping markets with a risk management approach. The risks, which are more related to the transport market, can be defined as the measurable liability for the financial loss arising from unpredicted imbalances between the supply and demand for transport (Karakitsos & Varnavides, 2014). By including several risk factors, it approximates the real exposure to certain risk. Taking the perspective of a shipping-oriented investor, viewing vessels as financial assets, it is important to mention such a constraint, as shipping is known for its high value assets (large hi-tech vessel will cost more than €200 million in construction), and its high total-debt-to-assets ratio (see Drobetz *et al*., 2013).

Diversification in investments can help to balance risk. King (1993) implemented new models to account for several common factors on asset pricing and the covariance structure to show how diversification can be used to balance risk. Friend & Blume (1970) discussed the comprehensive re-assessment of the valuation of capital assets under uncertainty. A spinoff of this reconsideration was a theory of equilibrium in the stock market. Blume (1970) proposes two different methods of assessing future performance of stocks or, more technically, of assessing predictive or subjective distributions of future return of investment. Applying a predictive posterior distribution (PPD), it can be shown that the new distributions tend to understate the probability of Extreme Values (EV). This method can be used as a tool for risk management. Especially the models of Nobelists Fama & French (1993) using three factors portfolios in investment models have received great attention. These models have gained support and have been employed by the financial industry with equity and investment appraisal problems (Leibowitz *et al.*, 1989). The models of Chen *et al.* (1986) focus on utilizing macroeconomic factors to explain capital market returns. Consequently, they will provide with a starting point for modeling the covariance structure among shipping assets.

## 5. Portfolio theory and asset allocation

The concepts of portfolio optimization and diversification are among the main tools in financial decision making (Rachev *et al.*, 2008). Portfolio optimization problems have been of interest to financial researchers since the early 1952s. Modern Portfolio Theory (MPT) is an investment theory built upon work by Harry Markowitz and was first published in the Journal of Finance in 1952 under the title "Portfolio Selection". MPT has become the main method for financial decision-making and the theory has created an organized paradigm towards forming a portfolio with the highest expected rate of return at a certain level of risk. According to Markowitz' theory, a person can, for a given level of return, minimize portfolio variance by minimizing investment risk, or at a certain level of risk that is tolerable to the investor, one can maximize the expected return, which increases the expected rate of return on the portfolio (Lin *et al.*, 2008). Three quantitative finance pioneers have been awarded the Nobel Prize in 1990 in Economic Science: Merton Miller, William Sharpe and Harry Markowitz for their work on portfolio optimization (Varian, 1993).

The focus in this article is entirely on the asset itself and excludes specific investment decisions of investors, like, e.g., debt, credit, financing, and leasing. Markowitz´ (1952) optimization procedure requires expectations of future returns, variances and covariances. The procedure itself is widely accepted and used by practitioners and academics. Using this approach, investors can expand the basket and add or remove asset from portfolio to gauge if the return per unit of risk can be improved.

The variety of investment methods and the complexity of investment decisions have increased dramatically in recent decades. This widespread growth has created a growing need for inclusive and integrated models. Since Markowitz´ ground-breaking work in portfolio investing, an evolutionary process has taken place. The application of mathematical modeling and programming which has introduced extensions of efficient portfolio modelling (Fabozzi *et al.*, 2007). Yu *et al.* (2012), for example, presented a new model for the problem of multi-period portfolio selection. In this model, the maximum absolute deviation is used to measure risk rather than variance. The risk is controlled in two stages, unlike the traditional method that risk is calculated through variance. First, the risk should be minimized in each period, where the risk is the highest standard deviation of all assets, and in the second, a parameter that represents the highest level of risk over the period is used. The optimal stock portfolio is obtained by solving the above model using dynamic programming.

## 6. Methodology

Although portfolio optimization is widely used, it has not specifically been applied before in the sector of maritime investments. In this article a mixed method of qualitative and quantitative analyses applied to examine the case of portfolio optimization in the shipping industry. It investigates whether a diversified portfolio of ships outperforms in the fleet with minimizing the risk of losses while profiting from diversification opportunities in two major dimensions: fleet mix with more LNG ships or with a higher weight in investments in HFO and scrubber. By default, the total portfolio only consists of LSFO ships in the fleet.

In this article the fuel prices are gathered using Rotterdam port bunker fuel prices (DNV, 2018). LNG prices as a bunker fuel are collected and refined based on the data needed and were calculated based on heating point value considering EU gas price level in Germany (Eurostat, 2019). The collected data was used to determine the annual cost of different fuels used by ships. It means both initial investment and operating costs have been taken into consideration. After introducing fuel data, it evaluate the complete fleet and the combination of ship investment feasibility of the dual fuel propulsion. Using these data, it examine the optimal portfolio with respect to return and risk.

The research is not handling any issue related to operational or major investment decisions. The investment decision, initial investment, macro economical and supply risks are all validated by the empirical data from expert interviews, focus group meetings and case studies. Two different shipping lines with similar ships in their fleets were considered. Most of the ships operate in the SECA. The fleet of both lines is similar in size and numbers. The ships operate between the main ports of Helsinki, Stockholm, Riga and Tallinn and some other ports. The presented case study addresses the current situation of the fuel type and consumption of each ship base on the speed and time of sailing. In the case study, the proposed method as well as optimization of the ten ships for different fleet and modes were implemented. The number of ships with the fuel type was calculated using the modern portfolio theory and the optimal portfolio brought to the light with frontier efficient in the accepted interval. The new fleet mix and combination of different ships in the fleet proposed as a result.

## 7. Assumptions

Investors or shipping lines buying new or second-hand ships were forced to decide before the Global cap 2020 implementation. After the SECA regulation, ship owners needed to decide the strategy toward their fleet management. It means to buy new ships, decide what kind of propulsion, engine and fuels. The company will decide if the ships should use single or dual fuels engine. With a high probability the following three options are among the best solutions for ship owners to choose from: HFO+ scrubber, LNG or LSFO. On the other hand, to minimize the risk of investment and operation, ship owners will opt for the option of using dual fuel engine. For mixing ships with two different fuels the company has the following possible probabilities in the sample space: (HFO+ scrubber) +LNG, LNG+LSFO or LSFO+ (HFO+ scrubber). The company even might choose triple technology engine to have an engine and equipment with the following fuels all together: LNG, LSFO, HFO+ scrubber. The only disadvantage that both dual fuel and triple fuel engine have is a reduced return of capital, because of unused or less used equipment onboard.

## 8. The fleet portfolio

Portfolio optimization is very sensitive to its inputs. Since it is very difficult to accurately estimate the input parameters correctly, you cannot always rely on the resulting portfolio allocation. Portfolio optimization uses variance minimization. That would not yield the same results due to differing volatility in spot. In the past as the enforcement solution besides of LSFO, ship owners are talking about using scrubber and making an investment in a scrubber with installed capacity necessary. Taking into account the time of operation, the scrubber built and designed based on KW's engine power, after the SECA it is more vital for ships that most of the time sailing in BSR. Currently, to face with Global Cap it will be necessary for all ships using HFO and sailing out of SECA as well. The scrubber will help them to meet the 0.5% sulphur emission. The study firstly reviews the compliance investment expected return of a scrubber retrofit with a continuance use of HFO with an engine upgrade that involves the boiler, all piping, tankers and auxiliary engines and other necessary equipment. Next, with consideration of different ships which are running by LSMGO or ULSFO (0.1% Sulphur content) or LNG.

The initial investment of the vessel may vary, e.g. initial investments of LNG propulsion for the new ship, tankers and all necessary equipment may be 15 percent costlier than ships with other fuels. This may result in a 5 to 10 percent increase in operating costs. However, when a technology is used more widely by the industry, it might become more cost-effective. Here the focus is primarily on the expected return. Numerous evidence indicates that managers in the industry consider alternate measures such as IRR, payback period, and return duration, along with NPV, real options and many other technics when making capital budgeting decisions. There is also evidence that non-financial criteria can play an important role in the ultimate decision to invest in the maritime industry. Further work can be done to explore scenarios with different objectives, some of which may not be defined in financial terms. Vessel returns will therefore depend on earnings less operating expenses (OPEX) from the saving of expensive fuel to the cheaper alternative bunker fuel. For vessel fleet, the expected return of the fleet return is calculated by the following equation:

$$R_p = \sum_{i=1}^{n} X_i \cdot R_i, \qquad (1)$$

where $R_p$ = the expected return on the fleet;
$X_i$ = the proportion, or weights of total funds invested in $i$;
$R_i$ = the expected return for investment $i$.

Equation (1) illustrates the expected return on shipping investments as a function of vessel net earnings and capital appreciation. In order to reflect earnings on the boat, a viable adjustment factor is required. The main assumption is that the ship is running by a single fuel. If it runs by dual fuel, then the composition of portfolio will change. The parameters which are important to get the desired result are:

- Annual fuel consumption
- Annual fuel price average
- Total fuel cost
- Earning from changing the fuel to the cheaper fuel
- Volatility of fuel prices

Since in this article the three compliant fueling options considered for the ship owner consisting of LSFO, HFO plus scrubber (HFO&S) and LNG we are able to formulate the corresponding formulas for the return and the risk of a certain fleet:

$$R_{fleet} = W_{LSFO} \cdot R_{LSFO} + W_{HFO\&S} \cdot R_{HFO\&S} + W_{LNG} \cdot R_{LNG}, \qquad (2)$$

where the W represent the percentage for all kind of ships in the fleet that are propelled with a certain fuel and the R express the expected rates of return of each type of used fuel. Since the W express only percentages, the overall return of a certain fleet can be gained by multiplying with the number No of ships in the fleet. It has to be kept in mind that a real fleet consists of entire ships, i.e. only those fleets are realistic where the terms W No yield integers. Nevertheless, for calculation reasons the percentage approach is appropriate in order to apply mathematical instruments.

A special reflection is necessary for in the case of LSFO. Since the use of LSFO is considered in the paper as reference point for the use of the other fuels, the return for LSFO is set to the small constant ε around zero because no additional fuel cost savings can be expected by using the reference fuel, i.e. $R_{LSFO} = \varepsilon$. The same consideration applies for the LSFO when it comes to risk aspects. The standard deviation representing the risk in portfolio theory will be set for the reference point LSFO again to a small constant. In order to avoid calculation problems we can set for the standard deviation the same small constant ε unequal to zero so that we have $\sigma_{LSFO} = \varepsilon$. Hence, by taking into account these reflections, in the mathematical model we can neglect the return as well as the risk for low-fuel sulfur ships by setting them to a value close but unequal to zero, i.e. in our case to ε.

With the same percentages for the fleet shares W like in the formula (2) we are able to model the variance of a fleet composition σ2fleet by integrating variance and covariance figure that lead to formula 3:

$$\sigma_{fleet}^2 = w_{LSFO}^2 \cdot \sigma_{LSFO}^2 + w_{HFO\&S}^2 \cdot \sigma_{HFO\&S}^2 + w_{LNG}^2 \cdot \sigma_{LNG}^2 \quad (3)$$

$$+ 2 \cdot w_{LSFO} \cdot w_{HFO\&S} \cdot COV(LSFO, HFO\&S)$$

$$+ 2 \cdot w_{LSFO} \cdot w_{LNG} \cdot COV(LSFO, LNG)$$

$$+ 2 \cdot w_{HFO\&S} \cdot w_{LNG} \cdot COV(HFO\&S, LNG).$$

This formula can be substituted by using the standard deviations of the three fuels together with the correlations of the different fuel types. The resulting formula expresses the fleet variance in form of a quadratic form that stems from a matrix calculation with the correlation matrix of the three fuel in the center (3M):

$$\sigma_{fleet}^2 = (w_{LSFO} \cdot \sigma_{LSFO}, w_{HFO\&S} \cdot \sigma_{HFO\&S}, w_{LNG} \cdot \sigma_{LNG}) \begin{pmatrix} 1 & r_{12} & r_{13} \\ r_{12} & 1 & r_{23} \\ r_{13} & r_{23} & 1 \end{pmatrix} \begin{pmatrix} w_{LSFO} \cdot \sigma_{LSFO} \\ w_{HFO\&S} \cdot \sigma_{HFO\&S} \\ w_{LNG} \cdot \sigma_{LNG} \end{pmatrix}. \quad (3M)$$

The correlation matrix in the middle of equation (3M) is symmetric and will be calculated later from historical data about fuel prices. A short matrix calculation reveals that the terms for the fleet variance in formula (3) as well as in formula (3M) yield the same result. Since with these formulas the fleet variance is calculated, we have to take the square root from the fleet variance to achieve the fleet risk, which is expressed in form of the standard deviation.

Coming back to the considerations concerning the return and the risk related to the LSFO by examination of the risk shape – return – curve of the fleet portfolio. One simple sample portfolio fleet composition can consists of 100% LSFO ships, i.e. a fleet that only consists of LSFO propelled vessels. Such a fleet enjoys the following return and variance values:

$R_{fleet} = W_{LSFO} \cdot R_{LSFO} = \varepsilon$; $\sigma_{fleet}^2 = w_{LSFO}^2 \cdot \sigma_{LSFO}^2 = \varepsilon^2$.

Thus, by letting $\varepsilon \rightarrow 0$ converge to zero it shows that in the return as well as the risk of the portfolio touch the origin, i.e. the point (0, 0). Furthermore, knowing that the return and risk functions are continuous, even differentiable, and the return as well as risk increase with growing percentage of HFO plus scrubber and LNG installations thus the efficient portfolio curve of each fleet has the typical logarithmic shape like in figure 1:

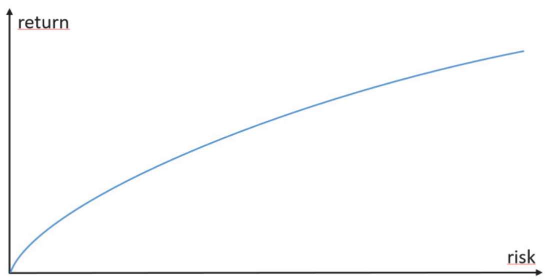


*Figure 1.* Risk – Return – Portfolio

When we can have portfolios with the same amount of risk in the chart, it can't produce a model that is linear or logarithmic. The chart above highlights that a fleet owner who wants to avoid any risk has to decide for a fleet composition of 100% LSFO driven vessels and none of HFO plus scrubber nor LNG fueled. Of course, such a fleet composition also is linked to a zero return, i.e., no savings due to smart fuel usage can be expected.

In case of a 50-50 mix of LNG and HFO plus scrubber vessels in the fleet the return expectations are higher, namely the average of the expected savings from LNG and HFO plus scrubber use, which are estimated to be significantly higher than zero. However, this higher return is paid with a higher risk since the standard deviations of LNG and HFO are higher than zero. In this case, until now we have still all three fuel types in our consideration. The value for risk and return of LSFO are nearly zero. We can reformulate and facilitate the equations (2) and (3) by focusing only on the two non-LSFO fuels leading to formula (4):

$R_{fleet} = W'_{HFO\&S} \cdot R_{HFO\&S} + W'_{LNG} \cdot R_{LNG}$. (4)

$\sigma^2_{fleet} = w'^2_{HFO\&S} \cdot \sigma^2_{HFO\&S} + w'^2_{LNG} \cdot \sigma^2_{LNG} + 2 \cdot w_{HFO\&S} \cdot w_{LNG} \cdot COV(HFO\&S, LNG)$.

With $w'_{HFO\&S} + w'_{LNG} \leq 1$; $w'_i \geq 0$ and $w'_{LSFO} = 1 - w'_{HFO\&S} - w'_{LNG}$.

With this approach the risk level can be lowered by keeping the percentages for LSFO propelled vessels and return of the fleet also decreases due to a certain number of LSFO driven ships that does not generate any savings compared to LSFO use.

The starting point for finding an optimal fleet composition consisting of the three different engine types is the determination of the efficient risk – return portfolios. Therefore, it is necessary to calculate the returns of each propelling type that depend on the underlying spreads between LSFO and the other two fuel types. This leads to the return amounts as well as to the corresponding related risk values for the returns. This indirect approach to calculate the return and risk values for the different engine types based on the underlying spread values is necessary since we do not have market price like in the classical case of the Markowitz portfolio concept (1952).

## 9. Findings and discussion

### 9.1. The fleet portfolio

For a portfolio approach in fleet management it is necessary to agree on a risk measure. Most financial economists use standard deviation (STD) as measure of asset variability (McDonnell, 2008). Hence, by following this traditional way standard deviation is calculated from time series for maritime fuel. The risk for LNG is measured by the annualized volatility of historical EU gas price whereas the risk of HFO is calculated on the base of the volatility of Rotterdam port fuel prices. Since all investigations take place relative to the use of low Sulphur oil the LSFO price plays the role of a reference point, i.e. the volatility of LSFO price in respect to itself delivers a standard deviation of zero as well as an expected return which is also zero. Thus, the calculations deliver the value that are shown in Table 1.

**Table 1.** Expected return and standard deviation of LNG and HFO-380

| Ship type | STD of years return | Average 5 years Return |
|---|---|---|
| LSFO | 0,00 | 0,00 |
| LNG | 2025400.32 | 8479905.918 |
| HFO-380 | 1004655.911 | 4928894.428 |

Next important step in constructing a fleet portfolio represents the determination of the spread values of the bunker fuel prices together with their cross correlation to be able to calculate the portfolio risk. This approach is necessary since we do not have market prices for the return values of the three engine types so that the return as well as the risk values have to be calculated based in the different spread prices. After having analyzed the spread values the determination of the corresponding return and risk values is easy to calculate because fuel price fluctuation directly affects the saving cost of operation income. These values are again calculated by executing time series analysis for Rotterdam fuel prices between 2015 and 2020. The table shows a relative high correlation value between the LNG and LSFO spreads whereas the HFO fuel figures are much lower. Table 2 presents the cross correlations.

**Table 2.** Cross correlation of maritime bunker fuels spread from 2015 to 2020

| | LSFO | Spread LSFO-HFO | Spread LSFO-LNG |
|---|---|---|---|
| **LSFO** | 1 | | |
| **Spread LSFO-HFO** | 0.555147458 | 1 | |
| **Spread LSFO-LNG** | 0.818996114 | 0.315471895 | 1 |

Now it is possible to draft a chart for a tentative fleet portfolio. The fleet has to be comply this the SECA regulations, i.e. in our case there are the three compliance options consisting of the use of LSFO, HFO plus scrubber as well as LNG. Since a considered fleet consists of ships with three different compliance options, each possible fleet composition can be represented by a 3-dimensional vector (x,y,z) with non-negative percentage figures that sum up to 100%. In a concrete case of n ships a multiplication of the three components of the vector yields an approximate composition of the fleet. Hence, a draft for the shape of the portfolio based on the calculated returns, standard deviations and cross correlations can be drafted by considering the subset of 3-dimensional vectors that consists of percentages that are multiples of 10%. This set of vectors includes the vectors LSFO (100%), HFO (0%), LNG (0%) which is located at points 0.0 and in front in contrast to the lowest portfolio at the highest level of the chart representing the most risky portfolio with highest amount of return it includes this combination and the weight of the assets are LNG (100%), HFO (0%), LSFO (0%). This set of vectors consists of 68 elements and drafts the fleet portfolio. The graph of this enumeration is presented in figure 2 with the standard deviation on the x-axis and the return on the y-axis.

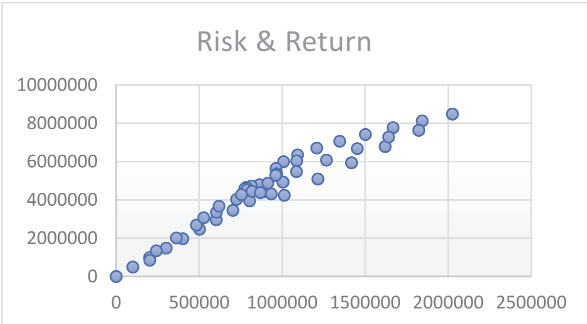


*Figure 2.* Result for three type of ships as an asset – Risk and Return

The result turn out there is positive relationship in terms of risk and returns. The higher return the amount of risks increases with the same return. The relationship between portfolios are positive, strong and linear. In this case it can interpret, the higher the percentage of LSFO vessels in the fleet portfolio, the lower the rate of return but also lower the risk level. In case of the description of a real fleet there are two issues need to be discussed. First, the number of fleet compositions might be higher and second, not all vectors that are composed of percentages might lead to a real fleet composition, because ships can be only represented by integers. Nevertheless, the shape of a real portfolio will be always close to the situation depicted in figure 2 since the underlying parameters of the shape are the return, the standard deviations and the cross correlations and these parameters not depend on the number of ships in fleet.

The efficient portfolio can be constructed from the results of figure 2 by connecting the upper portfolio point for each risk value. From the graph of figure 2 it is furthermore visible that the efficient portfolio is the superposition of three different curve, namely a linear part between the risk values zero to ca. 750 t€, then the upper part of a first parable between ca. 750 t€ and 960 t€ and finally a second parable starting from ca. 960 t€. The first part of the efficient portfolio is characterized by low risk starting from zero up to a risk level of about 750 t€. In this section the usage of LSFO dominated the fleet composition yielding low investment risks together with low fuel cost savings, i.e. low return rates. The two upper risk parts are dominated by fleet compositions with high shares of HFO plus scrubber and LNG engines in the fleet. The determination of optimal fleet portfolios require the formulation of a decision approach. The theory offers different decision rules starting with the analysis of a linear risk prime as well as the evaluation of the return on investment approach. The classical methodology of the consideration of a Capital Market Line (CML) like proposed in portfolio theory is not fully transferable to the situation of fleet management.

### 9.2. Determination of an optimal fleet portfolio

There exists no unique approach to determine an optimal fleet portfolio. Like already mentioned, the CML concept from classical portfolio theory is not directly applicable since the concept of real risk-free capital such as free liquid cash or bond, which delivers a unique touching point with the efficient portfolios. Consequently, there does not exist the Sharpe ratio and the corresponding tangency portfolio. However, two other classical approaches in risk theory are able to deliver optimal portfolios, i.e. the concept of the maximal risk prime with certain risk slope and the consideration of a modified return on investment (ROI) (Kendall & Rollins, 2003).

Concerning the maximal risk prime leads to the analysis of the touching point between the efficient portfolio and the line including the point (0, 0). Such a line with the highest slope touching the efficient portfolio represents the fleet composition generating the highest risk prime since this touching point represents the composition with the highest ratio return per risk units. Undoubtedly, the origin (0,0) has to be excluded from the consideration. A detailed calculation delivers as such optimal fleet composition with highest linear risk prime. The point (2,025,400.32, 8,479,905.92) representing a fleet composition of (0% LSFO, 0% HFO, 100% LNG). By following the maximal risk prime approach it has to be kept in mind that in this case only considered discrete portfolios since a fleet composition can barely consist of integer numbers of ships. Furthermore, literature discusses beyond linear risk prims also other type of decision functions (Goerlandt & Montewka, 2015).

The ROI approach considers for each fleet composition the total investment amount of the fleet abatement equipment and related this amount in form of a ROI to the expected returns, i.e. one considers the ratio of the total return to the total investment sum. The optimal fleet composition is represented by those point with the highest ROI ratio. In case of several points on the efficient portfolio curve with the same ROI as optimal fleet composition that point with the lowest risk value is chosen. The result with consideration of four million Euro free cash (the amount which not invested) on scrubber equipment, and 8 million Euro the amount which not invested on LNG equipment's and divert them to the portfolios and the point of touching can be our market portfolio with highest Sharpe ratio, which has the average return and average STD.

The purpose of this solution could be measure reward to risk of expected return, which was measured by the slope of the lending and borrowing amount on CML and then pointing on the expected return. But in the end the solution is to get the minimum variance portfolio from the efficient portfolios on the curve. As a result, portfolios that are both high-risk and low-income due to low sulfur fuel are scattered at the bottom of the chart. As always, the Minimum Variance portfolio is at the left-most tip of the efficient frontier curve in the top rated return portfolios. However, this is not enough to solve this problem, and we also need to choose the optimal portfolio from them after building the built-in portfolios. To solve this problem, the following mathematical solution can be found to find the optimal portfolio with an unlimited number of assets, which is based on the Lagrange multiplier.

Where the λ is a constant value. By analysing the possible fleet portfolios some special observations can be made. First, the risk averse portfolio has a highest expected return and risk that is between the other 3 asset portfolios, and notably does lie on the efficient frontier. The results can be used to make a performance appraisal of the portfolio manager. A portfolio's expected return is equivalent to the portfolio's weighted average return on individual assets. Markowitz also presented the importance of the correlation between two assets. In general, as a primary decision, a rational investor should seek to minimize portfolio risk and maximize return by combining less than perfectly correlated assets. Applying this theory to a maritime industry and risky assets, one can derive an efficient frontier of dominant portfolios in a mean-variance plot. The model's goal is to determine the leverage of each single asset with an offsetting gain or loss within the group of assets, thereby hedging the total portfolio exposure for the agreed level of risk compared to the estimated portfolio return rate. Simply replacing the ship investment in a minimum variance portfolio as a risky asset, the portfolio the same as stock market when traded in the portfolio the risk can be hedged. Since most of the high return high risk portfolios consist of two assets, therefore to find the exact minimum variance portfolio allowance for two assets, employed the following equation of minimum variance of optimal portfolio:

$$W = \frac{\left(\sigma_{LNG}^2 - \sigma_{LNG}\sigma_{SCR}\rho_{LNG,SCR}\right)}{\left(\sigma_{LNG}^2 + \sigma_{SCR}^2 - 2\sigma_{LNG}\sigma_{SCR}\rho_{LNG,SCR}\right)}. \quad (6)$$

The optimal portfolio variance with weights and standard deviations:

$$\sigma_P^2 = w_{LNG}^2\sigma_{LNG}^2 + w_{SCR}^2\sigma_{SCR}^2 + 2w_{LNG}w_{SCR}\sigma_{LNG}\sigma_{SCR}\rho_{LNG,SCR}.$$

The optimal portfolio based on the efficient market hypothesis:

$$\frac{d\sigma}{dx} = \frac{\left(\mathrm{E}(\mathrm{r_{SCR}}) - r_f\right)\times\sigma_{\mathrm{LNG}}^2 - \left(\mathrm{E}(\mathrm{r_{LNG}}) - r_f\right)\times\sigma_{\mathrm{LNG}}\sigma_{\mathrm{SCR}}\rho_{\mathrm{LNG,SCR}}}{\left(\mathrm{E}(\mathrm{r_{SCR}}) - r_f\right)\times\sigma_{\mathrm{LNG}}^2 + \left(\mathrm{E}(\mathrm{r_{LNG}}) - r_f\right)\times\sigma_{\mathrm{SCR}}^2 - \left(\mathrm{E}(\mathrm{r_{SCR}}) - r_f + \mathrm{E}(\mathrm{r_{LNG}}) - r_f\right)\times\sigma_{\mathrm{LNG}}\sigma_{\mathrm{SCR}}\rho_{\mathrm{LNG,SCR}}}.$$

$W_2 = 1 - W_1$.

Based on this, portfolios with two assets were created and low correlation portfolios are shown in the chart below. This is indicated by the main point of mean-variance and the color of the line in Efficient Frontier changes accordingly. In Figure 3, the portfolios in blue represent portfolios with high risks and low return, while the red colour line of efficient frontier represents portfolios with high return and high risk, indeed this is based on the analysis of selected portfolios of the total portfolios. The point where the blue and red lines touch on the efficient frontier will be our optimal portfolio, the so-called minimum variance portfolio. To control entirely risks together, the portfolio managers can add to the portfolios of ships by LSFO and replace other ships with LSFO ships. Those ships will not add to the savings and generate extra income for the fleet, they can help shipping line to cope with other probable risks.

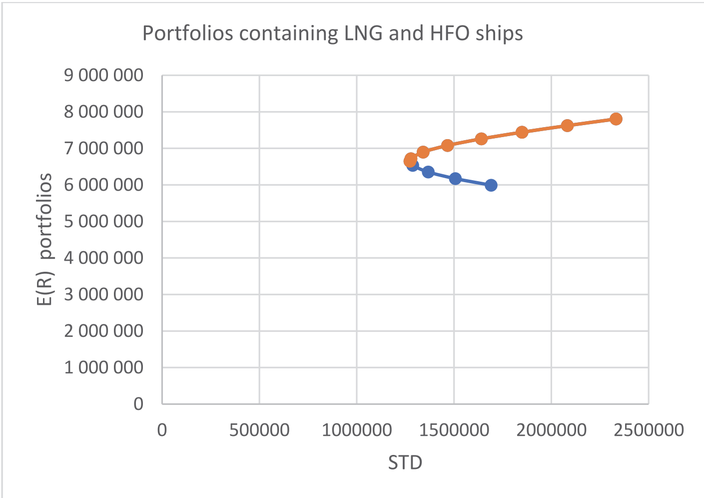


*Figure 3.* Efficient market portfolio, separated risky portfolio from low risk

The result, as illustrated in Table 3, shows the necessary investments with actual fuel prices in the current market and the forecast for next five years. The optimal solution for this case study with fleet of ten ships is the so-called market efficiency portfolio. According to Markowitz´ optimization the optimal portfolio of our case study consists of four ships with LNG and six ships with high sulphur using the scrubber on board.

**Table 3.** Final result for the optimal portfolio consisting of ten ships

| No | Fuel type | Portfolio weight | Number of ships in the portfolio |
|---|---|---|---|
| **1** | LNG | 3.664 ≈ 4 | 4 |
| **2** | High Sulphur | 6.333≈6 | 6 |
| | | Total | 10 |

Shipping lines aim to have an optimum fleet/portfolio for better utilization and higher operation efficiency. The ship owners should be able to keep the fleet as a minimum to cover fixed expenses. A popular way of making such a fleet with different ship mixes can be seen in the different fleets holding the different assets. Among them RORO, ROPAX beside of tanker, dry bulk and containerships are the most prevalent. The aim of making such a wide range of fleets was previously to cover sailing times and routes. However, risk facing and risk management also has been added to the options of making a wider range of fleet. Markowitz´ modern portfolio theory can provide a good solution to optimize current fleet of shipping lines. It can consider the volatility of fuel price, steel price, labour force availability and salaries and other raw materials and additional costs that can affect the operating cost and initial investment.

The fundamental goal of modern portfolio theory is to optimally allocate investment capital among different assets. The modern portfolio theory can be a suitable approach for investors currently coping with the new regulations. In future research this optimization model can be tested on different shipping lines with different fleet sizes, ship dimensions and volumes. Employing Markowitz' theory can shift the focus of investors from traditional models to new models based on modern portfolio theory. In this study, the focus was on smaller shipping lines with most of the cruise and ferry ships with roughly the same size and similar vessels in their fleet. New types of fleet portfolio construction can be tested to add more green and suitable vessels which are run by so-called wind vessels, either with ethanol, methanol, biodiesels fuels, or other green or low sulphur fuels. It should take into consideration that such a green fuel, like LNG, have no problems with supply, distribution, storage and ports infrastructure, and have a broad utilization plan, which requires a serious attention of the companies, communities and professionals active in the field.

Wang and Notteboom (2014) reviewed more than 33 studies in the field of LNG as the main fuel of the ship, concerning its advantages and disadvantages have been well addressed. The results of their literature review showed that over the last five years LNG was favourable and suggest that it could make investors focus more on this fuel in the shipping industry, i.e. the LNG solution seems to be promising. However, according to the result of this paper in the case study, the weight for HFO use together with a scrubber is still higher than LNG for the optimal fleet portfolio. Assuming similar price spread changes between LNG and other IMO-compliant marine fuels, new built LNG-driven ships seems to be under current conditions the most favourable choice for ship owners. The results this research revealed as well that the major obstacle for quicker grow of LNG-driven vessels is related to the lack of investments in infrastructure and LNG distribution, i.e. the general availability of the fuel.

The research also complements the investigations of Kavussanos and Visvik (2016) who developed new models of financial management in maritime industry by neglecting risk aspects. The results of the portfolio approach in sustainable fleet management provides a new model for risk management model in the sustainable shipping industry that fills this gap in risk management. Finally, the optimal solution of the fleet portfolio is gained by approximation of integer solutions; here further research from the area of discrete mathematics is necessary to offer an algorithm to solve to portfolio problem with an optimal point having integer coordinates.

## 10. Conclusion

The research provides a new model for investment and risk assessment for fleet management in maritime industry. Until now, after the implementation of SECA regulations and the 2020 Global CAP, most of the vessels turned from low-cost high Sulphur fuel to expensive compliant marine fuel like MDO or LSFO, others retrofitted their vessels for the use of LNG or scrubbers. Since the prices of all compliant fuels are subject to high volatility as well as the correlations between them, ship owners face complex investment decisions for compliance. The paper analyse and discusses sustainable investment decisions for maritime fleets by following a portfolio approach in order to provide a model together with an optimal solution and an risk assessment for an investment decision in shipping industry.

The findings are based on Markowitz´ approach of modern portfolio theory and the results show that the elaborated model has the ability to optimally allocate and distribute sustainable investment capital for fleets of shipping companies. The considered fleets consist of vessels using different types of fuels and engines together with potential abatement technologies. The different compliance options of the fleet and their interconnection are evaluated by spreads of fuel prices together with their correlations. The deducted portfolio model facilitates investment decisions for fleet owners and leads to optimal solutions by assessing return and risk aspects. The fleet portfolio model is easily transferable to different frame conditions and supports maritime fleet managers and ship owners to optimise their sustainable investment decisions in the context of green shipping.

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## Publication II

**Atari, S.,** Bakkar, Y., Olaniyi, E. O., & Prause, G. (2019). Real options analysis of abatement investments for sulphur emission control compliance. *Entrepreneurship and Sustainability Issues*, Volume 6, Issue 3, 1062–1087. DOI: 10.9770/jesi.2019.6.3(1)

**ENTREPRENEURSHIP AND SUSTAINABILITY ISSUES**
ISSN 2345-0282 (online) http://jssidoi.org/jesi/
2019 Volume 6 Number 3 (March)
http://doi.org/10.9770/jesi.2019.6.3(1)

**Publisher**
http://jssidoi.org/esc/home

# REAL OPTIONS ANALYSIS OF ABATEMENT INVESTMENTS FOR SULPHUR EMISSION CONTROL AREAS COMPLIANCE*

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*Received 20 October 2018; accepted 25 February 2019; published 30 March 2019*

**Abstract.** Since the introduction of the Sulphur Emission Control Areas (SECA) regulations in the Baltic Sea Region (BSR) in 2015, the BSR has witnessed high compliance rate. However, a closer look to the situation reveals that the currently preferred compliance strategies depend on low oil price where ship owners shun investments in abatement technologies which may lead into an economic trap in the event of the oil price increase. The research considers incentive provisions for maritime investors who make investment decisions related to clean shipping and maritime fuel management. Traditionally, the financial assessments of these decisions are based on capital budgeting methods comprising cash flow analyses and net present value calculations. The findings reveal that the Real-Option approach represents a more realistic, reliable and promising method for the evaluation of abatement projects, especially under uncertainty and high volatility in material resource markets. The results can be applied to the evaluation of all projects in the maritime industry that depends on the price variation of the underlying asset during a specific period.

**Keywords:** SECA regulations; maritime investments; Real-Options; Monte Carlo simulation; clean shipping

**Reference** to this paper should be made as follows: Atari, S.; Bakkar, Y.; Olaniyi, E. O.; Prause, G. 2019. Real options analysis of abatement investments for sulphur emission control compliance, *Entrepreneurship and Sustainability Issues* 6(3): 1062-1087. http://doi.org/10.9770/jesi.2019.6.3(1)

**JEL Classifications:** G31, G32, L26, L98, M1

* *This work is in principle linked to the EnviSuM – Environmental Impact of Low Emission Shipping: Measurements and Modelling Strategies project sponsored by the European Regional Development Fund.*

**ENTREPRENEURSHIP AND SUSTAINABILITY ISSUES**
ISSN 2345-0282 (online) http://jssidoi.org/jesi/
2019 Volume 6 Number 3 (March)
http://doi.org/10.9770/jesi.2019.6.3(1)

## 1. Introduction

Green and environmentally friendly shipping have received much attention based on concerns for its local and global contribution to air pollution and environmental problems. Therefore, the Sulphur Emission Control Areas (SECA) was implemented targeting reduction of sulphur emissions from shipping (Olaniyi, 2017). International Maritime Organization (IMO) decided that all ships in SECA have to use marine fuels with a lower amount than 0.1% of Sulphur content from January 2015 (IMO, 2015, 2016) to ensure a greener and more sustainable maritime transportation system.

There are three primary SECA regulations compliance options for the ship owners. First, as Turesson and Weddmark (2015) stated, is to switch the use of the marine heavy fuel oil (HFO) to the cleaner low-sulphur fuel such as the Marine Gas Oil (MGO) and Marine Diesel Oil (MDO). The second alternative is to continue with the high-sulphur fuel (i.e. HFO) and installing an exhaust gas treatment system, an abatement technology called the scrubber which gives room for the continuous use of the HFO (Farrell et al., 2002). The third option is to switch to other alternative sources of fuel such as Liquefied Natural Gas (LNG), methanol or hydrogen cells. These alternative fuels are being considered for future solutions to meet the SECA requirements (Turesson & Weddmark, 2015). Olaniyi, Atari and Prause (2018) result also revealed that most of the ships are switching to the use of the low sulphur fuel because it removes the hassles of capital compliance investments. Moreover, Hämäläinen (2016) found out that, in Finland, 45 % of shipping operating costs are fuel costs. This finding makes fuel one of the most critical factor in shipping industry so that the optimisation of fuel consummation as well as the choice of the best alternative for abatement are not only important for environmental reasons but are also crucial for the maritime industry due to economic conditional.

The Global Marine Fuel Trends 2030 study (DNV GL, 2018), affirms that combining the use HFO with an abatement technology is likely the most cost-effective option for the ships for SECA compliance because the MGO is more expensive than the HFO. Furthermore, the limitations associated with the use of the LNG such as insufficient bunkering facilities and the expensive conversion costs for old vessels is also a hindrance (Bergqvist et al., 2015). With this background, the scrubber technology, in the light of different uncertain factors of other low sulphur fuels received much attention over the last years and the number of scrubbers installed on board ships increased slightly (Eelco & Maarten, 2015).

The scrubber technology was initially developed to prevent the pollution problem from the power plants with the first marine scrubber developed in Finland and started operation since 2012 (Matczak, 2013). Through installations on new ships and retrofitting meanwhile, 87 scrubbers were installed by the end of the year 2016 in the BSR (HIS, 2017). Scrubbers are classified as open loop and closed loop, and some of those are built based on hybrid technology (i.e. a combination of the both the open and the close scrubber technology installed on one ship). The open loops are cheaper with lesser operating costs than closed loops. Scrubber installations have sparked a discussion on the ecological implications and specific problems the abatement technology so that Germany and Belgium are not allowing ships to enter their ports, which are operating with an open loop scrubber (Lindstad et al., 2015).

It is no gainsaying that clean shipping initiative demands best business solutions for the maritime industry since the economic impact of the SECA regulations is as significant as the environmental impacts for clean shipping infrastructure investments and development of sustainable business models for public and private maritime enterprises. Making investment decisions require advanced analytical methods because the known traditional methods have many shortages and are not particularly precise when they measure static conditions without forecasting and estimating or taking many parameters in future into consideration (Dixit and Pindyck, 1994). Right decision-making process regarding investments or financing project is essential to creating positive projects economic conditions and this applies to projects with high risks in front lines of technology (Cox et al., 1979).

Accordingly, the SECA regulation and compliance can promote the enhancement of high technology and in response to new needs; the analysis of the actual disposal of the new rationale concerning investment and valuation decisions is needed. Thus, the objective of this work is to provide empirical validation of methods that can solve investors' challenge of SECA compliance investment decisions to avoid loss and maximise profit. Through a case study, the work focuses on the analysis of the historical time series data of fuel prices, scrubber inward investment, operating cost of scrubber-retrofitted ships, as well as on the analysis of the NPV and Real-Option investments calculations. All activities took place in the frame of "EnviSuM−Environmental Impact of Low Emission Shipping: Measurements and Modelling Strategies" project sponsored by the EU regional development fund.

This paper intends to assess the economic performance of this innovation project of the shipping companies. Methods for economic analysis are currently the most diffused methods for evaluation of innovation projects (Ryan and Ryan, 2002). Although the existing methods largely differ in their implementation, they all share a common principle, that is, the capital budgeting approach for calculating the economic return of a project as a sequence of discounted cash flows (Chiesa and Frattini, 2009). Besides the standalone practices for analysis of investments and assessment of innovative projects, these traditional techniques are extended in this work through the use of the real-options approaches and dynamic analyses into project evaluation, which considers the value of embedded options and the flexibility of the dynamic process of decision-making (Brealey et al., 2012). The authors also suggest the use of analytical and numerical methods like the Black-Scholes model, binomial model and Monte Carlo simulations to quantify risks and uncertainties associated with the feasibility of investments in scrubber technologies.

The remainder of the paper is arranged in the following manner: In the next section, the authors describe the theoretical framework that forms the bases for this study. The third section presents the empirical methodology described briefly above, with an emphasis on the identification of exogenous parameters related to the study case, the capital budgeting approaches and the real option valuation methods. The fourth section illustrates the case study, layout our estimations and discusses the main results and findings. The last section concludes the article.

## 2. Theoretical background

### 2.1. Investment and capital budgeting in scrubber technology

Evaluating corporate investments' value or assessing innovative projects' performance allows managers to effectively improve their business decisions and investment planning, in order to guide the project management, optimize the project efficiency and maximize the project economic return. Finance theory states that expected (future) cash flows (CF), either the positive or negative income streams an investor would receive from an investment should be discounted at the opportunity cost of capital and adjusted for the time value of money, so as to estimate the net present value of the investment. Thus, the project valuation and the investment decision are made thoroughly.

It is widely recognized that the process facilitating the decision-making is called the Discounted Cash Flow (DCF) method. This method (DCF) is viewed as a plausible and robust approach to quantify the complex and large-scale investment in single parameters (e.g. the net present value−NPV generated by investments to summarise performance indexes that illustrate the attractiveness of the investment (e.g. the internal rate of return−IRR and the profitability index) (Ye and Tiong, 2000; Downes and Goodman, 1998). The reliability of this method is motivated by the fact that its parameters are easily observed and calculated, takes into account the time-dependent value of money and involves predicting cash inflows and outflows related to the investment over its lifespan (Savvides, 1994; among others). In addition, although the existing methods largely differ in their implementation, they all share a common principle, that is, the capital budgeting approach for calculating the economic return of a project as a

ENTREPRENEURSHIP AND SUSTAINABILITY ISSUES
ISSN 2345-0282 (online) http://jssidoi.org/jesi/
2019 Volume 6 Number 3 (March)
http://doi.org/10.9770/jesi.2019.6.3(1)

sequence of discounted cash flows (Di Lorenzo et al., 2012, Copeland et al., 2010; Chiesa and Frattini, 2009; among others).

One another hand, the Net Present Value (NPV) is the most commonly used economic approach to evaluate different types of investments (Ross, 1995). It consists of discounting all future cash flows (both in- and out-flow) resulting from the innovation project with a given discount rate and then summing them together as reported in equation 1. The most straightforward rule of the NPV decision is to discard all projects with negative NPVs and undertake all projects with positive NPVs. This type of decision rule ensures that companies maximise value for their investments. Therefore, the merit of innovation is measured considering its contribution to the creation of economic value out of the investment initial cost, i.e. when the NPV is greater than zero. Thus, when applying the NPV approach to the scrubber investments in the shipping industry, the NPV of a scrubber is expressed with the flowing specification:

$$NPV_t = \sum_{t=1}^{T} \frac{CF_t}{(1+r)^t} - CapEx_0 \qquad (1)$$

In this given formula, CFt is the expected cash flow generated in year t, representing the savings from operating income at the end of year t, which assumed to be constant over the whole investment period. T is the investment period (i.e. the economic life of a scrubber); r is the risk-free interest rate - usually in financial evaluation, cash flows are discounted at the weighted-average cost of capital (WACC). The term (1+ r) is in the finance literature called the discount factor and $CapEx_0$ is the capital expenditure, which corresponds to the initial capital investment in a SOx scrubber. The sum of the discounted values of the cash flows corresponds to the present value (PV) of the inflows sequence.

This approach is risk-adjusted, while other metrics of capital budgeting and performance criteria such as ROI, IRR (Internal Rate of Return) or MIRR (Modified Internal Rate of Return) are not (e.g. Maquieira et al., 2012; Jackson and Sawyers, 2008; Kierulff, 2008). In its basic application the discount rate is calculated looking at the "real" cost of capital employed in the project, that is, by calculating the weighted average cost of equity and debt used to finance the project. This was discussed from theoretical and empirical standpoints in Lifland (2015), Chiesa and Frattini (2009), Myers, et al. (1976), Myers (1972).

However, when flexibility is the core project objective, the standard DCF based method and the NPV indicator underestimate the current value of the investment i.e. the present-worth asset-value, as well as some management options such as sensitivity and scenario approaches and real-option analysis (e.g. Di Lorenzo et al., 2012; Farragher et al. 2001; Copeland, 2001; Ho and Pike, 1998). For instance, Milne and Whalley (1999) discussed that in the event of delayed investment, the future income and option values have to be added to the current year NPV, so to take into consideration compensation of the time-value of money, the asset value should be higher than the commencing investment in the options. This description mainly makes the NPV and standard-DCF method inappropriate and insufficient for evaluating shipping industry investments.

The recognized inappropriateness of the DCF method has necessitated the undertaking of different approaches such as the real-option pricing approach and scenario techniques, which introduced sensitivity analysis, uncertainty associated to the option value and dynamic analysis to the project valuation (Di Lorenzo et al., 2012). Similarly, McLeish (2005), Copeland (2001) and Dixit and Pindyck (1994) have in the past proposed better models based on the NPV indicator, the uncertainties associated with future discounted cash-flows and the probability of the different possible scenarios in different market conditions to evaluate investment appraisal.

ISSN 2345-0282 (online) http://jssidoi.org/jesi/
2019 Volume 6 Number 3 (March)
http://doi.org/10.9770/jesi.2019.6.3(1)

Di Lorenzo et al. (2012) and Dixit and Pindyck (1995) propose that the DCF could be used together with Real-Option integration to assess investments plan in a common project or in a high-tech industry where the company want to commercialise new products.

### 2.2. Real-Option investment evaluation of the scrubber technology

Options trading is a major part of investments in the capital market and its use in the evaluation of investment appraisals is popular. It is important to emphasize that the real option valuation method of investment projects is the extension of financial options theory on real property. Black and Schools (1973) introduced options trading approach into investment appraisal by using the option pricing to evaluate an investment from the zero points of the project. By incorporating a constant price variation of the asset, the money value of the time, the option's exercise price and the option's expiration value, the Black and Schools model calculates the price of a call option and put option in general. Boyle (1977) introduced a new option valuation approach called Monte Carlo Simulation (MCS) where the options traders generate random variables to get the pricing value. With this approach, a simplified simulation is to generate an optional quantity of random variables. However, it has been less acceptable than other approaches for the evaluation of an option price (Glasserman, 2013).

Maritime investors, especially in the shipping industry, appreciate investment decisions, which allow reaction and adaption on price movements for energy commodities since there is no reliable method to predict future prices trend. Thus, the authors propose that it might be of a higher value to obtain a scrubber or install engines that allow them to switch between energy sources to be able to use the most economical fuel. Acciaro (2014a) suggested such an abatement technology installation model for maritime industry and used the model to determine the optimal time for deferrals of investments and to evaluate investments at the present or in the future. Acciaro investment model was empirically tested and validated with an abatement project on a handy size vessel which was LNG retrofitted. Cox et al. (1979) offered the first simplified future pricing and option valuation model popular among options traders. According to Brach, (2003), the application of Cox's model delivers an expected asset value, the best and worst-case fuel prices scenario as well as the risk-free rate where the investment cost is the same as the exercise price. In the case of a new abatement technology such as the scrubber, investment as an option forces managers to make a decision based on their profit in the first two or three years. However, if the company want to know what could happen within the market in a longer period, then the binomial option-pricing approach would be helpful to illustrate or make investments strategic map where it shows the upper and the lower bands values in the best and worst investment scenarios. Because of this, it has been a more favourable approach among investors. The different fuel scenarios with the highest (VMax) and lowest (VMin) value of saved capital will be calculated to draw the strategic investment binomial lattice (tree) of scrubber technology investment. To acquire the expected asset value of the periodic cash flow C so savings from a constant HFO fuel price over time will be calculated as:

$$C = Max\left(0; \frac{P.V_{Max} + (1-P).V_{Min}}{(1+r)^t} - K.(1-r)^t\right) \quad (2)$$

where, K is scrubber costs; r is risk-free rate or WACC (weighted average cost of capital), proxied by the LIBOR rate; T is time at which the option can be exercised; $V_{Max}$ is lattice's up-factor that reflects the maximum value of the saved capital and $V_{Min}$ is lattice's down-factor that reflects the minimum value of the saved capital. In the binomial tree approach (Cox-Ross-Rubinstein) these two factors generate the project's random (present value) of cash flows (CF) so that the original cash flow volatility is preserved. Hence, the next period project cash flow values will move in two directions to conform to the lattice's up and down multiplicative factors and expressed as follows:

$$V_{Max} = e^{\sigma\sqrt{\Delta t}} \qquad V_{Min} = {}^{1}\!/_{V_{Max}} = e^{-\sigma\sqrt{\Delta t}} \tag{3}$$

where, σ is the volatility of the underlying assets' value, i.e. the present value of cash flows and Δt is one time period.
With this approach, it should be noted that the option value is calculated by applying the risk¬ neutral probability P of the investment result. The risk-neutral probabilities allow discounting the cash flow and asset over the period at the internal rate of company risk-free added to the cost of the capital. In other words, instead of using the simple decision tree to calculate the option values, a risk-neutral probability decision tree has to be used discounting asset values at the risk-free rate r. The weighted probability P using the actual outcome of the sum of probabilities on upward and downward option values will be:

$$P = \frac{(1+r) - V_{Min}}{V_{Max} - V_{Min}} \tag{4}$$

Where P is the risk-neutral probability.
Acciaro (2014b) option evaluation model was based on a discrete binomial tree approach and he argued that using Black and Scholes's method as an option-pricing approach is not appropriate for real asset option-pricing in maritime sector due to several reasons, one of which is the difficulty of proving the historical normal distribution of the underlying data.

### 2.3. Real-Options and deferral investments

A real project is a tangible asset with the same value as a corporate investment opportunity. It means that the integration between DCF and the Real-Option is similar to a call option where the investor has the right but not the obligation to invest in an underlying asset at a specified fixed price during an agreed period of time or at a given date (Cherry, 2007; Hull, 2006; Luehrman, 1998; Natenberg, 1994. As a common managerial option, its use in practice is through an option to defer, i.e. to wait until further information reduces market uncertainty, and an option to abandon, i.e. to dispose of any unprofitable project or investment (Fusaro, 1998; Trigeorgis, 1996).

Fundamentally, the price of an option in both financial and real project reflects the expected future payoff of the underlying asset at the time of exercise where the expected future payoff is discounted back to the present at the risk-free rate revealing the present option value (Fusaro, 1998; Luehrman, 1998). There is an essential acquisition time for the call options, exercising (strike) options time, twin security arbitrage options of selling and buying or lending and borrowing the capital for the investment (Fusaro, 1998; Trigeorgis, 1996). Arbitrage occurs when a security is purchased in a single market concurrently and using the twin security strategy and investment decision at the time of investment is like a mixture of lending and borrowing. Capital investors can thus build a continued duplicating portfolio to hedge the options this way (Poon and Granger, 2003). However, in diverse financial market options, the strike prices (i.e. the price at which the holder of options can buy) are fixed, while in Real-Options acquisition are not constant. The value of the Real-Option also depends on how uncertain costs and future cash flows correlate to each other (Trigeorgis, 1996).

Furthermore, in Real-Options pricing, it is assumed that the twin investment security option exists which would allow the investors to choose between the real projects or invest in two or more securities at the same time. This situation allows the risks and payoff of the projects to better conform to the market, the options and stock risks or gives room to construct a risk-free hedge in a very optimal situation. In financial market options, the strike prices are fixed, while in Real-Option acquisition, the strike time is set for the future (Poon and Granger, 2003). The value of the Real-Option will depend on how uncertain the costs and future cash flows correlate with each other.

Therefore, investors in an uncertain situation can predict the costs of the options accusation that will eventually take place (Bareley et al., 2012). In fact, the situation for Real-Options is different in financials market where the value of the asset is observable at any time of exercise, expiration and sales are well defined (Ho and Liao, 2011).

Notably, the options are essential for the sizeable capital-intensive project because of the proven efficiency in diverse industries to evaluate nuclear plants, airlines, and railroads (Fernandes et al., 2011). They are also crucial for projects involving new products where the acceptance in the market is uncertain and is equivalent to a firm having a portfolio of call and put options (a call option is like restarting an operation when a project is currently shut down while a put option is like shutting down a current project operation) (Bengtsson, 2001). The option to choose when to start a project is an initiation or deferment option. Initiation options are particularly valuable in natural resource dependent companies where a firm can delay purchasing a commodity like a scrubber or change the fuel type it uses until the market conditions are favourable. This is what it means to wait before taking any action until more is known or when the timing is expected to be more favourable (Dixit, 1992). In a typical market, this approach entails understanding when to introduce a new product or replace an existing piece of equipment to increase or decrease the scale of operation in response to demand, which is comparable with the option to expand or abandon which are crucial for after-investment progress (Trigeorgis, 1993).

The key action for the uncertain situation is to be able to delay investment without losing the available opportunity done by creating a call option on the future investment (Myers and Majluf, 1984). The riskiness of cash flow generated by the project can change significantly during the project lifespan and in the case of projects with production facilities. It may not be optimal to operate a plant for a given period if revenues do not cover the variable costs (Grimsey & Lewis, 2002). In this view, if the price of fuel or any other correlated alternative fuel type falls below the cost of initially calculated, it may be optimal to temporarily shut down the engine type and switch to another type of fuel source until the oil price recovers. An electric utility may also have the option to switch between various fuel sources to produce electricity on the ship.

Against this backdrop, this work will be considering a pricing model of options that depend on the approach of Black¬ Scholes model and the Binomial option-pricing model (i.e. Hull, 2006; Black and Scholes, 1973; Cox and Rubinstein, 2001). The option prices are determined by the simple discounting method with the expectation that the values of each option at the expiration date will be traded using unreasonable risks premiums as discount factors that were to reflect the volatility of the option according to Jensen (1972). However, the Black-Scholes pricing methods of financial asset assume a lognormal distribution of future returns in a continued period of work from Black and Scholes (1973) where they called the practice a diffusion process or a continued and unhindered arrival of information that causes price change with either a constant or changing variance. These price changes are normally distributed or logged to resolve market uncertainties so that investors can make better and informed decision regarding whether to invest or defer (Arriojas & Mohammed, 2007).

In shipping, operators may have a different approach to the investment on prices and project available to provide better insights into market conditions. Aforementioned, they may decide for example to exchange input resources, that is, switch from one energy form to another or from one type of engine and fuel to another. The commodities between the two include the following generic basics: investment ambiguity, irreversibility, the ability to choose between two or more alternatives (Black and Scholes, 1973).

Following the general option-pricing model of Black and Scholes (1973) and upward and downward probability (this will replace later by a real value to the main formula), investment opportunity in a scrubber technology can be modelled as a call option on the net present value of the expected future revenues from the operating scrubber gas treatment system. This offers the option to invest or postpone regarding the circumstances that affect the formation of the net present value of this project. Therefore, the price of the call option is estimated by solving the following nonlinear equation:

$$Option\ Call\ Price = S_0 N(d_1) - Ke^{-rT} N(d_2) \tag{5}$$

Where $N(d_1)$ and $N(d_2)$ denominate the standard normal cumulative distribution function and e is Euler's constant. The formulas for $d_1$ and $d_2$ are given as follows:

$$d_1 = \frac{ln\left(\frac{S_0}{K_t}\right)+\left(r+\frac{\sigma^2}{2}\right)\times T}{\sigma\sqrt{T}} \qquad d_2 = d_1 - \sigma\sqrt{T} \tag{6}$$

Where C is the value of a call option. $S_0$ is the present value of future cash flows from the investing in the scrubber (i.e. the expected revenues from the operational risky investment in scrubber). T is option's time to maturity or expiration (i.e. the length of time option is viable). N(x) is the cumulative distribution for the standard normal distribution. σ the riskiness of the scrubber, the volatility of the worst- and best-case scenario of the investment (i.e. the standard deviation of the expected rate of return on S). K is the option's exercise price at the end of the period (i.e. the cost of converting the investment opportunity into the option's underlying operational project) and $d_1$, $d_2$ are deviations from the expected value of the normal distribution.

Thus, the proposed pricing in the maritime industry for obtaining new technologies specifically scrubber technology will be calculated as:

$$Option\ Call\ Price\ = S_0 \times N(pward\ probability) - scrubber\ cost\ \times e^{-rT} \times N(downward\ probability) \tag{7}$$

In reality, the daily fuel consumption of any ships is a critical factor in calculating the daily and annual cost of fuel consumption, so the time spent within or outside SECA and the time of sail are considered for computation. With these numbers, it would be easy to calculate the value of the cost of fuel consumption easily. If the ship owners decide to operate their ships with fuel change, then, the price spread can be considered for calculations to determine the additional costs of operation and how much savings can be achieved by not changing fuel. The savings are the future cash flow parameters in option value and the cash flows for each period in the traditional methods.

**2.4. Real-Options and dynamic analysis: Monte Carlo simulation**

The paper empirically examines the joint stance of the DCF and Monte Carlo Simulation (MCS) analyses so to approximate the true NPV of the scrubber investment by incorporating a set of dynamic variables that directly affect the anticipated cash inflow-outflow valuations. The MCS introduces dynamic (probabilistic) analysis into project evaluation by using random inputs in order to model uncertainty and as such, it makes the DCF method more precise for investment appraisal and reliable decision tool in the project risk management (e.g. Di Lorenzo et al., 2012; McLeish, 2005; Ryan and Ryan, 2002). Based on multiple statistical simulations (modelling various scenarios), the MCS technique is likely to be realistic and reflects the dynamic nature of the investment lifespan (e.g. see Ara and Lee (2017)).

More formally, the MCS primarily allows producing an estimate of the project's NPV conditional on the set of random variables drawn from their underlying distribution and to assess the risk associated with the project (i.e. the Value-at-Risk related to the investment). Specifically, in this study, the MCS technique consists on generating stochastic variables by using a random uniformly distributed variable (in the [0,1] interval) to create a scenario analysis utilizing hundreds of possible iterations that continually change the NPV of the asset valuation (e.g. McLeish, 2005; Ryan and Ryan, 2002). The Black and Scholes (1973) model flowed back and the expectation function of the underlying asset defined (project's value) as a function of a geometric Brownian motion with a drift. Hence, the project's value was pre-specified and assumed to follows a stochastic process as follow:

$$dS_t = \mu S_t dt - \sigma S_t dWt \tag{8}$$

where $S_t$ is the value of the financial in each time period t, σ its estimated volatility, μ is the drift (yield) measuring the average growth per unit of time, Wt is normally distributed random variable with mean 0 and standard deviation √dt and W is a Brownian motion. Assumming that σ, μ and Wt are constants.

## 3. Methodology

The study was empirically validated through data from expert interviews, focus group meetings and other case studies done in the frame of EnviSuM–Environmental Impact of Low Emission Shipping project. The case project began in early 2017 until the end of the same year using investments in a scrubber with an installed capacity of 15 KW for the engine power of 48K KW sailing in BSR, mainly between the ports of Helsinki and Tallinn. The daily fuel consumption of the considered ship is assumed to be about 60 mt/day for 350 operating days/year.

The study reviews the compliance investment of a scrubber retrofit with a continuance use of IFO380 or an engine upgrade that involves the boiler and other necessary equipment for LSMGO or ULSFO with 0.1% Sulphur content. A case study was constructed to project real-life scenario to evaluate the scrubber project investment feasibility. The empirical data was used to determine the costs build-ups of the scrubber technology using the conventional investment evaluation tools, i.e. NPV, IRR, MIRR and the payback period comparable to using the proposed real options model. Afterwards, the result of the comparative analysis was used to determine which of the investment evaluation tool is most promising for SECA compliance investment decisions to avoid loss and maximise profit.

### 3.1. Case Study: application of Real-Option methodology to a maritime investment project

Investment evaluation with the Real-Option approach is not widespread in the maritime industry, and existing literature mostly used the real-option investment evaluation in mining, power plants and new sustainable energy resources with only a couple of research in the maritime industry working on LNG evaluation. With this investment evaluation approach, the authors made a qualitative analysis of the case in the shipping industry. The presented case study addresses an investment project of scrubber abatement and its evaluation. For this study, two evaluation methodologies were compared: the traditional NPV and the ROA (using Black and Scholes model, Monte Carlo method and Binomial option-pricing).

### 3.2. Project characteristics and descriptive

The cost of a new standard open loop 15 MW scrubber system for the mentioned ferry RoPax type sailing within SECA in the BSR with two main engines is roughly 5.5 million €. The price of a scrubber installation is calculated based on the ship engine power and the number of main engines. Results from the experts' interview indicated that an upfront investment for a ship with two powerful engines required a scrubber cost of €5.8 million. Usually, the flat rate of the scrubber initial cost start from over €2 million depends on the ship design and the choice between the dry or wet (open/close/hybrid loop) scrubber system. The design of the scrubber is usually tailor-made and is unique for every ship.

Half of the total costs are estimated as the actual cost while the other half is designated for installation. At the time of scrubber installation, the ship will be out of service for more than thirty days, involving fundamental construction

ISSN 2345-0282 (online) http://jssidoi.org/jesi/
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http://doi.org/10.9770/jesi.2019.6.3(1)

changes, commissioning, testing and training. The estimated cost of maintenance is approximately 20 000€/yr. The scrubber system was created using Caustic Soda (NaOH) solution, which is easily within reach globally.

The quickest approach to procure the scrubber chemicals is to order the needed amount of tank cars to the port that the vessel will visit. The cost of materials depends on where the chemical is purchased, and the delivery time, however, the usual price for NaOH was around 300 €/t in 2017. If the ship scrubber system running is a closed loop mode, the costs of operation include a bleed-off treatment unit (BOTU) for the water treatment. This unit usually consumes additional chemicals to complete the cleaning circle adding an operating cost that includes flocculent or coagulant additives. Sometimes to calculate the extra expenses and operating cost, a 2% maintenance and extra operation cost is added to the annual operating costs.

The scrubber has a lifespan of 15 years and the economic lifetime of the ship is 25 years (Atari and Prause, 2017). Some parts of the scrubber may have a shorter lifetime, which would require replacing with spare parts before the machine span life is over. For investment appraisal, it is crucial to predicting the risk-free rate as well as the cost of capital. Mkouar and Prigent (2014) explained that the primarily driven factor in erratic investment is the interest rate, which influences both the cost of capital and discount rate. Some part of the investments funding is from the company's equity while the remaining funding through bank loans, manufacturer companies or export credit financers. The subject case is using a bank credit of over 15 years set to be repayable through annual payments from the beginning of the scrubber operations and whose annual payments are subject to an interest rate and an opportunity cost on the capital.

## 4. Results and analyses

Among the advanced low-gas emission regulations in the shipping industry in the BSR, switching to low-sulphur fuel by installing scrubbers and/or using LNG is gaining widespread acceptance as promising options. Thus, its economic performance should be compared with that of identical without using the scrubber and low-sulphur fuel (i.e. ship using HGO 3.5%S).

The subsequent subsections will present and discuss different calculations methods and the main results for the appraisal of low-sulphur scrubber investment proposals. Importantly, such economic analyses are based only on the baseline results of the first-year cost-benefit evaluation of the project.

### 4.1. Investments evaluation using conventional methods for evaluation

Undertaking the switch to low-sulphur emission and investment in scrubber technology requires that the shipowner conducts cost-effectiveness and evaluation analyses, and as such evaluate the worthwhileness of installing an exhaust gas cleaning technology.

The conventional methods to evaluate the project viability in this case of study are a set of criteria: the NPV, the IRR, the MIRR, the payback period and the profitability index. These methods are optimistic assumptions because it is improbable that bunker fuel prices would remain constant over a span of 15 years. Hence, in the real world, fuel prices might be characterized by a significant variance over the time, and so the realized future cash flows are not constant over the operational period. Thus, the basic assumptions were slightly modified, to provide NPV and real options valuations with a realistic quantitative outcome. Thus the authors applied a dynamic approach by introducing a random variable to predict future fuel prices.

In this case, the pricing is based on the assumption that the movement of fuel prices follows some sort of random walk and all effective costs and benefits due to the scrubber technology solution adjustment for the annual inflation rate. The success and accuracy of DCF analysis are determined by the choice of concomitant discount rate. A

ISSN 2345-0282 (online) http://jssidoi.org/jesi/
2019 Volume 6 Number 3 (March)
http://doi.org/10.9770/jesi.2019.6.3(1)

discount rate of 11% is assumed, which is defined by disregarding the composition of funding sources. This assumption could strongly influence the project results. Therefore, bearing in mind these assumptions, the results of the project evaluation are reported in Table 1.

**Table 1.** Key input-variables, DCF primary results and criteria for evaluation

| Data | Value | Definition/Sources | Measure |
|---|---|---|---|
| Panel A: Inputs and cost-benefit analysis | | | |
| CapEx | €5 684 000.00 | Annual capital expenditures equal approximatively to the initial price of a scrubber. | |
| OpEx | €4 238 945.31 | Annual operating expenditures of the first operational year. | |
| Spread-saving | €4 768 908.00 | Annual spread savings equal to the daily spread prices between HFO and MGO prices of the first operational year. | |
| Saving-OpEx | €3 251 344.67 | Estimated annual cash flows of the first operational year. | |
| $NPV_{1y.}$ | €−2 432 655.33 | The net present value (NPV) of the first operating year, a forward-looking measure of the project profitability, equals the difference between saving-OpEx and CapEx. By default, keeping the NPV without 1y-index. | Equation (1) |
| Discount rate | 11.00% | The Weighted Average Cost of Capital (WACC) is the company's weighted cost of capital that, that includes all capital sources: equity and debts. It proxies the discount rate of the estimated cash flows (i.e. Block, 2011; Bennouna et al., 2010). | Proxy by Treasury bonds with a maturity of 10 years in the EU zone. |
| Panel B: Conventional investment evaluation indicators | | | |
| $NPV_{15y.}$ | €22 767 025.57 | The net present value (NPV) is the difference between the present value of the cash flows (the benefit) over the project lifespan (15 years) and the cost of the investment (i.e. Maquieira et al., 2012; Viviers and Cohen, 2011; Bennouna et al., 2010). | Equation (1) |
| Payback Period | 1.69 | The payback period (PP) is the expected number of years required to recover the original investment (i.e. Hermes et al., 2007; Ross et al., 2004). | $PBP = \frac{I_0}{Cumulative\ CF}$ |
| IRR | 56.92% | The internal rate of return (IRR) is the discount rate that equates the present value of cash flows over the whole 15 years and the initial cost of the investment (i.e. Maquieira et al., 2012; Jackson and Sawyers, 2008). | $\sum_{t=1}^{T} \frac{CF_t}{(1+IRR)^t} = 0$ |
| MIRR | 20.92% | The Modified Internal Rate of Returns (MIRR) is the average annual rate of return that will be earned on investment if the cash flows are reinvested at the WACC (i.e. Kierulff, 2008; Jackson and Sawyers, 2008). | $I_0 = \frac{\sum_{t=1}^{T} DCF \times (1+\mathrm{r})^{t-1}}{(1+MIRR)^T}$ |
| Profitability Index | 5.01 | Profitability Index (PI) metrics the relative profitability of the project to the initial investment cost. It is the ratio of the present value of expected net cash flows over the project's lifespan to the investment cost (i.e. Viviers and Cohen, 2011). | $PI = \frac{\sum_{t=1}^{T} \frac{CF_t}{(1+r)^t}}{I_0}$ |

*Source:* Computed by authors

Due to the investment-oriented approach of this project evaluation, the economic performance of installing a scrubber is assessed according to several criteria and indicators as shown in Table 1. Panels A and B of Table 1 display the statistics and definitions of all the input-data, indicators and indexes used for investment evaluation and economic performance assessment of the study case. Panel A reports the inputs of the investment evaluation and the baseline results of based on the estimations cost-benefit of the first operating year; whereas, Panel B displays the conventional investment evaluation criteria based on the overall project lifespan.

Speaking about the capital costs of a sulphur scrubber investment for our particular ship case, Table 1 (Panel A) shows that the initial cost of the equipment (i.e. scrubber price) equals approximatively to €5.68 million. It is noteworthy to say that the price of a scrubber tends to largely vary depending on the scrubber engine installed power and size, as well as the specific of ship operating fuel consumption.

The results of the costs analysis for the scrubber technology gives interesting findings of the project investment feasibility. First, the estimated annual scrubber capital expenditures (CapEx) are in the order of €5.68 million the first operating year. In addition to the price of a scrubber, the CapEx includes the costs of installing an exhaust gas cleaning technology on board the vessel (e.g. internal combustion engine, piping, etc.), start-up costs (10% of total capital costs) and other additional costs related to the engine power (weighted by 58 coefficient) and the unit-fuel cost (weighted by 0.5%). The additional capital expenditures are relatively insignificant compared to the initial price scrubber. For conveniently, we retain that the scrubber price proxies CapEx. The estimated annual scrubber operating expenditures (OpEx) are in the order of €4.24 million the first operating year. These costs incorporate consumable costs: additional scrubber fuel consumption (10% of HFO consumption), scrubber services (2% of investment cost) and other additional operating expenditures related to the vessel engine power and scrubber technology (e.g. sludge disposition in port, cost of chemicals supplies, periodic inspections and repairs, minor tests and adjustments to performance monitoring, water management system, etc.) (IMO, 2015); and financial operating costs: financial-interests costs of scrubber (6% interest rate) and depreciation. All annual operational scrubber expenditures are adjusted to 2% inflation-rate through the investment period. More interestingly, according to DNV GL (2018), the operational costs for methanol are expected to be compared with those for oil-fuelled vessels without scrubber technology. This simply implies that the OpEx costs associated with installing a scrubber technology to comply with the SECA requirements on the BSR could not be considered as a business constraint.

Before proceeding further, it is primarily important to clarify that installing a scrubber might take about 2 weeks to six months, which will be a lost revenue period also called off hiring period (Ruiz-Cabrero et al., 2017). However, this consideration will not be taken independently into account in the costs analyses approach, because it is implicitly considered in the annual scrubber operating costs.

Furthermore, Panel A of Table 1 shows that money-saving capability of the scrubber (OpEx) using low-sulphur fuel and a SOx scrubber relies on the daily spread prices between HFO and MGO prices. The authors followed a dynamic-based approach and construct the average fuel prices on the observed daily fuel prices over four years (2013−2017), i.e. using the average annual prices and the annual volatility of prices. On average, the daily spread prices are close to €214 with €52 standard deviation over the period spanning from 2013 to 2017. The spread prices were relatively constant, high and less volatile for this period of study; though, the HFO prices drop to €81/bbl at the beginning of 2016.

Against this backdrop and statistics, the authors assess how OpEx and CapEx contribute to the total investment in a scrubber and the feasibility of switching to low-sulphur fuel as well as the scrubber adoption. Similarly, the results show that the relative operating expenditures (OpEx) and the relative capital expenditures (CapEx) to the investment cost of installing scrubber (i.e. the price) are around 15% and 13%, respectively; which cannot be economically seen as a burden for the feasibly of the business.

From this, the result in Panel A suggests that the annual spread savings, due to this shift to low-sulfur fuel, is €4.77 million; and thus the balance of the cost-benefit analysis, i.e. the saving-OpEx indicator, accounts for approximatively €3.25 million and the net present value (NPV) of the first is €−2.43 million.

Alternatively, the discount rate is fixed as an imputed data; while the conventional criteria of the investment evaluation: the NPV15y., discounted payback period, the IRR, the MIRR and the profitability index are calculated based on the expected future cash flows, occurring at the end of each year over the investment lifespan (i.e. 15 years). In this case, the expected cash flows are estimated based on fuel prices predictions, annual predicted spread savings (HFO versus MGO costs), annual OpEx and annual CapEx expenditures.

ISSN 2345-0282 (online) http://jssidoi.org/jesi/
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http://doi.org/10.9770/jesi.2019.6.3(1)

Results in Panel B of Table 1 show that the project of a ship scrubber has a positive present value, which reveals that the wealth generates by this investment is attractive and economically viable. The project will, therefore, raise the value of the shipping company (by €22.22 million euros), which is the financial objective of the shipowners. Hence, the conclusion is that installing a scrubber is relevant and should be undertaken and can be implemented successfully. Interestingly, the initial investment in the scrubber is recovered during the second year and the investment payback occurred after 1.69 years (i.e. break-even point). By implication, this means that the operating costs and the capital expenditures are recovered by the income inflows generated by the project to break even within approximatively two years. Furthermore, the results show that the IRR equals to 57% and MIRR equals to 21%, supporting the acceptance of the scrubber investment since these rates exceed the cost of capital, i.e. indicating that the benefits exceed the WACC. MIRR is substantially lower than IRR since the MIRR assumes that project cash flows are reinvested at the cost of capital (instead of the project's own IRR). Lastly, the profitability index shows that the relative profitability of the project is greater than the threshold value of 1-one. Thus, the scrubber investment is expected to produce €5.01 cash inflows for each €1 of investment.

However, production uncertainties were not considered in this evaluation of performance, though it has to be considered carefully, although the NPV calculation only contains the endogenous value of the scrubber investment. As previously stated, this evaluation can be regarded as the first step leading toward real options valuation (ROA), as the ROA is used to overcome those uncertainties. Thus, the application of ROA in evaluating this project will be presented in the next section.

### 4.1. Investment evaluation using the ROA (Real Options Analysis)

In the application of the ROV (Real-Options Valuation) to evaluate the project using the binomial approach and the Black & Scholes model, two assumptions are taken into account. First, all data provided by traditional evaluation methods are considered, all estimations are conducted based on the cash flow of the first operating year. Other necessary data are unavailable such as future oil price and future scrubber price; however, since the primary objective of this study is to compare traditional investment evaluation method with the ROA methods, these drawbacks may be disregarded.

In contrast to the ships' operational costs, the cost of the scrubber itself is not usually affected by high levels of uncertainty. As a simplified assumption, other uncertainties such as technological changes or environmental policies were not considered. Moreover, since in the case of fuel switching, fuel costs will not have a significant impact on operating costs their values were not introduced. Thus, the primary uncertainty factor is the volatility of fuel prices. The prices considered were the fuel prices of long-term contracts and the average price of the EU main ports for the three years 2015, 2016 and 2017. For the research, spot prices were not included because they may have been strongly influenced by short-term factors such as demand and supply, new regulations, etc. Mean and standard deviation of 963 days IFO380 prices were calculated using yearly-basis rolling windows, reaching 399 €/mt and 178 €/mt, respectively. Then, a simulation with 1000 interactions was conducted to calculate the fuel volatility. The results show an annualized standard deviation of 31.44% approximately, corresponding to the project projected volatility.

It should be noted that investment in a scrubber is not implemented in phases, i.e., the probability of stopping scrubber running after its start-up is low. Given the current economic situation, policymakers may not willingly support its development or make it a priority. More so, legislation could change in the coming years, limiting the feasibility of the scrubber project making the cost of a new scrubber installation or retrofit unstable. In a worst-case scenario, the cost could still subject to ship-freight rate uncertainty as well as fuel prices in the open market. Therefore, the option of deferring the project within one year can be considered and is justified by the high uncertainty of regulatory change.

Therefore, for the scrubber investment, a deferral option corresponds to a call option, where the decision for a present investment will be taken if the NPV of the scrubber project exceeds the value of the option. These options are typically evaluated through the binomial tree, developed by Cox, et al. (1979). The parameters used to build the tree are displayed in Table 2.

**Table 2.** Inputs for the Real-Option Analysis

| Input data | Value | | Description |
|---|---|---|---|
| Present value of future cash flows S | €3.25 | Million | Saving-OpEx of the 1st operating year |
| Volatility σ | 31.44% | Annual | Variance of fuel prices |
| The risk-free rate of return r | 11% | Annual | WACC |
| Time to expiration T | 15 | Years | Duration |
| Time step Δt | 1 | Year | Analysis period |
| Investment cost K | €5.68 | million | Strike price |

*Source:* Computed by authors

The investment horizon in a scrubber is 15 years, the initial outlay is €5.68 million, the estimated cash flows in the first year is $1.5 million and its uncertainty (volatility) is computed as 31.44%, as shown in Table 1 above. The risk-free rate of returns would represent the return rate of treasury bonds with a maturity of 10 years in EU added to the opportunity cost of capital. The binomial tree results show a possible evaluation of the underlying asset price and the deferral option from left to right. Regarding the underlying asset, the value presented by the first node of the tree is the current price of the underlying asset (i.e. and the end of time t-1). As shown in the table in Table 3, the underlying asset value can increase or decrease depending on coefficients VMax and VMin respectively (see Equation 2).

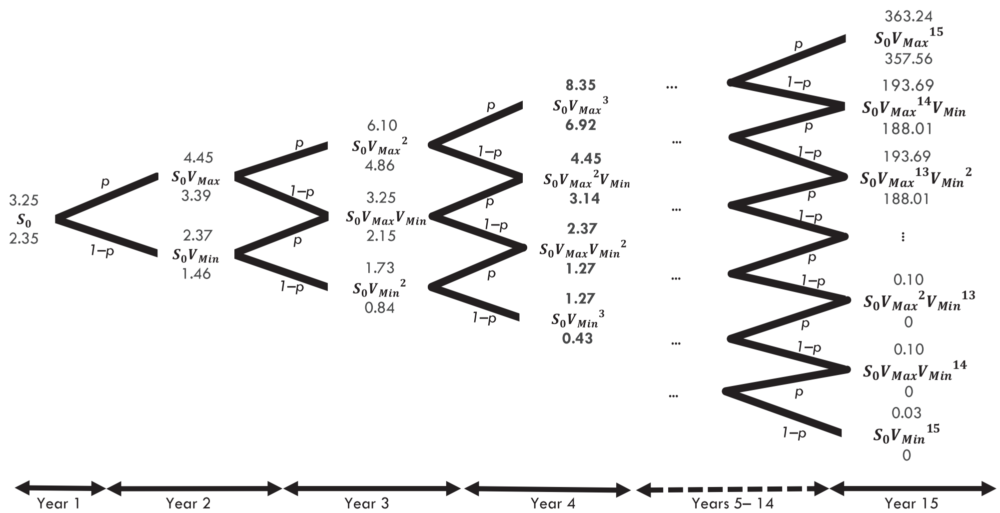
**Table 3.** Key parameters of Real Option-Value

| Input data | Calculated parameters | Source |
|---|---|---|
| Up factor ($V_{Max}$) | 2,12 | Equation 3 |
| Down factor ($V_{Min}$) | 0.47 | Equation 3 |
| Risk-neutral probability ($p$) | 0.60 | Equation 4 |

*Source:* Computed by authors

After identifying inputs factors required for setting up binomial model, the lattice's up-factor and down-factor, the authors thus construct the binomial lattice (tree) for the project's value, that approximates a lognormal distribution, and calculate the asset values on each node of the binomial lattice, using one-year time period. Currently, the present value of net cash flows (estimation of the first-year inflows) is $S_0$=100m, and the annual volatility of $S_0$ is σ=31.44%. The time of options maturity was divieded into several one-year phases. The results of a recombining lattice are displayed below in Figure 1. For analytic purposes, the truncated values of the lattice is reproduced below.

ISSN 2345-0282 (online) http://jssidoi.org/jesi/
2019 Volume 6 Number 3 (March)
http://doi.org/10.9770/jesi.2019.6.3(1)




All numbers are in million €.
Top numbers are asset values.
Bottom numbers are option values.

**Fig.1.** Tree for option to wait
*Source:* Computed by authors

Figure 1 forms the diagram of sequential decisions and possible ROA results. Upon completion of each phase, project management has the option whether to invest in a scrubber at that point or delay its implementation and wait until next period. Thus, the binomial lattice (tree) presents the diagram of the next periods' project's random values conform to the value of expected cash flows arising from investing in the scrubber, $S_0$, multiplied with the up-factor and down-factor to obtain $S_0V_{Max}$ and $S_0V_{Min}$. These two factors generate random project's values (i.e. present value of cash flows) so that the original $S_0$ volatility is preserved. For instance, it was verified that at the end of the first year, the project cash flow values conform to $S_1$(up) = $S_0V_{Max}$= €4.45 million and $S_1$(down) = $S_0V_{Min}$= €2.37 million. The investment option's values in the end of the second year show three scenarios: $S_2(\text{up} - \text{up}) = S_1(up)V_{Max}$= €6.10 million, $S_2(\text{up} - \text{down}) = S_2(\text{down} - \text{up}) = S_1(up)V_{Min}$=$S_1(\text{down})V_{Max}$= €3.25 million and $S_2(\text{down} - \text{down})$= $S_1(down)V_{Min}$= €1.73 million. Additionally, this binomial option-pricing model assigns two associated probabilities to the various nodes that constitute the diagram. Hence, Results shows that the asset value has to be corrected by two coefficients: p=0.60 and 1−p=0.40 (see Equation 4). Finally, as seen in the diagram, the options gave only the right but not the obligation for the manager to make the investment, implying that the payoff scheme to the option holder/ship owner is asymmetric.

Similarly, with the same procedure, the calculation is repeated to show the expected values of option values for every node of the binomial tree until the last year. In Figure 1, the upper numbers on the binominal lattice present expected future asset values over the options life period and bottom numbers indicate option values.

The last column of the binomial tree represents the possible values of the underlying asset at the option maturity date. Since the deferral option is similar to a call option, the last values of the tree are determined by subtracting the values of the underlying asset to the exercise price. The result can fluctuate between (S – K) and 0 with the option value S and the underlying asset price K. The other values are determined by the application of a neutral probability

ISSN 2345-0282 (online) http://jssidoi.org/jesi/
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to each pair of vertically adjacent values. The result shows that a scrubber project value in the first year with the option of delay in the binomial tree is €2.35 million, higher than the NPV of the first year which equals €−2.43 million (this value represents the difference between Saving-OpEx and CapEx of the first-year estimations (see Panel A of Table1)); hence, with high volatility of the market conditions the ROV value exceeds the NPV from investing in scrubber ''*today*''. Thus, it is better to postpone the investment decision.

Furthermore, an option value of delay is offered by calculating the difference between the expanded NPV (predict future cash flows, i.e. ROV) and the computed NPV of the 1st operating year which yields a value of €4.79 million and suggests that the deferral option value is higher than the value of investing immediately. Creating a shortened outcome or a shortcut investment in the NPV analysis will be negative in the first year, a situation not so surprising for such a significant investment. Thus, the project can be postponed until more favourable investment conditions appear.

Since investment decisions are subject to opportunity costs in regards to deferring, the investment should be made only when its NPV is higher than the value of the option. This result is so because an immediate investment implies a loss of opportunity to invest later and corresponds to the value of delaying the option. Even though the value generated by the scrubber project cannot make up for the total cost of investment, it would be sufficient to cover the deferral option. If these assumptions are applied to a binomial tree, the decision tree of current investment will signal to “invest” or “delay”, at each node, which simplifies the decision-making processes for managers. The advantage of using the binomial tree for a case like this is that the result will show if the option of investing now is better when the underlying asset reaches a higher value. If the underlying asset has a lower value, then the option of postponing the project for the next period would be a better choice.

Thus, the investor will only invest if the evaluation of bunker fuel remuneration exceeds the investment initial cost together with the opportunity costs of not postponing the project for one year ahead. Since the project presents a low static NPV in the first year (despite its positive outcome over the years), it will be necessary to invest €5.68 million in implementing the scrubber project immediately or facing an increase of value in the daily ship fuel consumption. This action will risk a decrease in the cash flow as well as a decrease in the cost of the underlying asset. For example, after 4 years and 15 years, the investor will obtain future cash flows of €8.35 million and €363.42 million respectively, according to the lattice values. Having this amount of underlying asset value is a motivation for the investor to invest because the value compares to the option value is positive. Whereas at a pessimistic scenario of making future cash flows of €1.27 million and €29 102, the underlying asset value confirms that a risk avoidance will be a better option. On the other hand, a negative option price will be a signal not to take the risk of investment. This way, even with a positive NPV static the tree shows that the project should be postponed because the value of the deferral option is superior.

Next, using the approach outlined in the Equations 5, 6 and 7, the Black-Scholes option valuation model was used to calculate the real call-option value by specifying the required parameters to set-up the Black & Scholes model (1973), which are the same as in binomial option-pricing model: i.e. the initial cash flows, the volatility of the project, etc. (see Table 2). Herewith, once the inputs parameters required for setting up the model are identified, then the call-option value is calculated using Equations 5, 6 and 7. Results are as follows (Table 4):

**Table 4.** Values obtained with the Black & Scholes model

| Input parameters | Value |
|---|---|
| d1 | 1.51 |
| d2 | 0.29 |
| Value of the call option: C | 2 366 992.83 € |

*Source:* Computed and constructed by authors

The results display the value of the real option (C) and the deviations from the expected value of the normal distribution (d1 and d2) by applying the Black-Scholes model. As described above, the estimated value of the real-option (ROV) in $t$ = 1 by Black & Scholes option is positive and approximately amounts to €2.37 million, which does not imply that this project may be accepted and undertaken immediately. Realistically, this suggests that the investor should hold the option of this project investment and retard the investment, but not abandon the project. It also indicates the implicit value of taking the flexibility and the option into account. The large size of this value can be explained by the high volatility of the project's cash flows (31.44%) and the significant long lifetime of the option (15 years). Note, that this situation is not surprising for such a significant investment. Similarly, to the binomial model, the option value of delay is measured by adding the ROV amount to the project's NPV of the first-year leaves us with the extended strategic NPV equalling: −2.43+2.37=€4.80 million, which suggests that the deferral option value is substantially higher than the investment. Thus, in this case, also, the implication is that the investor would postpone the full project program and decide to operate it in next coming periods until better investment conditions appear. In all, the authors found the results provided by Black & Scholes formula converge to those provided by the binomial option-pricing approach, under certain assumptions.

### 4.3. Monte Carlo Simulation and further investigations

In this subsection, the stochastic Monte Carlo simulation is developed for the analysis of the NPV, for the investment analysis. Hence, in Table 5 below, the project scope and the inputs parameters that lead to implementing the stochastic simulation of the project valuation is defined and identified.

**Table 5**. Parameter used in calibration of Monte Carlo Simulation

| Inputs parameters | Value | |
|---|---|---|
| Initial $NPV_{15y.}$ ($S_0$) | €25.24 | Million |
| Volatility ($\sigma$) | 31.44 | Percent |
| Drift ($\mu$) | [0−1] | Random number |
| Trials | 1000 | Iterations |

*Source:* Computed by authors

Using the approach outlined in the Equation 5 with a normal distribution, thousand unique iterations of the Monte Carlo simulation is conducted to obtain randomly the possible project values and generate a sample of the NPVs of the asset valuation paths. The most important assumption underlying this Monte Carlo model is that the generated variables (i.e. NPVs) are independent. The primary outputs of the Monte Carlo simulation, the parameters and the main descriptive statistics of the NPV of the project over the whole investment period, are presented as follows in Table 6.

**Table 6.** Summary statistics and Risk analysis for the simulated NPV of the Monte Carlo Simulation

| Inputs parameters | Value | |
|---|---|---|
| Average | €14.97 | Million |
| Median | €14.78 | Million |
| Standard Deviation | €5.02 | Volatility, Million |
| Min | €0.90 | Million |
| Max | €29.67 | Million |
| Asymmetry | 0.12 | Skewness |
| Flattening | −0.28 | Kurtosis |
| $VaR^{1\%}$ | €4.58 | Parametric Value-at-Risk at 1% quantile, Million. |
| $VaR^{10\%}$ | €8.47 | Parametric Value-at-Risk at 10% quantile, Million. |

*Source:* Computed by authors

Table 6 displays the primary outputs of the Monte Carlo simulation and presents descriptive statistics and

ISSN 2345-0282 (online) http://jssidoi.org/jesi/
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http://doi.org/10.9770/jesi.2019.6.3(1)

characteristics for the distribution of the one thousand estimated NPV iterations. Overall, within these data, the average (median) NPV is €14.97 million (€14.78 million), which is slightly lower than the estimated NPV in the project analysis that equals to €22.76 million over the whole 15-years lifespan. Dispersion in this NPV is relatively low with a standard deviation of €5.02 million, which is strongly reliant on fuel prices volatility. Across these data, an interesting result is that the NPV is simulated plausibly positive in all the experiments. Therefore, looking at the minimum and maximum values, results of the Monte Carlo iterations reveal a positive minimum value (€0.90 million), thus ranging the NPVs from €0.90 million to €29.67 million (maximum value). Moreover, aforementioned, the asymmetry (skewness) is 0.12, which shows a slightly expanded distribution to the right; and the flattening (kurtosis) stands at −0.28, indicating a slight flattening compared to a normal distribution.
Therefore, these empirical results and the absolute positive value of the simulated NPVs give support to the previous findings, implying that the project will deliver an acceptable NPV and so the relevance of undertaking scrubber technology.
Based on data obtained, the graph of the distribution of frequencies and cumulative frequencies cumulative diagram (probabilities) for the one thousand NPV iterations of the project are drawn in the following chart.

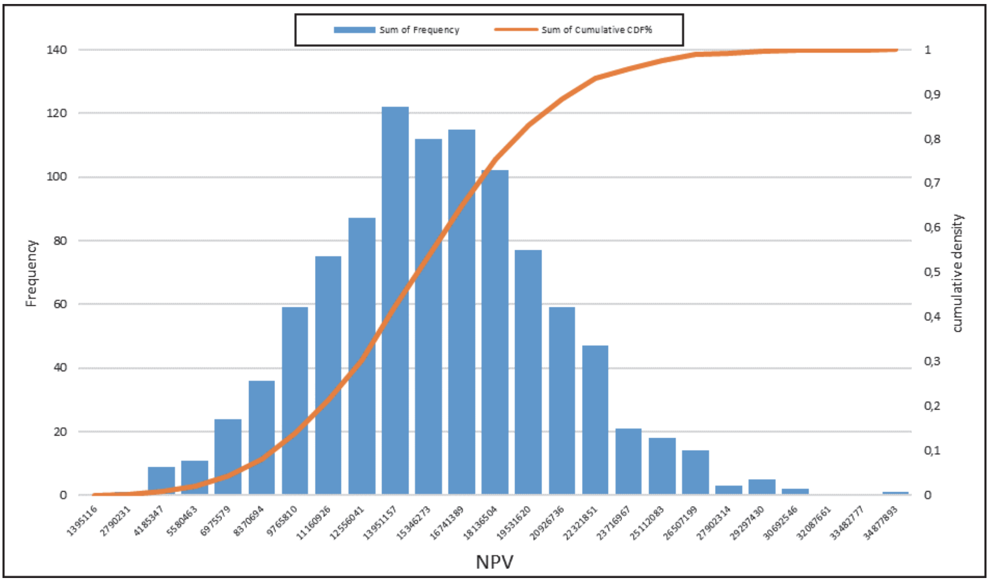


**Fig.2.** Probabilistic distribution of the simulated $NPV_{15y}$

*Source:* Computed by authors

Figure 2 presents the histogram of the Monte Carlo simulation results (frequencies and cumulative distribution function−CDF for the one thousand NPV experiments). As can be seen, there is strong evidence that the frequencies of the project value are normally distributed. Implications of Monte Carlo simulation drawn in Figure 2 show that 60% of the analyzed cases of the NPV are higher than €13 million. Also, it results in a probability of approximatively 22% that the project value will be higher than the initially estimated project value (€22.76).

In the same stream, according to these results and the CDF, risk analysis of the Value-at-Risk indicators at 1-percent and 10-percent quantiles give interesting insights. Hence, the investors would have 99% (90%) confidence that the project expected NPV over 15 years will generate at least an amount of €4.58 million (€8.47 million).

To address the nexus between NPV and ROV for the results obtained from the MCS, the authors process primarily by evaluation the option value (discounted by the risk-free rate) for each iteration and then calculate the average ROV of these one hundred iterations. Simulation results show that the average value of the real-option in the 1st operating year is positive and approximately equals to €1.79 million. Additionally, the option value of delay is computed as the difference between the ROV and NPV (i.e. the value-added) which amounts to a value of €4.22 million. This also supports previous findings; hence, the investor will face the decision to accept the option of the project investment, but with postponing the full project program until better investment conditions appear.

Not surprisingly, the parallel Monte Carlo simulation results, with the same input data of an option traded at 31.44% and 1000 random trials, present very similar findings to those obtained with the binomial approach and the Black & Scholes model. These results are by and large in line and consistent with the main findings of the other approaches on real options analysis.

### 4.4. Discussion

Under the same procedure and assumptions, results had given comparative option values at the first operating year. This gives a perception that the value of the introduction of a new scrubber investment is approximately the value provided by the binomial option-pricing model, the Black & Scholes option valuation model or the Monte Carlo method. Overall, throughout the analyses, the results are reliable and robust to various methodologies and they are not driven by any specific specification.

In contrast, when comparing the binomial results in the first year with the results of Black and Scholes, a small difference appears as shown below in Tables 7, where the three different approaches are compared with the conventional NPV calculation for the first operating year. These first-year results give useful insights to the investors when they gauge the project investment. They also allow them to decide about the best investment timing, i.e. either to launch it *today* or to postpone it for the next following year; to acquire enough guarantee about the uncertainty of the fuel market conditions and the inherently unstable nature and risks of the industry than *today*. Therefore, certainty and visibility are the essences for an investor. Subsequently, with less volatility of the market condition and a clear vision of the industry, the investor/stakeholders can generally decide easier to whether the investment is profitable in term of value creation and in line with the new regulation, or not; and the whether the payback period is satisfying or not. Thus, in presence of good economic conditions such as fewer volatility pressures or low-interest rates, there is no point to decline or postpone the investment.

**Table 7.** ROA Comparison between, Binomial, Black-Scholes and Monte Carlo approaches

| Method of option-pricing | NPV of the 1st-year investment | ROV for the 1st-year of investment | Value added (Difference between ROV and NPV) |
|---|---|---|---|
| Binominal | − 2 432 655.33 | 2353753.78 | 4 786 409.12 |
| Black-Scholes | − 2 432 655.33 | 2366992.83 | 4 799 648.17 |
| Monte-Carlo | − 2 432 655.33 | 1789960.35 | 4 222 615.68 |

*Source:* Computed by authors

Although these option-pricing methods provide similar insights, prior studies have provided some criticisms. Hence, to benchmark our findings, previous studies in the literature (Acciaro, 2014; Glasserman, 2013) have argued that using Black & Scholes method and Monte Carlo simulation are not favourable for investment analysis, especially for the call and put option in ROA. For example, they documented that the Black & Scholes results might not provide a historical normal distribution and the Monte Carlo results are generated from simulations and random numbers, which do not follow a particular trend nor a probability distribution. To that extent, compromises can

**ENTREPRENEURSHIP AND SUSTAINABILITY ISSUES**
ISSN 2345-0282 (online) http://jssidoi.org/jesi/
2019 Volume 6 Number 3 (March)
http://doi.org/10.9770/jesi.2019.6.3(1)

always be made between the three different ROA pricing approaches.

Considering the setbacks mentioned, the binomial option-pricing method could be said to have an advantage over the Black & Scholes and Monte Carlo methods, as it gives flexibility of decision-making over an extended period of investment. In contrast, the other methods focus only on a specific time slot, e.g. in the last year of binomial option-pricing, the investor thereby could decide only if there are favourable conditions to invest, as far as the option to defer the project is no longer possible. In such case, the investor can only invest if the spread value of the two main fuel prices is sufficiently (or expected to) high.

Furthermore, the project value grows as the decision is postponed, due to the implied uncertainty reductions. Nevertheless, the option to defer in the binomial case might involve losses in cash flows and competition. Thus, the decision whether the project will be implemented or not can only be made if these losses are taken into account in the final decision. This suggests that although the conventional investment method does not consider this flexibility, which underestimates the project value, the incorporation of ROA alongside NPV evaluation increases the project estimation accuracy because it gives room for a project deferral. Indeed, over the full investment period, our insights of the conventional investment evaluation indicators (Panel B of Table 1) and the MCS simulated outputs (Table 6) suggest that the project presents a good investment opportunity over a long-term run.

Finally, the ROA approach allows the investor to define the best investment opportunity and decisions with the highest return for regulation compliance. The results indicate that the best short or long-term investment and capital budgeting strategies for the future of maritime companies with significant value can be considered at the early stages of a new ship investment or scrubbers retrofit device for older ships. By assessing different scenarios of the scrubber investment, the ship owners can maximise the benefit of their asset.

**Conclusion**

The objective of this work was to validate methods that can solve investors' challenges of SECA compliance investment decisions to avoid loss and maximise profit using the scrubber abatement technology. The results validate a stochastic approach for assessing real options with a case study for compliance with sulphur regulations. From the analysis made, the application of ROA, in particular, the Binomial approach looks promising. Given this result, a potential investor has the flexibility to re-evaluate the scrubber project and redefine a new strategy if need be.

Getting similar results although slightly different by few points between ROA between the Binomial, Black & Scholes and Monte Carlo models demonstrates that the real options approaches are practical for simulating various investment scenarios with the different situation of future oil prices. This paper contribution is new to the maritime industry that is highly characterised by burdensome uncertainties because it integrated the valuation of the payback period and discounted cash flow of the low sulphur fuel like the MGO versus the scrubber technology option as a popular solution. The findings prove that the Real-Option approach as an investment evaluation method could be a reliable and worthy approach. Investors in the maritime industry can thus rely on and take advantages of this method. The obtained results bear critical policy implications for the industry operators, the regulators of the SBR, and the IMO.

Further work will be directed towards benching marking these results with LNG driven ships. This will create a more precise picture regarding compliance investments and reduce investment decision risks.

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***Aknowledgement***

*This work is in principle linked to the EnviSuM – Environmental Impact of Low Emission Shipping: Measurements and Modelling Strategies project sponsored by the European Regional Development Fund*

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EUROPEAN UNION

EUROPEAN REGIONAL DEVELOPMENT FUND

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## Publication III

**Atari, S.**, & Prause, G. (2018). Risk assessment of emission abatement technologies for clean shipping. In *Reliability and Statistics in Transportation and Communication: Selected Papers from the 17th International Conference on Reliability and Statistics in Transportation and Communication, RelStat'17, 18-21 October, 2017, Riga, Latvia* (pp. 93–101). Springer International Publishing.


I. Kabashkin et al. (eds.), Reliability and Statistics in Transportation and Communication, Lecture Notes in Networks and Systems 36, https://doi.org/10.1007/978-3-319-74454-4_9

# Risk Assessment of Emission Abatement Technologies for Clean Shipping

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**Abstract.** The purpose of this study is recognizing and assessing the existing risks of SECA related investments of ship owners and the consideration of their risk attributes. Complying with the SECA regulations, maritime stakeholders have to choose among different abatement strategies, which are generally linked to high and risky investments. The paper focusses on the evaluation of scrubber technologies and their relationship to other abatement techniques.

Literature review reveals shortcomings in investment risk evaluation among the ship owners operating in emission control areas (ECA). The research fills this gap by presenting a comprehensive compilation of identified risks attributes in an analytical framework together with a risk assessment in the context of HFO and MGO fuel and scrubber related performance indicators comprising CAPEX and OPEX. The results in a classification framework categorize the investment risks and different elements of value at risk (VaR) as well as historical and parametric evaluation of risks. Besides that, this study contributes to new knowledge in the disciplines of green transport and shipping. For future research, the identified risk and investment must be tested in a real business case study and in different scenarios to measure and analyze its performance and efficiency.

The results of the paper are based on empiric activities, which were realized during 2017 in the frame of the EU project "EnviSuM". The empiric measures comprise primary and secondary data analysis, focus group meetings and expert interviews with specialists from shipping sector in BSR.

**Keywords:** Investment appraisal · SECA regulation · Payback period
Value at risk · Scrubber

## 1 Introduction

In order to improve the Maritime's carbon footprint and to make shipping greener, Sulphur Emission Control Areas (SECA) were implemented in Northern Europe which force ship operators to use on-board fuel oil with a Sulphur content of no more than 0.10% [1]. All global SECA regions together represent about 0.3% of the world's water surface and includes the North Sea, the English Channel (together with the coastal waters around USA and Canada) and the Baltic Sea region (BSR) [2]. Strengthened regulations and environmental awareness are of vital importance to stimulate clean shipping but it


I. Kabashkin et al. (eds.), *Reliability and Statistics in Transportation and Communication*, Lecture Notes in Networks and Systems 36,
https://doi.org/10.1007/978-3-319-74454-4_9

has a number of consequences for shipping business, which are linked, directly or indirectly, to their economic decisions [3].

Since 2015, maritime stakeholders are forced to comply with SECA regulations in BSR in order to be able to run legally a shipping business by taking under account the benefits, acceptable risks and the investment costs of the available compliance options. Olaniyi and Viirmae [4] pointed out that SECA regulation compliance costs (transaction costs) are high and can interfere with the effective productivity; so, making compliance choices can be considered as being strategic for whole shipping industry. However, recent results from BSR show that due to low oil price most maritime actors tried to postpone risky investment decisions by using low Sulphur oil [5].

A large number of failures of long lead transport investments stress that risk represents an important element in all investment decisions [6]. This applies especially for investment risks related to recently implemented SECA regulations in BSR. Literature reveals that there is a lack of research on investment risk appraisals for green shipping industries. Thus, this study aims to analyze the capital budgeting practices and to measure the risks for abatement technologies of shipping companies in BSR from a comparative perspective. The research is based on quantitative and qualitative data collection, which took place in the frame of "EnviSuM" project within the last year.

The results show that shipping companies are able to face the SECA investments risks and the estimated payback periods turn out to be rather short. The right choice of bunker fuel together with the corresponding abatement solution positively influences the payback period as well as the related risks, which are assessed with methods of VaR.

## 2 Theoretical Background

### 2.1 SECA Compliance

Since 2015, the SECA regulations in BSR limit the sulfur content of fuel to 0.1% in the emission control areas. Three alternative solutions can be used for compliance (1) switching to low sulfur fuel, (2) installing LNG-compatible machinery or (3) installing an exhaust gas scrubber which all need to be assessed [7, 8]. On the other hand, Patricksson and Erikstad [9] carried out five possible initial machinery concepts, which considered as a main solution: diesel machinery, diesel machinery with a scrubber system, dual fuel machinery, pure gas engines (LNG), and dual fuel ready complete machinery. There are sets of reconfiguration possibilities available also for each alternative solution. If the ship is already running on a low Sulphur fuel with no traffic outside of ECA, and is compliant with the rules, there is obviously no need to install a secondary cleaning method. One might also want to have a look at the annual fuel usage, and compare it to the installation cost and OPEX of a scrubber system.

The crude oil itself is then refined to various products such as MGO, MDO or HFO. The price of crude oil is based on supply and demand. Prices are affected by short-term expectations depending on economic forecasts, production estimates from the oil producing countries, stock levels, seasonality, accidents, weather and force major situations [10, 11]. HFO fuel turns out to be the cheapest, the most popular and available bunker fuel in shipping industry but it usually has Sulphur content of about 3.5%, i.e. it exceeds the limits of SECA regulations.

Most well-known viable bunker fuel types are IFO 180 and 380 which are both intermediate fuel oil and they are often mixed with different portions of residual oil and distillate oil. On the other hand, MGO and MDO are distillate oils with Sulphur content less than 0.1%, thus they are more expensive for production, and i.e. they have a higher price than other bunker oils but they comply with SECA requirements.

The price spread between HFO and MGO play an important role for selecting the right investment in this research. Based on expert interviews, Olaniyi et al. [5] predicted a sharp reduction in HFO demand by 2020 which will be accompanied by a strong increase of distillates fuels such as MGO, MDO, and ULSFO (Ultra-light Sulphur fuel oil). Thus, a scrubber installation together with the use of globally available HFO becomes a viable option for ship owners. The attractiveness of scrubber use increased significantly after MEPC's announcement of the "global fuel Sulphur cap 2020" in September 2016, which limits the global Sulphur content of maritime fuel to 0.5%.

The most commonly and widely used scrubbers are still wet scrubbers which are washing the exhaust gases. The initial investment costs of scrubbers range from €2.5 to €5 million per ship. The costs depend on particular features such as ship capacity, engine and boiler type, scrubber type and new build or retrofit for used ships. Scrubbers need space for installation and extra space for all the equipment consisting of the scrubber, pumps, tanks, engines and a piping system for the wash water allowing the use of scrubbers only in large vessels [10]. Additionally increased operating costs of scrubber have to be considered due to higher energy needs for the scrubber support systems, which cause higher fuel consumption up to 3% or even more [4].

Consequently, ship owners have to concern not only about the availability of compliant Sulphur fuel, but also about the price spreads between bunker fuels, the scrubber investments costs as well as additional operating costs.

## 2.2 VaR in Investment Appraisal

Future operating costs and revenues in the appraisal of investment opportunities are linked to uncertainties and risks, which also apply to scrubber investments. In the case of scrubber investments, the assessment uses usually dynamic approaches comprising net present values (NPV) and payback periods [12]:

$$\mathrm{NPV} = \sum\nolimits_{t=1}^{n} \frac{\mathrm{CF}_t}{(1+r)^t} - \mathrm{Outlay},$$

or introducing $\mathrm{CF}_0$ yields:

$$\mathrm{NPV} = \sum\nolimits_{\mathrm{t}=0}^{\mathrm{n}} \frac{\mathrm{CF}_\mathrm{t}}{(1+\mathrm{r})^\mathrm{t}},$$

$\mathrm{CF}_\mathrm{t}$ Represents the cash flow during period t and the outlay the investment expenditures at period zero. Further variables are the normal lifetime of n periods of a scrubber (usually 15 years) as well as the annual average interest rate of the investment r. The cash flow of period t is calculated according to the following formula:

$$CF_t = V_t \cdot spread_t \cdot (100\% - e\%) - add\_cost_t,$$

with $V_t$ annual fuel consumption, $spread_t$ = HFO – MGO spread in period $t$, e% additional scrubber energy consumption, and additional cost $add\_cost_t$. Under the condition of NPV > 0 the investment is usually considered as favorable since it adds a positive value to the capital of the company [13].

Besides the capital budgeting calculation related to an investment, the paper also considers the risk aspects. The linkage between capital budgeting methods and their related risks will be done by using a VaR approach that describes the capital or percentage of capital loss to be surpassed with an assured probability or words confidence level over a certain period [14]. In the case of a scrubber investment, a 10% VaR (over a horizon of 2 years) of 500 t€ means, that there is a 0.1 probability that the value of the scrubber investment will fall to a value of more than 500,000 € (over a period of 2 years). Since the value of a scrubber, investment depends on the distribution of the price spread between HFO and MGO the spread distribution together with its quantiles have to be calculated by using historical data analysis [15]. The related value of the scrubber investment will be determined by the NPV of net fuel cost savings. The research identifies the VaR of scrubber investments enabling ship operators to quickly determine the risk level of their investments, i.e. the VaR is set equal to the loss on the scrubber investment at the hundreds of X percentile point of the distribution [16]. In theory, the investors seek to maximize the overall amount of return consistent with the rate of risk they feel appropriate [17] (Fig. 1).

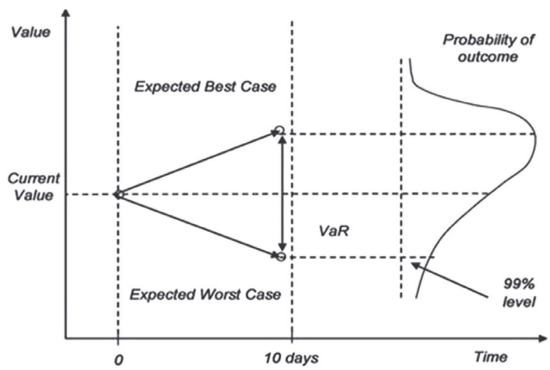


**Fig. 1.** Value at risk for investment appraisal [18].

## 3 Methodology

The research is based on empirical data from different sources. Expert interviews, focus group meetings and case studies have been carried out between March 2016 and May 2017 within the frame of the EU project "EnviSuM". These sources have been used to understand and assess the cost structures of different abatement and scrubber technologies as well as to identify trends and motivations of ship owners associated different scrubber investments decisions. The result of this research is important to the maritime industry investors to make a long-term investment strategy and with model minimize the risks during the process.

The research has been complemented by the analysis of statistical data and historical data over the last four years in order to determine the distribution of the spread between HFO and MGO used in shipping industry. The statistical analysis used data from one of the Estonian bunker fuel producer and conducted several statistical methods comprising correlation analysis, the calculation of empiric probability distribution of the spread value between HFO and MGO of the last four years as well statistical test theory.

The empiric probability distribution of the spread serves as input data for a Value-at-Risk analysis for scrubber investments by associating to each spread the NPV of a scrubber investment with the corresponding spread.

## 4 Data Analysis

The historical data analysis revealed a high correlation between HFO and MGO. The two main variable MGO and HFO of the current research in our study correlated with each other with a positive Pearson coefficient, which is, proves the results (Fig. 2).

Then, based on the sample data, the empiric probability distribution of the spread between HFO and MGO between 2013 and 2017 was calculated and tested. Both tests, the Kolmogorov–Smirnov test as well as the Shapiro-Wilk test confirmed a normality of the distribution of the spread between HFO and MGO (Fig. 3).

The statistical results have been combined with the other empirical data to model the VaR scenario for scrubber installations. The historical approach of VaR used in this research relies on a quantity, which already specified the period. Historical simulation approaches use the actual interval of observation period. The VaR with certain confidence level $\alpha$ is: $Prob(x \leq -VaR\alpha) = 1–\alpha$, If the distribution is bounded below then it means that if the probability density function of the distribution is $f(x)$ and the –L is lower bound of distribution so the model will be [19]:

$$\int_{-L}^{-\mathrm{VaR}\alpha} \mathrm{f(x)dx} = 1 - \alpha.$$

The model then was empirically validated by a case study for a ferry shuttling daily between Tallinn and Helsinki.

## 5 Case Study and Discussion

In the case study, the research focused on ferry ship – RoPax type which operates daily between Tallinn–Helsinki. The engine has a power of 48 MW and a maximal speed of 27 knots. Expert interviews revealed that for this ship a suitable scrubber system requires


**Fig. 2.** The spread of the HFO and MGO (USD) over the period (Calculations by Authors).

a power of 15 MW and the cost for an open loop scrubber is 4 984 000 million € plus installation costs of 0.7 million €. Scrubber installation, construction, testing, commissioning etc. will take about thirty days, which makes ship out of service in those days. In addition to that, annual maintenance costs of approximately 21 t€ p.a. are estimated as well as material costs of about 300€/ton fuel have to be added for chemicals and waste treatment of scrubber residuals.

The considered RoPax ferry has a daily fuel consumption of 60 t HFO, which yields an annual HFO bunkering volume of 60 t × 360 days = 21 600 tons. The data studied covered a period of 962 days where oil prices were observed to measure the spread between two major fuels HFO and MGO and to calculate VaR in the lower 10%, 5% and 1% quantiles of the related distribution of the spread. In theory, the VaR calculations focus on left tail of probability distributions. Consequently the corresponding value of a quantile is calculated by discounted value method, so the fuel cost saving which are set in the case study to $n = 15$ in the means of discounted value over the 15 years, and r = 11% as a risk free value. The results lead to the following Table 1.

| | |
|---|---|
| Mean | 273.4884376 |
| Standard Error | 2.011091842 |
| Median | 270.625 |
| Mode | 344.25 |
| Standard Deviation | 62.37627562 |
| Sample Variance | 3890.79976 |
| Kurtosis | -1.147358631 |
| Skewness | -0.129092029 |
| Range | 254.125 |
| Minimum | 134.5 |
| Maximum | 388.625 |
| Sum | 263095.877 |
| Count | 962 |

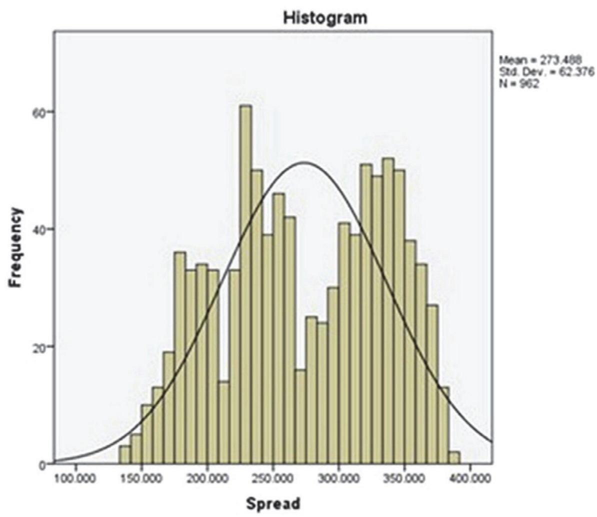


**Fig. 3.** Distribution of HFO/MGO spread (USD) (Calculations of Authors).

**Table 1.** Quantiles and PV of spread distributions earnings during project life time (Calculations by Authors).

| Historical data | Days | Saving money from the fuel difference annually/Euro | Fuel spread | PV (Euro) in 15 years |
|---|---|---|---|---|
| 10% days | 96.2 | 3,356,640.00 | 155.4 | 19,768,031.74 |
| 5% days | 48.1 | 3,143,448.00 | 145.53 | 18,512,494.59 |
| 1% days | 9.62 | 2,748,816.00 | 127.26 | 16,188,415.18 |

The calculations show that the lower 5% quantile of the spread distribution leads to bunkering money of the scrubber investment of the ferry to minimum 3 143 448,00 Euro per year. The savings of bunkering by using HFO and scrubber technology for the ferry will bring with a probability of 95% a benefit of minimal about 18 million Euro over the scrubber lifetime of 15 years compared to using MGO. A further look into the table shows that a decrease of the spread to 127, 26 Euro leads to lower saving but this situation is also related to the lower 1% quantile of the spread distribution.

The crucial point in the calculation is related to the question if the spread distribution continues to be normal distributed with the same statistical parameters over the next year so the scrubber investment is not risky. Furthermore it has to be mentioned that the calculation of the NPV depends on the two variables spread and HFO price, i.e. NPV = NPV (spread, HFO). In order to be able to calculate the NPV only on the base of the spread a linear regression has been realized. The R square fits of the model was calculated to be 93% so the underlying model enjoys a high level of explanation.

## 6 Conclusion

The current scholar paper validates an academic approach for assessing risk for compliance to Sulphur regulations. The developed VaR model demonstrates that historical data analysis is a practical approach for simulating investment scenarios with different situation of oil prices of the future. As well as integrating and valuing the NPV and discounted cash flow of the MGO vs HFO. All these together with Scrubber options as a popular solution. The approach allows defining the best investment opportunity and making best decision with highest return.

The model tested on the real case and shows the higher risk time of the investment on scrubber with new VaR approach. It shows if the spread of fuel on a certain amount what will be the value at risk of investment. So the model proves if we assume the price for scrubber and services will constant and the spread prices are normally distributed then the model can work for measuring the value at risk of investment.

The results generally indicate the best investment strategies with a significant value and can considered at the early stages in a new ship orders as a new investment or investment on scrubber as retrofit devices for older ships. The model also can be used in different scenarios beside of scrubber and it can be the comparison of different fuel types and evaluates the risk of investment.

Future possibility of this research can be comparison of LNG, methanol, ethanol, CNG and other types of fuel or air purification technologies as a solution to each other to find the VaR of investment with analysis of historical data of each fuel spread with other solution or technologies.

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## Publication IV

Olaniyi, E. O., **Atari, S.,** & Prause, G. (2018). Maritime energy contracting for clean shipping, *Transport and Telecommunication Journal*, Volume 19, Issue 1, 31–44, DOI: 10.2478/ttj-2018-0004

*Transport and Telecommunication, 2018, volume 19, no. 1, 31–44*
*Transport and Telecommunication Institute, Lomonosova 1, Riga, LV-1019, Latvia*
*DOI 10.2478/ttj-2018-0004*

# MARITIME ENERGY CONTRACTING FOR CLEAN SHIPPING

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To reduce the Sulphur emission from shipping and ensure clean shipping, a number of Sulphur Emission Control Areas (SECA) were enforced in special areas around the globe. From 2015, in SECA, ship owners are not allowed to use fuel with more than 0.1% Sulphur content. One of the major concerns for the SECA regulation is that maritime stakeholders have had to take into consideration the costs as well as the tolerable risks of their compliance investment options. Besides that, low freight rates have increased the competition and had caused financial pressure on ship owners so that lower capital reserves and low credibility levels limit the manoeuvring space for investment activities.

The indications from BSR after 2015 showed that the low fuel price has eased the economic effects of the SECA regulation and as a result, most ship owners have delayed their investment decisions. Even though the postponement of emission abatement techniques seems to have reduced the compliance expenses for SECA, they, however, did not improve the position of shipowners relative to their competitors. Consequently, new policy instruments to stimulate innovation, to raise competitiveness and to comply with the new environmental regulations are needed. It would have been easier to hedge fuel price volatility and offer maritime logistics services for a lower price, but to be able to ensure sustainable results in long-term, maritime stakeholders must be ready to device astute strategies that can propel them to unparalleled advantage.

This research first appraised the investment risks and payback period associated with the scrubber using different capital budgeting methods. It further illustrated the Maritime Energy Contracting (MEC) model as a market mechanism for the delivery of a cost-effective emission reduction using the scrubber technology as well as an instrument to realise a competitive advantage for ship operators. The results are empirically validated by case studies from BSR.

**Keywords:** Investment appraisal, VaR, Scrubber, SECA, Energy Contracting, Business model

## 1. Introduction

The motivation for environmental regulations is mostly related to improving health and quality of life (Lindstad *et al*., 2015). Shipping activities are responsible for up to 15% of the world's anthropogenic pollution of sulphur oxides (SOx), nitrogen oxide (NOx) emissions and some other harmful elements. These emissions are dangerous to human health and can travel long distances (Abadie *et al*., 2017). SOx emissions specifically cause acid rain and generate particulate matter (PM), which is the root-cause of respiratory and cardiovascular diseases (Notteboom, 2010). This why maritime transportation showing efforts to reduce the impact of health-damaging emissions and ensure cost efficiency in the activities that can curtail it (Lindstad and Eskeland, 2016). Stricter emissions and bunkering fuel requirement regulations by IMO on sulphur emissions was enacted in the MARPOL, Annex 2 where Sulphur emissions from ships are not allowed beyond 0.1% since 2015 (IMO, 2016). SECA regions are about 0.3% of the world's water surface and consist of the North Sea, the English Channel (plus the coastal waters around USA and Canada) and the Baltic Sea region (BSR) (Notteboom, 2010). The sulphur restrictions on another dimension involve a global standard that currently allows 3.5% sulphur content from fuel and ship emissions outside SECA and has stipulated that from 2020, only 0.5% of sulphur emissions will be allowed on all water surfaces worldwide (IMO, 2016). Other sulphur related regulations are the Chinese regulation for coastal waters (published in December 2015 and came into effect in 2016) (North, 2016) and the EU directive 2005/33/EC.

The first two years of the SECA regulation have shown that predictions on the negative implications of the regulation are wrong and the low fuel cost and freight rates have played a huge role in ensuring this (Olaniyi, 2017). Consequently, dependence and pursuit of abatement technologies have declined. Nevertheless, the incoming 2020 global sulphur cap seems to have escalated the urgency of solutions for compliance and clean shipping globally. Stakeholders are now frantic about the options available and economic optimisation of their decisions (Atari and Prause, 2018), although there are speculations that, pushing the 2020 regulation to 2025 will save the maritime industry between $30 billion and $50 billion annually (Platts, 2016). There are also studies that insisted that applying a costly global approach to coastal emission areas might bring more negative result than positive especially in terms of fuel efficiency and increasing CO2 emissions concerns (Lindstad *et al*., 2015). Their argument is that a continual use of HFO at high sea will ensure the cooling effect of global shipping in a 20 years' perspective and further ensure the 100-year CO2 equivalent emissions at 35–40% of CO2 emissions, which can reduce the speculated annual cost of sulphur regulation from 10 billion to 4–5 billion USD. Even at this, the truth is that the sulphur regulations have come to stay and the global limit take-off may not be reviewed forward (Abadie *et al*., 2017). Maritime stakeholders must now look for innovative ways of obeying the sulphur regulations in the face of possible excess fuel demand that cannot be met by the industry (Wiśnicki *et al*., 2014) and at the same time ensure reduction of their compliance costs.

Olaniyi and Viirmae (2016) explained that the compliance costs for SECA regulation are expensive and have the possibility of interfering with the production, turnover and profits of the companies involved. With the high unpredictability nature of fuel prices, compliance strategies must involve experimental and revolutionary ingenuity on the part of the stakeholders. In this regard, this study pools two objectives, first, it presented a case study of the Maritime Energy Contract (MEC) business model, a market mechanism for the delivery of emission reduction the scrubber technology that cushions the economic effect of the SECA regulations. Second, because the scrubber technology is an integral element in the MEC model, the study calculated the investment risks and payback period involved in the scrubber technology to validate the scrubber investments and to fill the investments risk appraisal gap for ship owners.

Both quantitative and qualitative data approaches were used to collect data from April 2016 to May 2017 in the frame of "EnviSuM" - Environmental Impact of Low Emission Shipping: Measurements and Modelling Strategies project. Through the study of different cases, the authors seek to answer these research questions. What are the risks involved in scrubber retrofit? How profitable is the scrubber investment for the ship owners? What are the cost and the benefits of the MEC model for the ship owners? Results show that the estimated payback period of the scrubber installation on the ship is short because the use of bunker fuel together with a corresponding abatement solution such as the scrubber will positively influence the payback period as well as reduce the risks involved. The MEC model is a stimulus that can be used for value creation and the realisation of competitive advantage in the maritime industry for a new entrepreneurial process.

Work is arranged in the following way: the next section is the literature review on maritime and SECA Compliance, the Value-at-Risk (VaR) in Investment Appraisal and Energy Service Contracting (ESC). The third section presents the method of data gathering and analysis of results. The next section highlighted the results and the last section is the conclusion.

## 2. Literature Review

### 2.1. Maritime and SECA Compliance

There are different approaches to satisfy the SECA requirement. The popular choices for ship owners are fuel switching from heavy fuel oil (HFO) to marine gasoline oil (MGO), the installation of LNG engine followed by the use of the LNG fuel and installation of the scrubber into the exhaust of the ship to remove the sulphur from the emission (Acciaro, 2014; Daduna and Prause, 2017). All these approaches have their pros and cons and different ship owners have built their SECA regulation compliance strategy around one or more of them. Most of their decisions are borne from the contemplation between the capital expenditures and the OPEX of the compliance investments (GU and Wallace, 2017). Mostly, the factors that influence the various compliance methods ship owners make include: (a) fuel prices (b) the area in which the ship usually operates and the regulation it is accountable to (c) the number of days at sea and (d) vessel's lifespan (Abadie *et al*., 2017).

Fuel cost and ultimately fuel consumption is an integral part of shipping because it makes up to about 50 - 60% of voyage operational cost (Stopford, 2009). Now, the supply and demand of fuel appear to be balanced around the world, but regional surpluses and shortages are projected to occur towards and after 2020 (CE Delft, 2017). Another factor that affects the operational costs of a vessel as stated by Gu and Wallace (2017) is sailing pattern of a vessel e.g. routes, vessel speed and type of vessels. That was why at the onset of SECA, some ships have been replaced by bigger vessels to slow steam, also some routes were also increased or reduced (Olaniyi, 2017; Gu and Wallace, 2017).

Most compliant fuels are in fact blends of several refinery fractions. At the refinery, crude oil is refined to different fractions of oil that are used for bunkering such as Marine Gas Oil (MGO), Marine Diesel oil (MDO) and the Heavy Fuel Oil (HFO) (Brynolf *et al*., 2014). The MGO and MDO are distillates and more expensive but are SECA compliant. The HFO, on the other hand, is the lower fraction, a residual oil that was the preferred bunkering fuel until SECA (Acciaro, 2014). Even though through hydrodesulphurisation (partial hydrogenation of the fuel to remove sulphur), HFO can be refined to meet the new requirement, it is a very expensive refinery process and only the mega fuel producers are able to take such investment risk (CE Delft, 2017). The price of bunker fuel fluctuates as a response to supply and demand and are usually determined by factors like short-term expectations from forecasts, production estimation from the oil-producing countries, stock levels, seasonality, accidents, weather and sometimes war (Bergqvist *et al*., 2015; Hämäläinen *et al*., 2016).

Another option for SECA compliance is using Liquefied Natural Gas (LNG), to curtail the ship emissions during combustions. The LNG is widely accepted because it also fulfils other regulations such as the CO2 and the NOx and is the cheapest of the fuels (Bas *et al*., 2017). However, there are many challenges that prevent a faster development of the LNG fuel such as the availability of the infrastructure for its bunkering, the need to store the fuel and distribute at a particular temperature that requires special storage and costly retrofit and LNG-fuelled ships (Brynolf *et al*., 2014). All the issues increase the costs of distribution depending on the distance from ports to the LNG import terminals (Bas *et al*., 2017). Although reports are showing that the LNG infrastructure is developing fast worldwide, for example, according to CE Delft (2017) LNG projects are already increasing in North America and most part of Asia like China, South Korea, Japan, and Singapore. Yet, the LNG is not finding a wider use outside shipping. All these setbacks are said to be related to the regulatory framework, the economic capacity and sustainability, technical practicality and the public-social responsiveness (Bas *et al*., 2017; Notteboom, 2014).

A third option, scrubber technology, is an option that allows the use of the HFO by “scrubbing” out the sulphur emission from the exhaust of the ship up to 98% (Abadie *et al*., 2017). With an installed scrubber, the vessel can still run with HFO and remain SECA complaint. Costs of the scrubber installation depend on the ship size, engine size, and an additional cost of fuel for energy, chemicals and waste disposal (Lindstad *et al*., 2015). The age of the ship is used to determine if an investment in scrubber retrofit is right or wrong (Abadie *et al*., 2017).

The scrubber technology has two major technologies, which is the dry (popular for industrial use), and the wet scrubber technologies (Wiśnicki, 2014). The wet scrubber has been developed into the open loop, (uses only seawater), closed loop (uses the reaction of caustic soda and fresh water) and hybrid (combined both the opened and the closed technology) (Abadie *et al*., 2017). The open loop has been demonstrated to be cheaper and smaller making it more desirable because it takes less space for installation but has sparked several debates on the ecological implication of using a device that flushes chemical back into the sea. Running a closed loop scrubber is the most expensive because of the broad treatment of the closed loop circulating water (Lindstad *et al*., 2015).

The actual costs of the scrubber i.e. its operating costs and maintenance costs depend largely on the ship’s size, engine capacity, broiler type and the scrubber technology itself (Bergqvist, *et al*., 2015, Jiang *et al*., 2014; Abadie *et al*., 2017) and ranges from 3 to 6 million € for a ship. Because of its weight, when installing the scrubber, extra fortifications are made to stabilize the ship and ensure the scrubber is in an upright position (Brynolf *et al*., 2014). Apart from the space, the scrubber itself takes up, extra space is further needed for the accessories like the pumps, tanks, engines and a piping system for the wash water (Bergqvist *et al*., 2015). It takes between 4-8 weeks for the installation process. Operating the scrubbers increases the fuel consumption rate of the engine at 1-5% (EMSA, 2010). These are some of the contributing factors that discourage ship owners from choosing the scrubber installation option.

According to Atari and Prause (2018), the scrubber lifespan is about 15 years and a payback period (called a breakeven point) of 2 to 5 years. The payback period calculation is one of the methods used to evaluate the worth of the scrubber investment to ensure the payback period is not greater than the scrubber's lifespan (Bergqvist, *et al*., 2015). This calculation prevents a situation whereby it is impossible to recover the purchase cost after discounting the cash flow (Ross, *et al*., 2002).

The price difference between MGO (which is a higher) and HFO is called the spread value and this spread is used to assess the economic efficiency of abatement technologies including scrubber investment (Jiang *et al*., 2014). A higher spread encourages the scrubber installation on the ship. Thus, in the scrubber installation, the cost of the MGO is directly proportional to the ship owner’s savings (OECD/ITF, 2016). Olaniyi *et al*. (2018a, 2018b) projected a high reduction in HFO demand by 2020, along with increased demand for distillates fuels and other hybrid fuel like the ULSFO (Ultra-light Sulphur fuel oil). Another angle of this projection according to WoodMacKenzie (2016) is that the decrease in HFO demand from the 2020 cap could push an increase in the spread from 2020. These predictions are also supported by the International bunker fuel association 2018 report, which has more or less projected the scrubber forward as a more rewarding option from an investment angle.

Many studies have proposed different approaches to making the choice for compliance ranging from the multi-criteria approach (Ren and Lützen, 2015), stochastic programming (Schinas and Stefanakos, 2012), cost-benefit analysis (Jiang *et al*., 2014) and costs function of emission abatement alternatives (Lindstad *et al*., 2015). For the newly built ship, it is most common to make a comparison between the investment annuity and the anticipated fuel cost savings (CE Delft, 2017). While the popular methods, especially for retrofits, is the evaluation of the payback time, Patricksson and Erikstad (2017) put forward sets of reconfiguration possibilities for ship owners whose ships are already running on a low Sulphur fuel with no traffic outside of SECA. They insisted that when a ship is already using SECA compliant fuel and plies within SECA there is no need for an abatement technology installed on the ship. However, they did not do a comparative analysis of the fuel usage on yearly bases nor compare the costs to the abatement costs for such ships. All studies point to one fact, which is that there is still a need for a better way to determine the best choice for regulatory compliance.

### 2.2. Value-at-Risk (VaR) in Investment Appraisal

To explore the market orientation of the SECA regulation, the authors' estimated and appraised the investment risk associated with the scrubber technology. Aforementioned, investments in scrubber technology are expensive and highly risky for ship owners because the efficiency of a scrubber investment depends on the price spread between MGO and HFO. High price spreads yield short payback periods whereas decreasing price spreads increases payback time and are linked so to higher risks.

Classical instruments for financial investment are studies in the area of capital budgeting and the most important concept represents the Net Present Value (NPV) which can be calculated by using the parameters of the investment (Herbst, 1998):

$$\text{NPV} = \sum_{t=1}^{n} \frac{CF_t}{(1+r)^t} - Outlay, \quad (1)$$

or $CF_0$ yields:

$$\text{NPV} = \sum_{t=0}^{n} \frac{CF_t}{(1+r)^t}, \quad (2)$$

where:

*$CF_t$*: cash flow during period (t),
*Outlay*: investment expenditures at period zero,
*n:* the normal lifetime of n periods of a scrubber (usually 15 years),
*r*: the annual average interest rate of the investment.

The cash flow of period (t):

$$CF_t = V_t \cdot spread_t \cdot (100\% - e\%) - add\_cost, \quad (3)$$

where:

$V_t$: annual fuel consumption,
$spread_t$: HFO-MGO spread over a period (t),
*e%:* additional scrubber energy consumption,
$add\_cost_t$: additional cost.

An investment is assumed to be favourable if the expected NPV is greater than 0. Based on the NPV approach, the determination of the payback period of an investment is possible by looking for the shortest period n* so that NPV (n*) > 0 (Hull and White, 1998). In both constructions, the NPV as well as the payback period revealed that the results of the investment appraisal depend on the price spread between MGO and HFO during the considered time so there is an associated risk with a scrubber investment, which has to be investigated more detailed.

An appropriate instrument for the control the risk of decisions and investments is through a value-at-risk (VaR) analysis where the VaR shows the capital or percentage of capital loss that should be expected over a particular period with a guaranteed probability or word confidence level (Angelidis and Skiadopoulos, 2008). It describes what loss a particular market volatility will encounter at a certain probability (Linsmeier and Pearson, 2000). Thus, it shows the likelihood and rate at which a loss might occur in any real investment. Using Dowd (2007), the investment in scrubber will be determined by the price spread between the HFO and MGO along with the spread distribution quantiles analysis from a historical figure. In other words, if the spread means is higher than 500 t€, then a 10% VaR of spread in a span of 2 years connotes a 0.1 probability that a scrubber investment of 5 000 000 €, for example, would increase to a higher value by 500,000 € for that 2 years. The NPV of Net fuel cost savings will determine all investment value associated with the scrubber. The study recognizes that the VaR of scrubber investments will help shipowners assess their investments risk level for example; the VaR will be comparable to the loss of the scrubber investment. This is at the 100s of X percentile level of the normal distribution (Jorion, 2006). In concept, it relates to how the stakeholders look for ways to ensure return on their investment and proportionate to the level of the risks involved (Baker and Haslem, 1974).

### 2.3. Energy Service Contracting

It is not possible to separate policy from the economic significance of compliance because policy framework determines the economic outcome of any industry (Sys *et al*., 2016) which makes the investment appraisal and associated risks imperative. As explained by Horbach *et al*. (2012), regulation is a part of the determinants and drivers of environmental innovation - regulatory push/pull effect. Usually it occurs not as the first introduction of a product cut but as a market or technology - diffusion as seen by the scrubber technology where manufacturing companies are adopting a technology used by chemical companies for the ship to expand their perspectives and capture value that would lead to a visible lessening of regulatory burdens (McGrath, 2010). The economic performance of such technology determines the sustainability of the regulation (Plouffe *et al*., 2011).

The production of SECA complaint fuels involves high risks and investments, the same goes for the costs for abatement technologies. Statistics indicate a decrease in scrubber installations due to low bunkering prices, and low freight rates (Olaniyi, 2017). It is clear that ship owners are unwilling to take a risk that ties down funds that they would otherwise prefer to run their ship. Apart from the unreliable fuel costs and supply, a continuation of this development will likely diminish the impact of a strong stimulus and determinant for innovation and technological push and further lead to the market failure of the scrubber technology (Horbach *et al*., 2012). Chesbrough (2010) explained that until the monetary value of a technology is available as a form of the commodity in any form, its usefulness would remain dormant.

Energy contracting models (EC) commonly used for energy efficiency and supply in the housing sector and stationary and complex buildings like hospitals (Sorrell, 2007). The adoption of energy contracting models in the maritime sector using the scrubber technology to optimise the scrubber technology is quite new and has been discussed by Olaniyi, Gerber and Prause (2018). This study is particularly positioned to submit a solution to the current negative reactions and criticism regarding the economic implication of the scrubber installation and operational costs among other implications such as the technology itself, ecological and environmental factors of using the technology (Lindstad *et al*., 2015; Abadie *et al*., 2017).

EC is a comprehensive energy service model commonly used to optimized energy cycle cost in the housing (Bleyl, 2011) mostly used in Germany, Austria, France, Netherlands, Belgium (Goldman *et al*., 2005). The common models of energy contract are the Energy Supply Contracting (ESC) that delivers basic needed energy and used in services that are short in capital investments and the Energy Performance Contracting (EPC) that ensures energy savings (Sorrell, 2007). Already some other sectors are adopting this model as seen in water treatment and supply, wastewater disposal, industrial gases supply, service management in telecommunications and security (Bleyl, 2011). Concentrating on the ESC for this study, the energy provider becomes responsible for both the installation of the technology as well as the delivery of the needed energy at a reduced price and the same time reduces the costs of operation for both the provider and the recipient company (Bertoldi *et al*., 2006). The ESC model is a customized process for singular customers where the total costs are determined by the associated risks or terms of the contract (Goldman *et al*., 2005).

## 3. Methodology

The study is established through empirical data from expert interviews, focus group meetings and case studies carried out in the frame of EnviSuM - Environmental Impact of Low Emission Shipping: Measurements and Modelling Strategies project sponsored by the EU regional development fund carried out between April 2016 and May 2017. Data were used to first evaluate the cost constructions of different abatement technologies including the scrubber technology. Through the data gathered, the tendencies and enthusiasms of the ship owners regarding scrubber investments were also determined. From the case studies involving the proposed model and investments calculations, constructs of real synopsis were projected for readers' conviction as described by Siggelkow (2007). Two case studies were presented.

The first case involved the statistical evaluation of historical fuel price data from 2013 and 2017 and fuel price predictions between 2017 and post 2020 to determine the distribution of the spread between HFO and MGO within these years. The analysis carried out, comprised correlation analysis, the empiric probability distribution of the spread value between HFO and MGO of the last four years and statistical test theory. The observed probability distribution of the spread was used as input data for a Value-at-Risk analysis for the scrubber investments. Each spread was associated with the NPV of a scrubber investment.

The second case described the intricacies involved in the adaptation of the energy contract into the maritime industry. Since there are already several energy servicing companies, a desktop research was first carried out to learn energy contracting and related success determinants. Five ESCO practitioners with retrofit experience of at least 10 years were interviewed. The interviews were made to pinpoint significant features of energy contract and to examine their deportment on the on a successful MEC project or contract. The interview analysis is presented as a description for a model contract based on thematic categorisation by Miles *et al*. (1984) and Kvale (2008). The analysis of the overall cost of the MEC model was then made using current real-life figures.

## 4. Results and Discussions

The application of VaR approach requires the determination of an underlying probability distribution. In the case of the scrubber installation, the risks depend on the price spread of the fuel so that a statistical evaluation of historical fuel price data from 2013 and 2017 and the spread between HFO and MGO within these years is done. Based on this analysis, the empiric probability distribution of the spread value between HFO and MGO of the last four years has been tested by statistical test theory.

### 4.1. Risks Analysis of Scrubber Investments

The historical time series from 2013 of the fuel prices of MGO and HFO in US$ reveals a high correlation with each other with a positive Pearson coefficient. The spread between MGO and HFO depicts a graph which is shown in Figure 1.

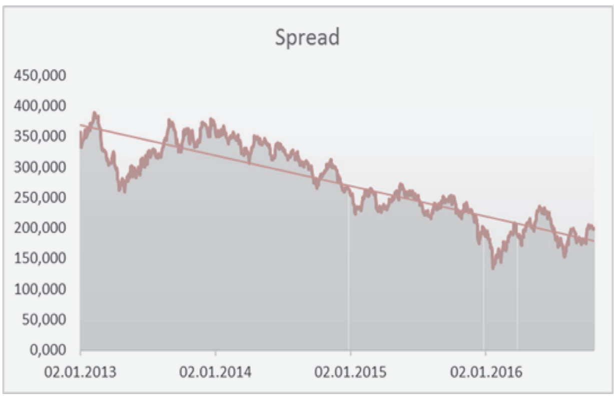


*Figure 1*. The spread of the HFO and MGO (USD) from 2013 (Computed by Authors)

The histogram of the spread values from 2013 based on 962 values led to an empiric distribution of the spread that has been analysed with the Kolmogorov–Smirnov test as well as with the Shapiro-Wilk test. The results proved that the spread between HFO and MGO is normally distributed with a mean of about 273.5 USD and a standard deviation of about 63.4 USD as shown in Figure 2.

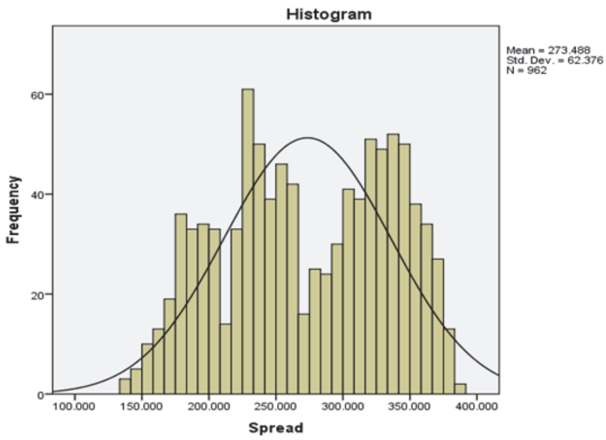


*Figure 2.* Distribution of HFO/MGO spread (USD) (Computed by Authors)

With the statistical results of the empirical data, it is now possible to conduct a VaR analysis for a scrubber installation on a ship. The property of the spread to be normal distributed allows calculating the quantile which can be used assess the risks of the spread during the investment period. The VaR with definite confidence level $\alpha$ is calculated as $Prob\ (x \leq -VaR\alpha) = 1 - \alpha$. If the distribution is bounded below by –L with probability density function $(x)$ the model yields (Hendricks, 1997):

$$\int_{-L}^{-VaR\alpha} f(x)dx = 1 - \alpha. \quad (4)$$

In order to make the following calculations compatible with Euro calculations the lower 10%, 5% and 1% quantiles of the underlying distribution of the spread are expressed in Euro and correspond to spread values of 155.4 €, 145.53 € and 127.26 €. The applications of these results are studied and empirically validated with the case of a RoPax ferry as follows:

*The RoPax Ferry Case*

The RoPax ferry enjoys an engine power of 48 MW and a maximal speed of 27 knots that plies Tallinn and Helsinki. From experts' interviews, it was gathered that for this particular ship, a suitable scrubber system would require a power of 15 MW. Calculations were made for suitable open loop scrubber that will cost about 4,984,000 million € with additional installation costs of 0.7 million €. The off hiring days that involves activities such as the scrubber installation, piping, testing, and commissioning will take about thirty days, annual maintenance costs of about 21 t€ p.a. and material costs of around 300€/ton fuel (for chemicals and waste treatment of scrubber residual) were all added and calculated.

Case RoPax ferry has a daily fuel usage of 60t HFO that amounts a yearly volume of 60t x 360 days = 21 600 tons. The HFO – MGO spread within 962 days of oil price data were used to calculate the VaR in the lower 10%, 5% and 1% quantiles of the linked distribution of the spread. In concept, the VaR analysis usually focuses on the left side of the probability distributions. Subsequently, the discounted value method is used to analyse the resultant value of the quantile so that fuel costs saving of n = 15 (discounted value over the 15 years of scrubber lifespan) and r =11% is set as a risk-free value. The results are as follows (Table 1):

**Table 1.** Quantiles and Present Value (PV) Of Spread Distributions Earnings during Project Lifetime

| Historical Data | Days | Annual Savings from difference in Costs of Fuel / Euro | Fuel Spread(Euro) | PV (Euro) in 15 years |
|---|---|---|---|---|
| 10% days | 96.2 | 3 356 640.00 | 155.4 | 19,768,031.74 |
| 5% days | 48.1 | 3 143 448.00 | 145.53 | 18,512,494.59 |
| 1% days | 9.62 | 2 748 816.00 | 127.26 | 16,188,415.18 |

Source: Calculations by Authors

Results show that a lower 5% quantile of the spread distribution will lead to a cost of bunker fuel up to 3,143,448 million € per year. The savings that will be made from using the HFO and the scrubber for the ferry with a probability of 95% will yield at least 18 million € within the 15 years scrubber lifespan as against if the ship was using MGO. Furthermore, from the figures, a spread decreased to 127.26 € will yield a lower saving because the lower 1% quantile of the spread distribution was used. If the trend of a higher spread distribution continues to be normal then the saving will increase.

The authors recognised that the NPV used in this study is dependent on two factors: first, the fuel spread and second the HFO price, i.e. NPV = NPV (Spread, HFO) as a function. Accordingly, a linear regression was used to calculate the NPV on the bases of the spread. The R square fit of 93% confirmed a high model fit. This result is on the assumptions that for the scrubber investment not to be risky, the spread distribution must remain normal with the same statistical parameters for the future years.

*The Long-Term Fuel Price Scenario*

Using a real-life future forecast from the International Bunker Fuel Association report, the authors constructed two different scenarios of savings using the scrubber.

First, from 2019, there is a likelihood of a sharp drop in demand of HFO as bunker fuel together with the expectation of an MGO price recovery up until 2023, when the spread is expected to close up again. Using this forecast, a very high MGO-HFO spread from the 2019-2013 forecasts will be 340 € that will produce a shorter payback period time as presented in Table 2:

**Table 2.** Scrubber Payback Period from 2019 (Forecasted Oil Price)

| HFO | MGO | Earnings from Installation of Scrubber (€) | Scrubber price (€) | Payback Period |
|---|---|---|---|---|
| 526 | 866 | 6 060 056 | 5 684 000 | Less than a year |

Source: Calculations by authors

Second, according to the same report, in 2024 the fuel price is expected to decrease and the MGO-HFO spread will reduce to 157.25 € which will be approximately around 11% of the VaR quantile. Using the same parameters and calculations, the total savings from using the scrubber technology will be 3,444,767.80 million € per year, a 9% lower value from the from VaR results from the historical fuel price data (Table 3). This also validates the VaR model.

**Table 3.** Quantiles Value of Spread Distributions with 2024 (Forecasted fuel price)

| Forecasted Data | Days | Annual Savings from difference in Costs of Fuel (€) | Fuel Spread (€) |
|---|---|---|---|
| 11% days | 105 | 3 444 767.80 | 157.25 |

Source: Calculations by authors

The valuation and integration of the NPV and discounted cash flow of the MGO as against the HFO established and validated the Scrubber options as viable investment prospect that is able to yield high returns for the investors. The evolved VaR used with the real-life scenario further helped to demonstrate the high or low-risk time or risk value of the scrubber investment for a particular duration. Forasmuch, as the assumption that the scrubber costs and services remain constant and that the MGO-HFO spread is evenly distributed this model can serve as a classical instrument to measure the value-at-risk of the scrubber investments.

## 4.2. Maritime Energy Contracting (MEC)

From the investment and risks analysis, the authors confirmed that the scrubber investments have a lot of potentials to be a profitable venture for the ship owners, however, existing empirical data (Olaniyi, 2017) shows a low number of scrubber installations because of the decline in the price of fuel. This has put a lot of pressure on fuel producers who must step up to produce the demanded volumes and types of needed fuel. Unfortunately, a critical challenge for the traditional fuel producers is to cope with the lack of existing production capacity so that they are forced to upgrade their refining process to meet up with their major markets. Olaniyi and Viirmae (2016) highlighted the high investments sums for fuel producers which are needed to produce low sulphur oil. The access to appropriate credits seems to be complicated for the majority of fuel producers due to low oil price and unclear developments in maritime fuel markets.

Even after having recognized the analysis of scrubber investments together with the related risk assessments, the majority of ship owners who are unwilling or even not able to make the financial commitment for scrubber installations which coincidences with the situation of the fuel producers whose product may no longer be marketable. In the end, to reduce the investment risks for ship owners and to ensure business continuity for fuel producers a new business model is thus proffered.

MEC is a revolutionary and feasible new business model for maritime fuel producers that can afford them the opportunity to metamorphose from the everyday fuel producing to energy producing and servicing. This will involve using the concept of the ESC for their energy (fuel) delivery. In theory, it involves fuel producers going into contract with ship owners by pre-financing the scrubber installation, accepting the responsibility of regular maintenance and at the same time supply HFO. In the end, the fuel producers supply energy solutions to ship owners through scrubber installation. All energy service packages are provided at the full expense of the fuel producers in accord to the contract specifications. In return, the fuel company is paid in full for the fuel supplied along with marginal costs of the scrubber costs for servicing and maintaining the scrubber. They guaranty the quality assurance for the use of the scrubber as well. Both companies share the cost savings described previously. The contract will secure energy costs savings that ensure that the reimbursement from the delivered energy during the contract period will comprise of the investment and risk costs already provided by the fuel producers.

Needless say that for the eradication of sulphur emission in shipping, the challenging issue borders on the execution of the compliance objective of the SECA regulation. The BSR has seen admirable compliance actions but because it is related to expensive and risky venture, its achievement is still not 100 percent. This has plagued it with many uncertainties especially as it has to do with the compliance options. Sadly, the low fuel cost has seemingly rendered most of the first investments somewhat pointless. However, with the 2020 global sulphur cap in view, fuel usage will certainly increase along with demand for low sulphur fuel. The maritime sector will likely witness a drastic change in its markets. This change might increase a likelihood of fuel cost or result to a scarcity in low Sulphur fuel supply.

MEC pools two goals: it lowers SECA compliance costs for the ship owners and fuel producers' and ensure SECA compliance. Elements of the MEC implementation consist of a project design (development, planning, contract scrubber installation, fuel supply, maintenance, maximisation, user incentive, quality monitoring and controlling, price bond and risk and technical contracting).

*The Long-Term Fuel Price Scenario*

In housing, the ESC contracts usually take up to 10 years. This is because buildings are immobile assets so they could be subjected to longer contracts. However, with ships, the conditions are different. First, they are not stationary assets, more so they move from different zone and region to another, which sometimes involves different countries. Under these conditions, circumstances are likely to change significantly, it is therefore suggested to limit the contract duration within 3 to 5 years, adjustable at intervals as well as client specific.

MEC pricing will subsist on two pricing element. (1) The cost of energy (fuel) supply. (2) Financing of the scrubber as an asset that includes supplementary services within the procured contract period also called the adjustment. Each element reviewed periodically (i.e. monthly, bi-monthly, quarterly or yearly) to accommodate arising impelling or unavoidable issues. Thus:

**Energy Supply:**

$$AP_{HFO}\,[€/mt] = AP_{0HFO}\,[€/mt] + FS\,[€/mt] - FS_0\,[€/mt] \tag{5}$$

where:

$AP_{HFO}$: Current fuel price at contract time/metric tonne of fuel (€/mt)
$AP_{0\_HFO}$: Baseline price from official statistics at the period €/mt
$FS$: Price for fuel supply per metric tonne €/mt
$FS_0$: Baseline price for fuel supply in a particular period (i.e. 01-06/2017) €/

**Non-Energy (Adjustment):**

$$LP\,[€/a] = LP_0\,[€/a] \times \left(0.5 + (0.3 + \frac{I}{I_0}) + (0.2 \times \frac{L}{L_0})\right), \tag{6}$$

where:

- *LP*: New fuel price at contract time per annum €/a,
- $LP_0$: Baseline fuel price from official statistics at the period €/a,
- $I_0$: Current price index for consumer goods taken as the baseline,
- *I*: Current price index for consumer goods proportionate to $I_0$,
- *L*: Average salary index at the contract period,
- $L_0$: Average salary index for setting as starting point for the contract.

The adjustment calculation takes into account the cost of the asset, inflation and modifications in the employee's salary. In principle, every year 50 % of the price is stable, where 30% is dependent on prevailing inflation (consumer good index). The remaining 20% will depend on salary costs build-up, which will affect the provided services like maintenance and monitoring during the contract period.

Along these lines, the cost of MEC will be as follows:

$$\boldsymbol{MEC\ Price} = Energy\ supply\ +\ Scrubber\ costs\ \ +Adjustments \tag{7}$$

In the sequel, the MEC model will be empirically validated with the same RoPax ferry case like in the VaR approach.

*MEC Validation*

Using already discussed RoPax ferry ship, the baseline cost is set as the price of fuel (MGO) the cruise was using as at 6th Oct 2017 at 585.08€/t. The annual cost for MGO will be the cost of MGO per tonne multiplied by the daily MGO consumption and multiplied by the number of operating days i.e. 585.08€/mt x 60mt/day x 360 days = 12, 637,796.30 € per year. The cost of HFO is 347.27 €/mt which yields an amount of 7,500,969.99 million €.

To calculate an adjustment for November 2017, the adjustment costs are based on the current Estonian consumer goods index at 01.01.2017 (TE, 2017a), the average salary index at 01.01.2017 (TE, 2017b) and a fictive fuel price of 450€/mt from 01.01.2017. Totalling 2,062, 592.24 €/a ≈ 28 % of HFO price/mt.

The annual scrubber costs will be the sum of the 10% additional scrubber fuel/annual (p.a.), 2% additional scrubber service p.a., 15 years depreciation of scrubber p.a. and interest costs p.a. Totalling 897, 881.00 €/a ≈ 12% of HFO price/mt. Thus, the cost savings and sharing is calculated below and is depicted in Figure 3:

$$MEC\ Price/tonne = (347.27\ \ +\ 41.67\ +\ 97.24) = 486.2€/mt$$
$$Cost\ saving\ for\ Shipowner\ = 585.08 - 486.2\ =\ 98.9€/mt$$

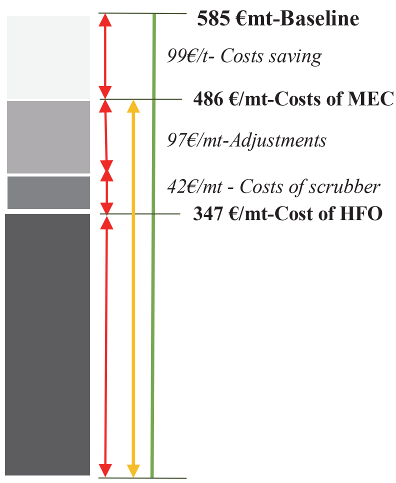


*Figure 3*. Cost savings in MEC model (Authors' calculations)

By considering the results of the case study it turns out that the shipowner will get the fuel for 99€ per ton cheaper compared to the MGO price whereas the fuel production company will enjoy an additional adjustment of 97€ per ton which generates additional revenues for the fuel company. Another major benefit for the ship-owner is the exchange of the CAPEX to the OPEX that signifies an indirect investment for them. The fuel producer changed his business model from a pure production company towards a service company, which offers now scrubber related services including financing. In comparison to the huge production plant investment for the fuel producing company, the new investments sums for the scrubber installations are smaller and better to handle.

In addition to the financial agreements, a MEC for maritime industry must include other contract conditions in order to become successful. Expert interviews revealed already a list of core points that must be part of MEC agreement between the shipowner and the fuel producer:

- The scrubber as the asset of the fuel producer throughout the agreed contract term.
- Descriptions of financial terms i.e. *Maritime Energy Contracting Price, Scrubber costs, Energy price, Adjustments.*
- Prevailing Interests' rates.
- Provisions for rebates or compensations.
- Terms for penalty and reimbursement for defaults.
- Terms for non-energy elements during the contract period.
- Guidelines for planned or unexpected termination.
- Other matter arising such as *the border of property, Space for scrubber and retrofit, Quality of supply, Additional energy consumption.*

In this regard, using the scrubber option for the MEC concept is a pivotal concept that can be targeted to yield distinctive prospects in the maritime sector because it is practicable and offers a fresh perspective to innovation in an unreliable environment such as the maritime sector. The alliance arrangement will guarantee the following:

(a) SOx emissions reduction.
(b) Scrubber installation costs savings.
(c) Risk transfer to fuel producer such as investment risks, technical risks, market risks, and performance risks, leaving only ‘‘zero risks" to the ship owners.
(d) Jobs creation.
(e) Lowered operational costs for the ship owner that allows the shipowner to focus on shipping activities, which is transportation (this helps them to remove energy efficiency issue from day to day operations).
(f) Free technology and expert support for the ship owners.
(g) Promises a higher margin for both companies.
(h) Customised contracts.

The MEC concept bears many advantages for fuel producers as well as for ship owners because it allows fuel producers to continue producing their traditional product whereas the shipowner gains a competitive advantage due to lower energy costs in shipping which generates additional margin in the transport competition. Yet, the MEC concept leaves open the question of whether the central desulphurisation in fuel producer's plant is more favourable to the decentralised desulphurisation through the scrubber on a ship from an ecological or economical viewpoint. The financial advantage of the scrubber approach is its scalability, which takes into account the credibility situation in the maritime sector.

## 5. Conclusion

Compliance with SECA regulation is related to investment decisions for shop owners as well as for maritime fuel producers. In the case of a scrubber installation, the Value-at-Risk model is able to demonstrate the risks associated with the scrubber including changes in payback time. Through the scrubber technology, a navigation can be set to mitigate or reduce the economic effect of the SECA regulation on ship owners or maritime fuel producers who do not have the capacity or the will to invest in refinery upgrade.

The research further discussed the concept of a Maritime Energy Contract as a dynamic market instrument to deliver emission reduction and to generate competitive advantages for the shipowner and the fuel company. Authors recognised the MEC as a decentralised method of the SECA regulation compliance for the fuel producers who eventually may have to find a way to make refinery upgrade investment in the long term, but would need to be proactive on the short term while they wait for the appropriate time to commit to a much higher investment.

With applicable political support, the ESC model which has been tried over a long period and in different countries can enhance the maritime sector by refocusing the attention of the maritime stakeholders to using the scrubber technology as providing ‘‘energy solutions’’. This way, a sustainable private sector in the maritime sector will emerge and score a much-desired technology-push-effect for the EU.

The limitation of the study borders around using only HFO/MGO spread scenario without including other sources of fuels, which can be an interesting angle for further research. There can be a comparative study on the VaR for the LNG, methanol, ethanol, CNG and other types of fuel or air purification technologies used to provide a holistic solution bank for the maritime sector.

## Acknowledgements

This work is linked to the EnviSuM – Environmental Impact of Low Emission Shipping: Measurements and Modelling Strategies project sponsored by the European Regional Development Fund.

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ISSN 2585-6901 (PDF)
ISBN 978-9916-80-286-1 (PDF)