Master's thesis

NTNU
Norwegian University of Science and Technology
Faculty of Engineering
Department of Marine Technology

Sindre Rudi

A Real Option Approach to Value Flexibility in Ship Design

Master's thesis in Marine Technology
Supervisor: Stein Ove Erikstad
June 2020

NTNU
Norwegian University of
Science and Technology

Sindre Rudi

A Real Option Approach to Value Flexibility in Ship Design

Master's thesis in Marine Technology
Supervisor: Stein Ove Erikstad
June 2020

Norwegian University of Science and Technology
Faculty of Engineering
Department of Marine Technology

NTNU
Norwegian University of
Science and Technology

Abstract

This thesis evaluates whether implementation of flexibility in ship design is a suitable approach to handle an uncertain future. Flexibility exploits opportunities and reduces downside risk. However, a flexible design is worthless if the flexibility is never exercised. Hence, in order to determine if implementation of a flexible design should be conducted, techniques for flexibility valuation are needed.

Options are providers of flexibility, and thus, real option analysis is suggested as a method to estimate the expected value of flexibility. A differentiation is made between real options *in* and *on* systems. In general, *on* options represent operational investment decisions, while *in* options often require technical understanding and have a higher degree of complexity. Methods applied for real option valuation include three-building methodologies, analytical solutions and Monte Carlo simulation.

An illustrative case study for an MR2 product tanker is conducted. Upcoming GHG emission regulations are recognized as an essential future uncertainty. New emission regulation implies a risk of increased costs, and the case study evaluates measures to handle future emission regulations. A reactive approach to changes is measured up against a proactive approach. Regulation compliance is obtained through retrofitting if necessary, and the retrofit is considered to be a reactive approach to future emission regulations. In turn, a proactive approach is represented by the implementation of a LPG dual fuel engine to obtain fuel flexibility. The latter is the provider of the option to perform a fuel switch, but a dual fuel configuration implies a higher initial investment. In order to determine if flexibility should be implemented, the expected value of the two approaches must be compared.

Monte Carlo simulation is used to simulate expected future earnings for the product tanker. The simulations are done by the use of a mean-reverting stochastic process. Available historical earnings data are investigated in order to estimate the parameters of the stochastic process. In addition, future fuel price are simulated. This is done in order to estimate the value of the real option to switch fuel. Further, a cash flow analysis of earnings and lifecycle costs is established. Net present value is used to compare the difference in the expected profitability between a flexible and a inflexible design. The results of the case study indicate that fuel flexibility is likely to be valuable. Future regulations that require a shift away from VLSFO are expected. If such expectations become reality, fuel flexibility outperforms the reactive approach of retrofitting. Though, there is a possibility a shift from VLSFO never is needed. If so, LPG needs to be a consistently cheaper fuel alternative than VLSFO for the flexible design to be valuable.

Implementation of flexibility in ship design is a strong candidate to increase the profitability in shipping. However, the degree of future uncertainty is an important factor. A distinction is made between flexibility that increases either the versatility or the retrofittability. During times of high uncertainty, it is argued that retrofittability may be favorable. This is due to the risk that a versatile flexibility is remained unused. Thus, when considering fuel flexibility, a comparison of versatility and retrofittability would be an interesting topic for further work.

Sammendrag

Denne avhandlingen evaluerer om implementering av fleksibilitet i skipsdesign er en passende tilnærming til å håndtere en usikker fremtid. Fleksibilitet utnytter muligheter og reduserer nedsiderisiko. Imidlertid er et fleksibelt design verdiløst hvis fleksibiliteten aldri utøves. For å bestemme om implementering av fleksible design skal gjennomføres, er det nødvendig med teknikker for verdsettelse av fleksibilitet.

Opsjoner er tilbydere av fleksibilitet, og derfor foreslås analyse av realopsjoner som en metode for å estimere den forventede verdien av fleksibilitet. Det skilles mellom realopsjoner *i* og *på* systemer. Generelt representerer opsjoner *på* systemer operasjonelle investeringsbeslutninger, mens opsjoner *i* systemer ofte krever teknisk forståelse og innehar en høyere grad av kompleksitet. Relevante metoder for verdsettelse av realopsjoner inkluderer trebygningsmetoder, analytiske løsninger og Monte Carlo-simulering.

En illustrativ casestudie for en MR2 produkttanker er utført. Fremtidige miljøreguleringer tilknyttet utslipp av klimagasser anerkjennes som en viktig fremtidig usikkerhet. Nye miljøreguleringer innebærer en risiko for økte kostnader, og casestudien evaluerer tiltak for å håndtere fremtidige miljøreguleringer. En reaktiv tilnærming til fremtiden måles opp mot en proaktiv tilnærming. Overholdelse av fremtidige miljøreguleringer kan oppnås ved å utføre etterinstallasjoner, og etterinstallasjoner anses for å være en reaktiv tilnærming. En proaktiv tilnærming er i casestudien representert ved implementering av drivstoff-fleksibilitet i form av en motor som kan gå på både lavsvovel-drivstoff og LPG. Sistnevnte gjør det mulig å bytte til drivstoffet som til enhver tid er billigst, men en slik konfigurasjon innebærer en høyere investeringskostnad. For å avgjøre om fleksibilitet skal implementeres, må den forventede verdien av de to tilnærmingene sammenlignes.

Monte Carlo-simulering brukes for å simulere forventet fremtidig inntjening for produkttankskipet. Simuleringene gjøres ved bruk av en tilbakevendende stokastisk prosess. Tilgjengelige historiske inntjeningsdata er undersøkt for å estimere parameterne for den stokastiske prosessen. I tillegg blir fremtidige drivstoffpriser simulert. Dette gjøres for å estimere verdien av realopsjonen av å kunne bytte drivstoff. Videre etableres en kontantstrømanalyse av inntekter og livssykluskostnader. Nåverdimetoden brukes til å sammenligne forventet lønnsomhet til et fleksibelt og ufleksibelt design. Resultatene fra casestudien indikerer at drivstoff-fleksibilitet trolig vil være verdifullt. Fremtidige reguleringer som krever at lavsvovel-drivstoff fases ut er forventet. Hvis slike forventninger blir virkelighet, utkonkurrer drivstoff-fleksibilitet alternativet om å etterinstallere. Det er imidlertid en mulighet for at et skifte fra lavsvovel-drivstoff aldri er nødvendig. I så fall må LPG være et gjennomgående billigere drivstoffalternativ enn lavsvovel-drivstoff for at drivstoff-fleksibilitet skal være verdifullt.

Implementering av fleksibilitet i skipsdesign er en sterk kandidat for å øke lønnsomheten innen skipsfart. Imidlertid er graden av fremtidig usikkerhet en viktig faktor. Det skilles mellom fleksibilitet som øker versatilitet eller fleksibilitet i form av å klargjøre fremtidige etterinstallasjoner. I tider med stor usikkerhet er det sannsynlig at sistnevnte kan være foretrukken. Dette skyldes risikoen ved at en versatil fleksibilitet aldri blir brukt. I forbindelse med drivstoff-fleksibilitet vil en sammenligning av versatilitet og klargjøring av etterinstallasjoner være et interessant tema for videre arbeid.

Preface

This thesis is the final part of my Master of Science degree with specialization in Marine Systems Design at the department of Marine Technology (IMT), Norwegian University of Science and Technology. The thesis was written during the spring of 2020. The workload corresponds to 30 ECTS, in which 30 ECTS equals a full study load for one semester. The thesis builds on work done in the project thesis, which was written during the autumn of 2019.

I would like to thank my supervisor, Stein Ove Erikstad, for guidance and advice during the semester. I would also like to thank Tore Haugen for his valuable insights and guidance.

10.06.2020, Trondheim
Sindre Rudi
Sindre Rudi

Master's thesis in Marine Systems Design
Stud. techn. Sindre Rudi
"A Real Option Approach to Value Flexibility in Ship Design"
Spring 2020

Background

Environmental regulations are becoming stricter in order to lower the environmental impact of shipping. However, implementation periods and definitions of the given regulations are yet to be concretized. This, in combination with fluctuating fuel prices and emerging technologies, makes the future operating context of deep-sea shipping uncertain. Implementation of flexibility in ship design is therefore suggested as an approach to handle future uncertainty in deep-sea shipping.

Overall aim and focus

The overall aim of the master's thesis is to evaluate whether flexibility in ship design is a suitable approach to handle future uncertainty.

Scope and main activities

The candidate should presumably cover the following main points:

1. *Describe relevant theory, methods and applications of marine systems design related to ship design complexity, uncertainty and valuation of flexibility.*
2. *Evaluate different methods to model an uncertain future.*
3. *Determine how a real option approach can serve as a decision tool by valuing flexibility in ship design.*
4. *Evaluate the market and the future operating context of the product tanker segment.*
5. *Perform an illustrative case study for a product tanker in order to investigate if implementation of flexibility is a suitable approach to face an uncertain future.*
6. *Discussion and conclusion.*

Modus operandi

At NTNU, Professor Stein-Ove Erikstad will be the responsible advisor.
The work shall follow the guidelines given by NTNU for thesis work.

Stein-Ove Erikstad
Professor/Responsible Advisor

Contents

List of Figures

List of Tables

1 Introduction

In light of the global coronavirus outbreak, recent times illustrate to what extent international shipping is affected by circumstances that hardly can be predicted or controlled. Uncertain factors affect the freight rates and expenditures with great volatility. Additionally, environmental regulations and emerging technology are in the near vicinity. Shipowners must take the reality of rapid change into consideration while facing an uncertain future operating context. Thus, flexibility in ship design may be a key factor to remain cost-competitive and value-robust.

1.1 Background

Conventional ship design has traditionally followed the methodology of the design spiral, as described by Evans (1959). This methodology is thorough while considering the technical aspects of a ship. However, the methodology does not describe any ways to account for future uncertainty. If the future uncertainties in shipping are not accounted for during the present ship design, the additional expenses during the operational life can potentially accumulate to high numbers. An essential future uncertainty relates to the environmental regulations of shipping. The IMO has adopted a strategy that aims to lower the average carbon intensity by 40 % within 2030 and 70 % within 2050, based on a 2008 baseline. In addition, the total amount of GHG emissions from shipping is aimed to be reduced by 50 % within 2050 (IMO, 2014). These goals are ambitious, yet necessary, but the goals come at a cost. The goals require shipping to speed up the uptake of new technology in order to lower the emissions. However, new and unproven technology affects the value of investments and projects, and thus, it implies uncertainty regarding economy and reliability. Additionally, it is not clear which technologies that may become the new standard in shipping. Regarding fuel, there are several uncertain factors which are affected by each other. These factors include, but do not limit to, technology-readiness level, availability, scalability, fuel prices and uptake frequency of different technology. Further, the environmental regulations are yet to be defined and concretized, and the implementation strategy remains vague and uncertain.

A possible way to handle the uncertainty is through implementation of flexibility in ship design. Flexibility can be defined as what was written by McManus & Hastings (2007): *"The ability of a system to be modified to do jobs not originally included in the requirements definition."* In other words, flexibility can be seen as the capability to be prepared for change. Thus, a flexible system is a provider of proactivity instead of having a reactive approach to changes. However, there is a balance between achieving flexibility and including unnecessary configurations. Hence, in order to decide to what degree a system should be designed with flexibility, the expected value of the given flexibility should be quantified.

1.2 Objective

The overall aim of this thesis is to evaluate whether flexibility in ship design is a suitable approach to handle future uncertainty. Through this evaluation, different system configurations can be evaluated in terms of how well the given configuration face an uncertain future. Thus, identification of future proof vessels can be conducted. Simultaneously, configurations that provide a ship with flexibility without adding sufficient value can be eliminated.

1.3 Approach

Initially, approaches and methods to handle design stage uncertainty in marine systems are evaluated. Following, the valuation of flexibility is discussed, focusing on finance related real options. Further, methods to model an uncertain future is elaborated, before different methods of flexibility valuation through real option analysis are presented. Following, a case study is performed for a MR2 product tanker, in which the product tanker market and future uncertainties are discussed. Specifically, the case study evaluates if fuel flexibility is a suitable approach to handle future uncertainty. Finally, based on the case findings, implementation of flexibility in ship design is discussed.

2 State of the Art

This section describes relevant theory and methods related to complexity, uncertainty and flexibility in marine systems design. Following, financial options theory is elaborated together with the concept of real options.

2.1 Understanding Complexity

The concept of complexity in systems engineering is used in order to fully understand the system of interest, and complexity have been defined by various researchers. Simon (1991) proposes that the complexity of a system can be described using a hierarchical approach. Going top-down, a system can be decomposed until it is fully understood. Kolmogorov (1983) states that there is a correlation between complexity and the amount of information that a system contains. A complex system implies that much information is needed in order to describe the given system. Thus, an increase in complexity consequently increases the amount of information needed for a sufficient description of the given system. Combining these definitions, complexity can be defined as the amount of relevant information needed in order to properly define a system (Gaspar et al., 2012). Complex systems may complicate the process to obtain the relevant information. Thus, methods to systematize the information can be an efficient tool.

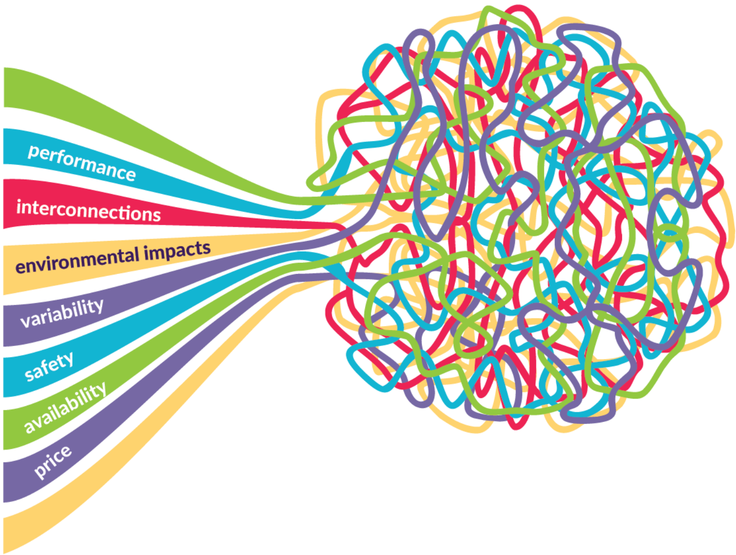


Figure 2.1: Tangled information in systems of high complexity, which can be chaotic if not categorized.

2.2 The Ship as a Complex System

The ship as a complex system is a well-established terminology in marine systems design (Gaspar et al., 2012). Traditionally, the core of the design task has been a tradeoff between technical and economic objectives (Evans, 1959). However, Hagen & Grimstad (2010) discuss whether the system boundaries of ship design should be extended by adding new design parameters. The reason is the need of being able to handle the current challenges of the shipping industry, including implementation of new technology and emission reduction. Singer et al. (2009) propose a method to handle the current increasing degree of complexity in ship design. Rather than performing an iteration process from a single ship, like in the design spiral of Evans (1959), set-based design is suggested. Essentially, the method can be described as followed. First, a feasible design space is defined, and further, multiple alternatives within the given design space are identified. Finally, by valuing how well each feasible design alternative meet pre-determined criteria, a final design can be proposed.

A well elaborated method to handle complexity in ship design is described by Rhodes & Ross (2010a); Rhodes & Ross (2010b). The studies propose to divide complexity into five separate aspects: Behavioral, structural, contextual, temporal and perceptual. The behavioral and structural aspects are traditional aspects in marine systems design, while contextual, temporal and perceptual aspects are introduced in order to widen the boundaries of marine system design. By dividing the complexity aspects, the categorization process of all available information in a system is simplified. Thus, relevant information about a system is easier to retrieve when needed. In addition, new available information is easier implemented in the marine system design. Table 2.1 and Figure 2.2 explain the five aspects of complexity.

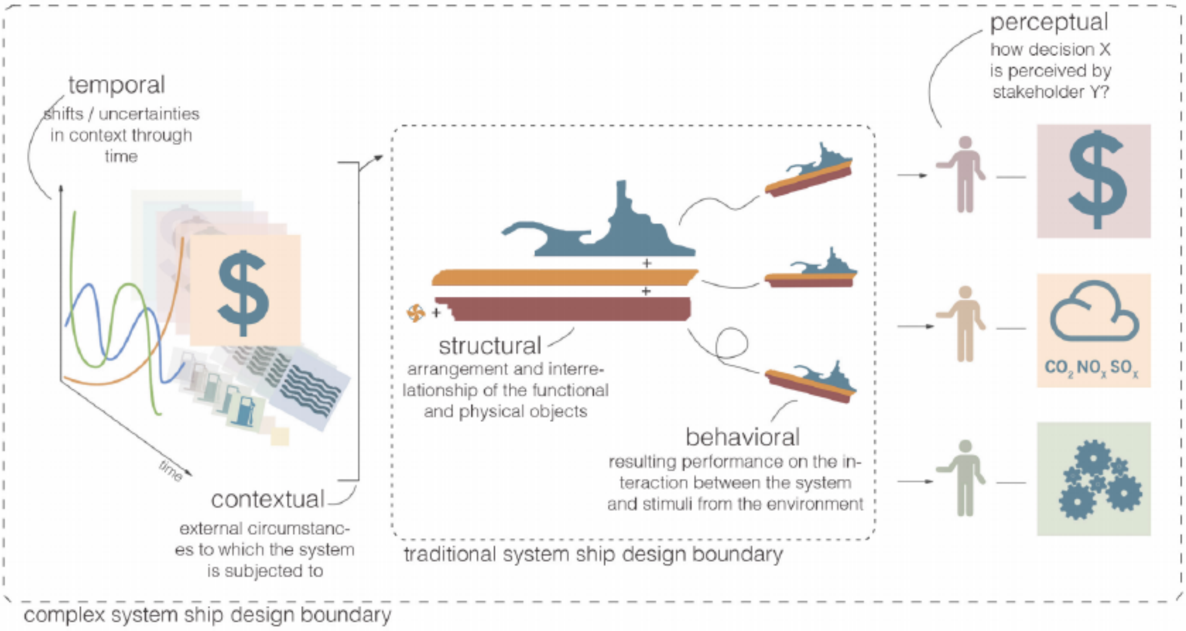


Figure 2.2: Aspects in complex system ship design. The differences between traditional and complex system ship design boundaries. (Gaspar et al., 2012).

Table 2.1: Explanation of the five aspects of complexity in ship design. Contextual, temporal and perceptual complexity aspects are introduced by Gaspar et al. (2012).

Aspect	**Explanation**
Structural	Describes the interaction between components, and the ship is modeled as a system of subsystems, each with interacting components.
Behavioral	A functional breakdown by mapping form and function which is handled by technical analyses of e.g. stability, propulsion, seakeeping etc. Additionally, it describes the interaction between stimuli and behavior, and the stimuli can either be internal or external.
Contextual	External factors that are hard to control, but that should be considered. Typically regulations, rules and market variables as fuel cost, building cost. The aspect also adds elements as risk and fleet estimation data.
Temporal	Describes different scenarios due to uncertainties, and describes "what if"-situations with corresponding solution.
Perceptual	System interpretation through the perspective of different stakeholders, typically answering "How does stakeholder A perceive decision Y?". KPIs to evaluate decisions, but different KPIs for different stakeholders.

2.3 Uncertainty and Risk

Uncertainty in this thesis is as defined by McManus & Hastings (2007) who describe uncertainty as "things that are not known, or only known imprecisely". The future operating context of shipping is uncertain, and by this it is meant that shipping is affected by external factors outside of the control of the shipping companies. The external factors are represented in the contextual aspects, and the external factors interacts with the behavior of a system as illustrated in Figure 2.3. Further, a different system behavior due to context change may also imply an uncertainty in the temporal aspect. Table 2.2 below characterize different types of uncertainty.

Table 2.2: Different types of uncertainty (Lin et al., 2013).

Type	Description
Exogenous	Uncertainties that are independent of project decisions.
Endogenous	Uncertainties that can be managed through project decisions.
Hybrid	Uncertainties that to a certain degree can be influenced by project decisions.

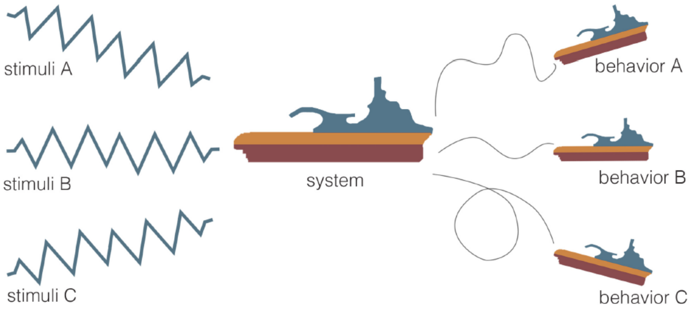


Figure 2.3: Different behavior of a system due to contextual changes (Gaspar, 2013).

One objective of current ship design should be to handle uncertainty in the best possible manner. Hence, the uncertain factors of ship design must be identified. If not, expensive surprises may occur. Uncertainty often implies risk, but it is important to remember that uncertainty is not limited to cause losses. If uncertainty is met in an adequate manner, uncertainty can create new opportunities and correspondingly gain profit. Unexpected changes can create benefits that were not imagined by the original designers of a system. Hence, when facing an uncertain future, it is important to not limit the focus to mitigate the risk, but also to take advantage from the opportunities. Erikstad & Rehn (2015) investigate methods and strategies for handling uncertainty related to marine systems design. Table 2.3 is based on their work and shows various types of uncertainties in marine systems design.

Table 2.3: Examples of various uncertainties in marine systems design.

Uncertainty	Example
Economic	Fuel price, freight rates, incentives, interest rate, supply and demand
Technology	Energy efficiency improvement, alternative fuels, wind-assisted propulsion
Regulatory	Emission reduction and ballast water treatment
Physical	Port size, water depth, bridges, weather, sea ice

In general, the uncertainties in Table 2.3 can be identified as exogenous uncertainties. Thus, the uncertainties are independent from project decisions. As mentioned, these contextual uncertainties often are related to downside risk, but they can also be the source of upside potential. This is especially applicable for the economic and technological examples. As an example, the uncertainty in fuel price can of course lead the price both up and down. The regulatory and physical aspects can also be the source of upside potential if a shipping company is better prepared for coming changes than their competitors.

2.3.1 Risk Management

In terms of managing downside risk, proper risk management is necessary. Harrington & Niehaus (2003) describe an acknowledged process of risk management involving four key steps, regardless of the type of risk in consideration. The steps include risk identification, risk evaluation, risk management and risk monitoring. The process is now further elaborated.

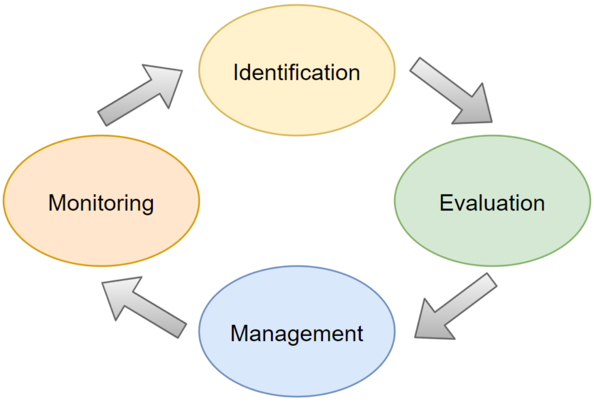


Figure 2.4: The continuous process of risk management.

The first step in the process of risk management is risk identification, and the purpose of this step is to identify all significant risks that can affect the value of a company or project. Common methods for risk identification include, but do not limit to, PESTEL and SWOT analysis, the interview method and the use of brainstorming sessions. A PESTEL analysis describes external factors that affect the performance of a company or project, and the different aspects are given by each letter of the analysis: Political, economic, social, technological, environmental and legal. SWOT on its side examines four areas of the business environment: The strengths, weaknesses, opportunities and threats. Further, the interview method concerns the process to involve subject matter experts to identify risk through interviews. In other words, risk identification requires an overall understanding of the business, together with knowledge about how uncertain factors may affect a project.

Risk evaluation often involves quantifying the exposure of a company or project towards the risk factors identified in the previous step. Typically, this involves measuring expected loss or consequence of unwanted events. Common methods of risk evaluation include, but do not limit to, failure mode, effects and criticality analysis (FMECA), measuring the value-at-risk (VaR) and performing sensitivity analyses. FMECA describes all possible unwanted events (failures) of a system together with the effect of the given failures, and a criticality analysis is performed by taking the product of frequency of occurrence and level of severity. The VaR is a measure of financial risk over a specified time frame, typically used to determine the occurrence and magnitude of loss making. Further, sensitivity analysis means to evaluate how changes of uncertain parameters affect the performance of a project. A sensitivity analysis can be describes as the generation of what-if scenarios. As an example, a sensitivity analysis can determine how the internal rate of return (IRR) of a project is affected if the interest rate increases by 1 %.

Erikstad (2017) suggests four main strategies to handle risk, including insurance, diversification, flexibility and information. The increase of information in a project may decrease the uncertainties in profitability calculations, and thus, increase the accuracy of the expected value of different pathways. Insurance is a commonly used measure by paying a premium to transfer parts or all of the risk to someone else. Diversification to reduce risk follows modern portfolio theory. Briefly explained, by dividing among several assets of the same expected value, the variance and thus also the risk, is reduced. However, this is under the assumption that there is no correlation and independent returns. The principle of diversification can be transferred to marine systems by providing design flexibility, which is elaborated in subsection 2.4.

Risk monitoring is applied in order to evaluate the component performance of the already identified risks and also the suitability of the methods that are used to handle the given risks. Additionally, risk monitoring includes the process to identify new risks as the exposure to risk may change during the lifetime of a project. Thus, the process of risk management is an iterative and continuous process.

2.3.2 Risk Preferences and Utility

Decision making under uncertainty typically aims to maximize the expected value. However, how a stakeholder perceive risk is decisive for the outcome in certain situations. Different risk preferences can be categorized in three groups: Risk averse, risk neutral and risk prone. To explain the differences, a simple scenario is illustrated in Figure 2.5. An investor can invest an equal amount of money in either Project A or Project B. Project A has two possible outcomes, either two or zero cash units, each with a probability of 50 %. Project B is certain to return one cash unit. In other words, the expected value of both projects are identical and equal to one cash unit.

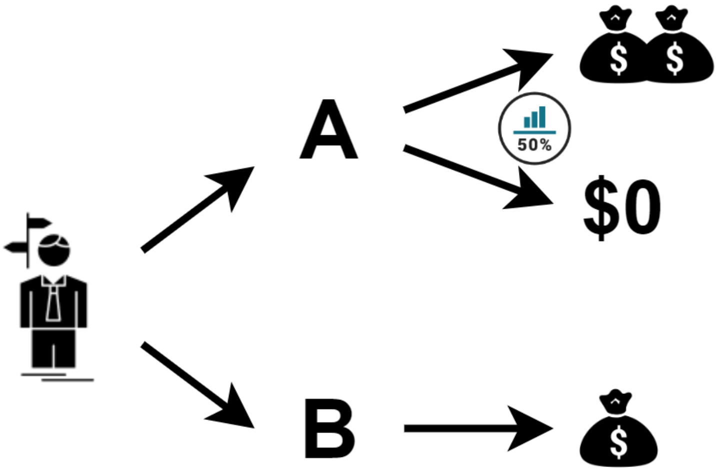


Figure 2.5: Two project investments, Project A and Project B, with the same expected value.

A risk neutral investor only looks at the potential outcome of the different projects and choose the project with the highest expected value. Someone who is risk prone prefers the gamble over the expected value, while an investor who is risk averse prefers the expected value of a gamble over the gamble itself. In this case, the expected value is identical, and the risk neutral investor may choose any of the two projects. A risk averse investor will choose Project B, while the risk prone will choose Project A.

An alternative approach to decision making under uncertainty is to maximize the utility rather than the expected value. Utility is a dimensionless measure meant to describe preferences. If case A has a higher utility than case B, then case A is preferred. It is assumed that people are greedy and always prefer more to a good than less, in addition to that each additional unit of a good gives less utility than its predecessor (Wijst, 2013). These two assumptions defines a concave utility function, which corresponds to the utility function of a risk averse investor. In other words, a single dollar provides a broke person with a higher increase in utility than what would be the case for a billionaire.

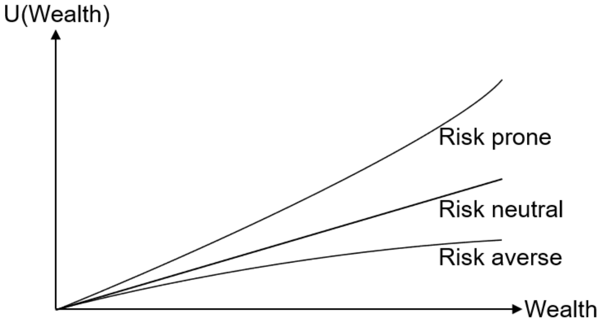


Figure 2.6: Utility function of wealth for different risk preferences.

2.4 Flexibility in Ship Design

Flexibility is defined by McManus & Hastings (2007) as *"Ability of the system to be modified to do jobs not originally included in the requirements definition."* In other relevant literature, such as Ross et al. (2008), the terms *flexibility* and *adaptability* are used to separate different types of *changeability*. In general, changeability corresponds with the ability of a system to change *form* or *function*. The form represents the shape, configuration and arrangement of a system, while the function defines what the system does in terms of activities, operations, and transformations that cause, create or contribute to performance (Crawley et al., 2016). Further, adaptability and flexibility are defined as the ability to be changed by a change agent, either system-internal or system-external respectively. However, this thesis uses the terms changeability and flexibility interchangeably. This is done in order to avoid confusion for the reader, as the reviewed literature contains various definitions.

The purpose of a flexible design is to achieve continuous value-robustness. By this it is meant that a system should be designed in such a way that changing circumstances can be responded in an easily and cost-efficiently manner. Inclusion of various flexible systems in a design should be done in order to protect against hazards and exploit possible opportunities that may show up. According to Neufville & Scholtes (2011) flexible designs fall into three main categories.

Table 2.4: Three major categories of flexible designs (Neufville & Scholtes, 2011).

Category	**Example**
Change in size	A ship can be designed in such a manner that future expansion of capacity is facilitated.
Change in function	The system is able to add or remove a function. An example is a combination carrier that can switch between different transport modes, as altering between dry and wet bulk shipping.
Accident protection	Inclusion of protective systems in the design, as system redundancy.

When facing an uncertain future by the use of design flexibility, different candidates of flexibility should be identified. A possible approach is to perform an evaluation of different future uncertainties. Given an uncertain factor, the evaluation of implementing a design configuration can be made in terms of how well the given implementation lowers the risk and exploits the opportunities of the assessed uncertainty.

The inclusion of flexibility in ship design comes together with an increase in investment costs. Thus, if every possible future uncertainty is taken into consideration, a wide variety of flexible systems may be included, which will accumulate the additional investment costs. This implies a risk of adding system configurations that increase the flexibility without gaining sufficient value to the ship, or even worse, the risk of adding system configurations that eventually are left unused. This is seen as an important aspect and requires further evaluation. Therefore, a distinction is made between design flexibility that increases either the *versatility* or *retrofittability*.

2.4.1 Tradeoff between Versatility and Retrofittability

Rehn (2018) defines versatility and retrofittability as the ability of a system to satisfy diverse needs *without* or *with* change of form, respectively. In other words, a versatile ship is already prepared for different future outcomes, while retrofittability is a measure on how well a ship is prepared for future modifications. Table 2.5 below displays various examples of versatility in ship design.

Table 2.5: Examples of versatility in ship design (Rehn & Garcia Agis, 2018).

Vessel name	Type	Built	Versatility description
Front Striver	Oil bulk ore	1992	Can carry either dry or wet bulk
AKOFS Seafarer	Well intervention unit	2010	Multi-purpose offshore ship
Wes Amelie	Container ship	2011	Diesel/LNG dual fuel engine

Designing for versatility in ship design can provide a shipping company with flexibility to perform changes quickly, by for example fuel change or through the change of transport mode, in cases were such a change is beneficial. Though, with an uncertain future operating context, it can be hard to predict whether such changes will become necessary. Thus, by designing for retrofittability and prepare a design for future change, the economical downside is lower than compared to a versatile design in cases when the predicted changes becomes unnecessary. By designing for retrofittability, decisions can be delayed until the circumstances of the future are less uncertain. Table 2.6 shows examples of retrofittability in ship design.

Table 2.6: Examples of retrofittability in ship design (Rehn & Garcia Agis, 2018). MSV = Multi-service vessel, AHTS = Anchor handling tug supply.

Vessel name	Type	Built	Preparation for
Olympic Intervention IV	MSV	2008	Light well intervention tower
Olympic Zeus	AHTS	2009	250 tonnes crane
MV Barzan	Container ship	2015	Dual fuel capabilities (LNG ready)
Dina Polaris	MSV	2017	150 tonnes crane and helideck

Further, Rehn (2018) states that market changes are the driving factor for flexibility in shipping. The shipping industry is capital intensive and a ship can exceed 30 years of operation. Thus, retrofit is a common approach to handle market or regulatory changes. Though, retrofits often include high investments, which can be seen in Table 2.7, which displays cost estimates of various types of retrofits.

Table 2.7: Cost estimate for various vessel retrofits (Rehn & Garcia Agis, 2018). PSV = Platform supply vessel, OCV = Offshore construction vessel, SOV = Service operation vessel.

Vessel name	**Type**	**Year of**		**Cost [$M]**		**Retrofit description**
		Build	**Retrofit**	**Built**	**Retrofit**	
Belle Carnell	PSV	2004	2013	25	40	Accommodation, equip.
Aker Wayfarer	OCV	2010	2016	220	90	Equipment
Vestland Cygnus	PSV	2015	2015	38	18	Conversion to SOV
Enchantment of Seas	Cruise	1997	2005	300	60	22 m elongation
MSC Lirica[1]	Cruise	2003	2014	250	65	24 m elongation

[1] The same accounts for three sister ships.

In terms of retrofittability the stakeholders of the ship must determine what is more valuable out of two options. Either, retrofittability can be implemented early and the ship is prepared for later change. The risk of retrofittability concerns that the installation that is prepared for never occurs in case it is unnecessary, something which could seem like a waste of capital for the stakeholders. The other option is to simply wait and see *if* the ship must be reconfigured or not. If needed, it is likely that the retrofit will be extensive with a higher investment cost than compared to a ship of higher retrofittability.

The tradeoff between versatility and retrofittability is investigated in Rehn, Garcia Agis, et al. (2018). The study concludes that versatility provides income potential, but at a higher up-front cost. Following, retrofittability is also seen to increase the upside potential of a design while requiring a low up-front cost. It should be mentioned that the results are concluded from a design study of non-transport vessels. However, it is reasonable to believe that the results are transferable to the deep-sea shipping industry.

An important consideration regarding the tradeoff between versatility and retrofittability is the cost of future retrofits. The future cost of retrofits will often be dynamic and driven by contextual changes. As an example, the global sulphur cap was implemented in deep-sea shipping by the beginning of 2020. The new regulation required shipowners to decide between either switching heavy fuel oil (HFO) with other fuel alternatives or to retrofit an exhaust gas cleaning system as the scrubber system. Thus, as seen in Figure 2.7, the number of installations increased drastically while approaching 2020. It is likely that the installation cost increased correspondingly to the higher demand of scrubber installations when the new regulations were approaching due to capacity issues at the drydocks. Thus, in some occasions, a sudden rise in demand as new regulations approaches may speak in favor of versatile ship design. Hence, timing of decisions regarding design flexibility can be an important factor.

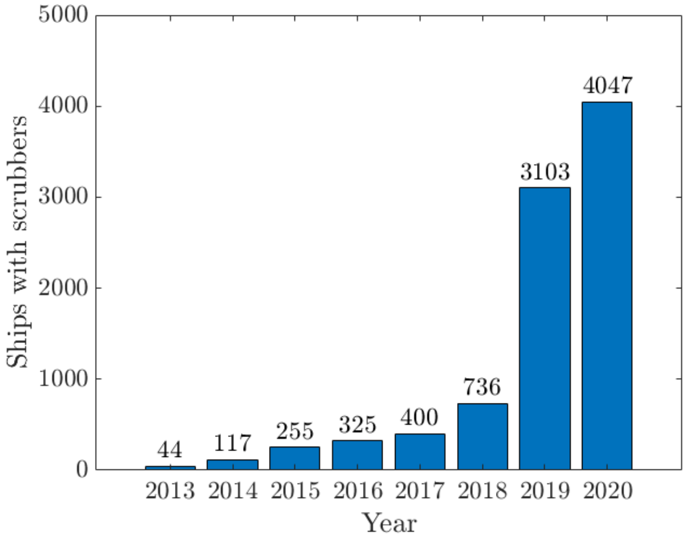


Figure 2.7: Total number of ships with scrubbers (DNV GL, 2020).

Further, in order to make a profound decision between different flexible design alternatives, methods for valuing the expected value of different projects are needed. This thesis desires to provide a decision support to choose between various flexible designs by quantifying the value of their respecting design flexibility. A possible tool for such valuation can be by the use of option pricing theory, which is discussed in the following section.

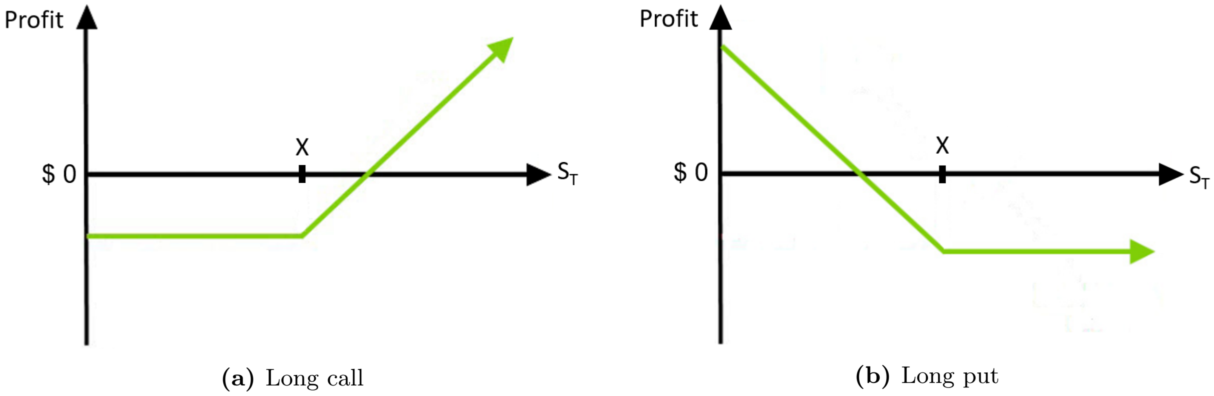
2.5 Financial Option Theory

Financial options are derivative securities, which means that the value of the security is depending upon the value of an underlying asset. Financial options give their buyer the possibility to buy or sell a security within (or at) a specified time to a predetermined price. The predetermined price is referred to as the *strike price* or the *exercise price*, while the time until the expiration of the option is referred to as the *time to maturity*. As the name implies, a financial option provides its holder with a choice. This freedom of choice is in an economical context referred to as *flexibility*. Economic flexibility in a financial investment context means to change cash flows in order to profit from good opportunities and cut off losses (Wijst, 2013). Option positions can be separated into long and short positions, which is the equivalent of buying or selling an option, respectively. Further, each position is either categorized as a *call* or a *put* option. Table 2.8 below explains the obligations and rights associated with the different option positions.

Table 2.8: Obligations and rights to different option positions (Wijst, 2013).

	Long position	**Short position**
Call	Right to buy	Obligation to sell
Put	Right to sell	Obligation to buy

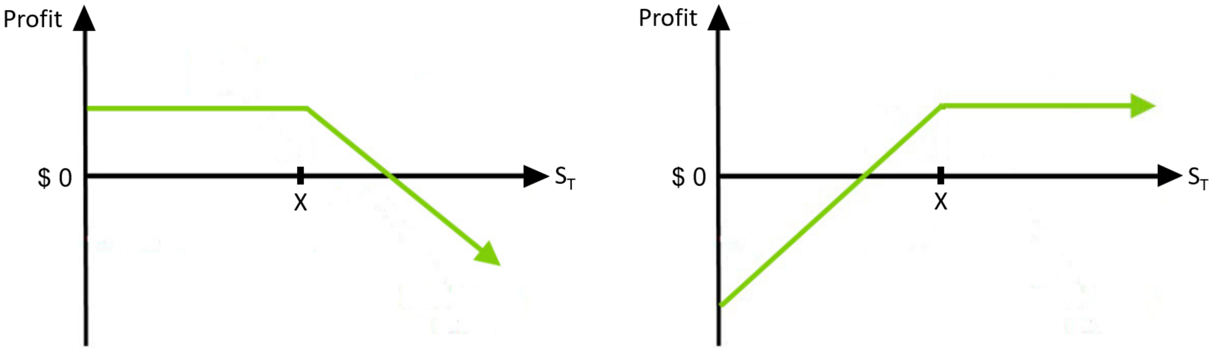
A long call option benefits from a rise in the value of the underlying asset, while a long put option benefits from a decrease. Similar for both is the characteristic as a limited liability investment. Long position options are only exercised if the value development makes it profitable, i.e. if the underlying price of the option is greater than the strike price. If it is not profitable to exercise the long position option, it is not exercised and only the transaction cost, the *option premium*, is lost. Figure 2.8 and figure 2.9 below illustrate the profit diagrams for long and short position options, respectively. X is the strike price, while S_T is the value of the underlying asset at maturity.



(a) Long call

(b) Long put

Figure 2.8: Profit diagrams for long position options.



(a) Short call **(b)** Short put

Figure 2.9: Profit diagrams for short position options.

Short position options are riskier than long position options. This is due to the fact that the seller of an option has either the obligation to buy or sell the underlying asset, depending upon if it is a put or a call, respectively. In principle, a short call has an infinite down-side as there is no defined upper limit for valuation of an underlying asset. Thus, short call positions are normally not taken isolated, but rather in combination with other options. There are various combination alternatives including straddles and spreads, but such combinations are not elaborated in this thesis. The upside of a short put position is limited to the option premium, and may be taken if future increase of the underlying asset is expected but the price of it is seen as too high. Short puts are also normal to combine with other options. Figure 2.9 illustrates the payoff diagrams for short position options. The definitions of X and S_T are the same as in figure 2.8.

2.5.1 Option Styles

There are various ways to determine the strike price and exercise time of an option, and this is dependent upon the *option style*. In general, options can be distinguished into two branches: Vanilla options or exotic options. Vanilla options have a specified time to maturity and a predetermined strike price, while exotic options tend to have a more complex structure. Additionally, an option is either *path dependent* or *path independent*. The value of a path independent option is solely calculated by its value at the exercise time, implying that the path does not matter. In turn, the value of a path dependent option varies by the price movements of the underlying asset through parts (or all) of the life time of the option. The complex nature of path dependent options increases their difficulty of valuation.

Both European and American options are categorized as vanilla options. The difference between them is that an American option can be exercised any time in prior to, or at maturity, while European options are limited to only be exercised at the predetermined date. Common for both European and American is that they are path-independent. Exotic option types include Asian, Bermuda, lookback and compound options. The value of an Asian option is calculated as the average level of the underlying asset over a period of time. Both geometric and arithmetic averages can be used in the settlement calculation, but the latter is most common. By taking the average value over a certain time, the risk is lowered due to that the option is less exposed to volatility. Additionally, Asian options are less exposed to market manipulation on the exercise date. Thus, Asian options are widely used on freight rates as an example. Further, Bermuda options falls in between European and American options as they can be exercised early, but only on predetermined dates, typically one date each month. Lookback options are settled at the optimal value of the underlying asset during the lifetime of the option. Naturally, the option premium on lookback options are very high. A compound options is an option on an option, which may be especially relevant during projects. A comparison between various option types can be seen in table Table 2.9.

2.5.2 Option Value and Uncertainty

The value of an option is as defined below:

$$\text{Option value} = \text{Intrinsic value} + \text{Time value} \tag{2.1}$$

The intrinsic value of an option is the amount of profit that currently exists. In the example of a long call, the intrinsic value is the difference between the value of the underlying asset and the strike price. An intrinsic value is never below zero. Naturally, an option premium is never lower than the intrinsic value. The remaining part of the option premium is reflected by the risk taken by the short option position holder, which is reflected in the time value. The time value of an option is related to the time value of money (TVM), which is the concept that present money is more valuable than future money. Thus, the time value of an option reflects the probability of an increase in intrinsic value, meaning that the time value decreases with time and reach zero at expiration.

An important aspect of options is that their value increase with uncertainty. This is a statement that may seem counter-intuitive as risky assets by some are considered less valuable. If deciding between two projects with the same expected return, the rational choice would be to choose the less risky one. This is the approach of a risk-averse investor. However, an increase in uncertainty increases both the upside and downside potential of an asset. Due to the limited liability of long position options, an option is only exercised if it is beneficial. Thus, increased uncertainty increase the upside potential of an option, while the downside potential of the option remains unchanged. Correspondingly, if there were none uncertainty, there would be zero option value. Thus, the option value is created by uncertainty (Neufville, Hodota, et al., 2008).

Table 2.9: Comparison of various option types (Alizadeh & Nomikos, 2009; Haug, 2007).

Option style	Path dependent	Early exercise	Relative cost	Category
European	No	No	Low	Vanilla
American	No	Possible	High	Vanilla
Asian	Yes	No[1]	Low	Exotic
Bermuda	No	At specified dates	Medium	Exotic
Lookback	Yes	Not relevant	Very high	Exotic

[1] Possibility of early exercise can be arranged, but it is unusual.

2.5.3 Replicating Portfolio

The riskiness and the corresponding value of an option increases or decreases with time, depending on the movements of the underlying stock. Thus, discount challenges occur as the discount rate must be continuously adjusted. This is solved by setting up a replicated portfolio by combining the underlying stock with lending at the risk-free rate. This is known as risk-neutral valuation, and a simplified illustrative example is presented below.

A 12-month call option on a stock is available in the market, and the risk-free interest rate, r_f, in the market is 5 %. The given stock has a current value of \$60 and the strike price is identical to its current value. There are two possible outcomes of stock price movement the following 12 months. The stock either increases with 25 % or decreases with 20 %. Thus, the option value is \$15 given the increase, while the option is worthless in case of the decrease.

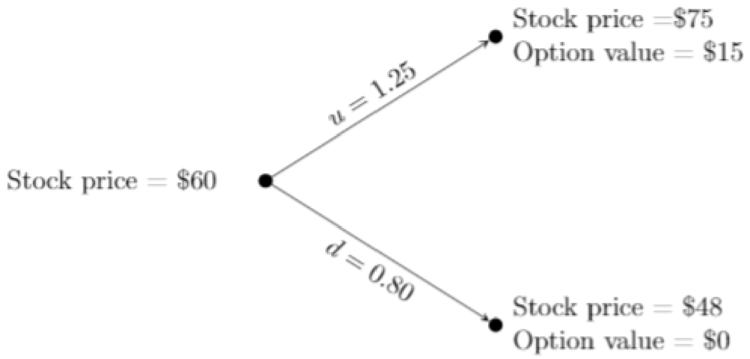


Figure 2.10: 12-month call option on a stock with a strike price of $60.

In order to create the replicated portfolio, shares and loan at the risk-free rate must be combined. The hedge ratio amount of a share, δ, must be bought and combined with an amount of debt, D, at the risk-free rate so that the payoff at expiration equals the option payoff. D and δ are calculated below.

$$\delta = \frac{O_u - O_d}{(u-d)S} = \frac{15-0}{(1.25-0.80)60} = \frac{5}{9} \tag{2.2}$$

$$D = \frac{uO_d - dO_u}{(u-d)(1+r_f)} = \frac{1.25 \cdot 0 - 0.80 \cdot 15}{(1.25-0.80) \cdot 1.05} = -\$25.40 \tag{2.3}$$

Thus, the replicated portfolio consists of $\frac{5}{9}$ of a $60 share and a bank loan of $25.40. The value of the replicated portfolio is therefore $7.94, which must be equal to the option value. Consequently, the method used in this example illustrates how a levered investment in the underlying asset replicates an option investment. In the case of a put option, the hedge ratio is calculated as

$$\delta_p = 1 - \delta_c. \tag{2.4}$$

2.6 Real Options and Flexibility

A natural extension of financial options is the use of real options. Myers (1977) was first to introduce the concept and defines it as *"opportunities to purchase real assets on possibly favorable terms"*. He states that investment opportunities during projects often share the attributes of call and put options. Real options provide managers with the flexibility to avoid unwanted outcomes and exploit possible advantages, and thus, according to Trigeorgis (1995) managerial flexibility can be quantified by the use of real options analysis. This is done by evaluating the different pathways of the investment decisions and examining possible outcomes. Various studies of real options and flexibility are available in the literature. An early study of the use of real options to value investment decisions in shipping is conducted in Dixit (1989). Dixit & Pindyck (1994) discuss real options and investment under uncertainty, while Kulatilaka (1993) investigates the value of flexibility in the case of a dual fuel industrial steam boiler. Further, several studies extend the application of real option analysis in shipping. Bjerksund & Ekern (1995) value the option to extend a time-charter shipping contract, while Hoegh (1998) discuss the value of options in shipbuilding contracts. Additionally, Bendall & Stent (2005) apply real option analysis for ship investment under uncertainty, while Sødal et al. (2008) use a real option approach to value the flexibility to be able to switch between the wet and dry bulk market. Real option analysis by the use of Monte Carlo simulation is discussed in Hassan et al. (2005) and Lin et al. (2013).

As an example, a real option can be the call option to expand a project at a certain time. In comparison with financial options, the parameters of real options may be less clear. Table 2.10

shows typical differences between traditional financial options and real options. It should be noted that the listed differences are typical, but deviations may occur.

Table 2.10: Typical differences between traditional financial options and real options. (Neufville & Scholtes, 2011; Wijst, 2013).

Parameter	**Financial option**	**Real option**
Time to maturity	Typically months	Typically years
Strike	Exercise price	Investment
Volatility	Stock σ	Price volatility
Underlying	Asset	Project revenue
Values	Smaller	Higher
Tradable	In secondary markets	Not tradable
Management influence	Low	High
Replicating portfolio	Obtainable	Difficult to determine
Market data	Available	Uncertain

As seen in the table above, the characteristics of real options are more uncertain than for financial options. It can be difficult to identify factors as price volatility and expected project revenue for an investment during a project. However, as mentioned in section 2.5, an option provides its holder with flexibility. By quantifying the value of flexibility provided by the real option, projects that originally were identified as loss-making can turn out to generate value. Thus, in order to understand how this can be true, the differences between the conventional model for project valuation and real options are discussed.

2.6.1 Project Valuation

The valuation of a project through its lifetime is commonly estimated by the use of a discounted cash flow (DCF) model. The model aims to estimate the net present value (NPV) of a project by using an appropriate discount rate. Typically, the discount rate, r, is assumed to be equal to the risk-adjusted rate, which can be found by considering the rate of return on projects with similar risk profiles (Alizadeh & Nomikos, 2009). The NPV can be calculated as

$$\mathrm{NPV} = \sum_{t=0}^{N} \frac{R_t - C_t}{(1+r)^t} \tag{2.5}$$

where R_t and C_T represent revenue and cost respectively, both in period t discounted at r. The project time periods from 0 to N is represented as t, typically either as months or years. When using the DCF model, a project is considered to be profitable if the NPV is greater than zero. Hence, the aim of a project should be to maximize the NPV. However, most projects tend to be dynamic and must adapt to an uncertain operating context, and the conventional DCF model is inadequate if the value of a given project changes with time. The model fails to adapt to managerial flexibility and uncertain cash flows. In turn, real options include the value of managerial flexibility by defining the choices along the path of the project as options. Thus, as proposed by Trigeorgis (1993), the NPV when including the value of real options can be defined as followed. NPV_{Static} represents the NPV calculated from the DCF model, while $NPV_{Expanded}$ is the value of options from active management.

$$NPV_{Strategic} = NPV_{Static} + NPV_{Expanded} \tag{2.6}$$

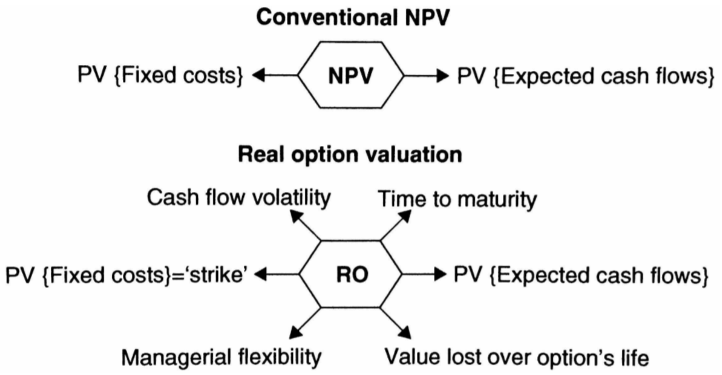


Figure 2.11: Drivers of NPV and real option analysis when valuating projects (Cuthbertson & Nitzsche, 2001).

There exist various tools for valuation of different types of real options. The methods and mathematics of these are carried out in section 4. A numeric example that shows the difference between the DCF model and real option valuation is elaborated in subsection 4.4.

2.6.2 Real Options *In* and *On* Projects

Real options can be distinguished between real options *in* and *on* projects (Wang & de Neufville, 2005). *On* options are typically purely investment decisions which treat technology as a "black box" without any change to the system configuration itself (Wang, 2005). In other words, real options *on* projects do not generally involve any design issues. Thus, uncertain factors as for example emission regulations are not included in the evaluation of real option *on* projects. An example of a real option *on* a project in shipping is the option to expand the fleet during times of high freight rates.

Real options *in* projects are options that require technical understanding and such options affect the design of a system. The changes made to the given system can increase the flexibility by preparing for given scenarios of an uncertain future operating context. As an example of real options *in* systems, the installation of a dual fuel engine is highlighted. Future environmental regulations are expected, however yet uncertain. With a dual fuel engine, the ship can use the fuel that is most favorable. As more environmental friendly fuels tend to be more expensive, the ship is provided with flexibility to use conventional and cheaper fuel as long as possible. Instead of switching to an expensive fuel today, it is possible to postpone the fuel switch until new regulations are implemented, or switch fuel earlier if the fuel costs make it beneficial. The installation requires technical knowledge because it affects various technical properties of the ship. In general, real options *in* projects can be characterized by one of the following aspects. Either as versatility explicitly designed or that the change considers any type of retrofit (Rehn, 2018). Another important aspect is the *changeability level* on the given ship. How well a ship is prepared for future changes is an important factor for the project revenue. Table 2.11 explains differences between the two option types, while examples of relevant real options in shipping can be seen in Table 2.12 and 2.13.

Table 2.11: Differences between real options *in* and *on* projects (Wang, 2005).

Real *on* options	**Real *in* options**
Value opportunities	Design flexibility
Valuation important	Decision important (go or no go)
Relatively easy to define	Difficult to define
Path-dependency less an issue	Path-dependency an important issue

Table 2.12: Real options *on* shipping projects (Alizadeh & Nomikos, 2009; Wijst, 2013).

***On* option**	**Example**
Abandon/Exit	The put option to abandon a project by selling the asset and exit the market, for example the option to scrap a vessel.
Expand	In times of good market conditions, it is possible to expand the fleet, which can be designed as a call option.
Extend	The call option to extend a TC-contract for a predefined period of time at expiration of the contract.
Lay-up	When ship earnings are lower than the operational costs, the vessel can be laid-up temporarily.
Delay	The option to delay a project, and wait for better financial conditions.

Table 2.13: Real options *in* shipping projects (Alizadeh & Nomikos, 2009; Wijst, 2013).

***In* option**	**Example**
Switch mode	Compound option to switch between markets, as done by combination carriers.
Switch fuel	Compound option to alter between different fuels, which is done when sailing in and out of ECA.
Expand capacity	Option to physically expand the ship by midship elongation.
Retrofit	Adding or change capabilities of a ship by retrofit various installations, such as the installation of a scrubber.

3 Modeling an Uncertain Future

Future predictions is a challenging process. This section describes varies techniques that can be used to model the future.

3.1 Times Series and Stochastic Processes

A time series is a sequence of discrete-time data and are popularly used in fields such as finance, statistics and engineering. Analysis of a time series can be used to determine statistical properties, which again can be used in order to model an uncertain future. This process is known as time series forecasting.

Fluctuating variables as stock prices, fuel prices and freight rates can be challenging to model as their future value is uncertain. Such variables follow a stochastic process, and a stochastic process describes how the value of a variable changes with time through probabilistic parameters. Hence, a stochastic process describes some sort of random motion. By evaluating the parameters, a future value can be predicted by defining the given stochastic process. Thus, in order to evaluate an option, the stochastic process of the underlying asset must be understood.

Stochastic processes can either be defined in continuous time or in discrete time. For discrete stochastic processes, the value changes at fixed points in time, while for a continuous stochastic process value changes can take place at any time. Following, relevant stochastic processes are described.

3.1.1 Markov Process

A Markov process can be described as a memory-less function. This is due to the Markov property, which states that the next value in a Markov chain only depends on the current value, while previous values are irrelevant. Typically, stock prices are assumed to follow the Markov process. This is consistent with the weak form of the efficient market hypothesis, which states that the market use all prior information available to price a stock. Thus, the current price of a stock does not predict its future direction, similar to the properties of the Markov Process. This is known as the random walk theory (Malkiel, 2007). The theory can be debated, e.g. through the concepts of technical analysis, but the discussion is not relevant for the thesis and is not further elaborated.

3.1.2 Geometric Brownian Motion

Geometric Brownian Motion (GBM) is a commonly used stochastic process to model non-negative asset prices. An asset needs to provide a sufficient return, otherwise investors will identify other alternatives. Thus, an expected change in the value of an asset should be proportional to the actual value of the asset. This is taken into account in the GBM process by defining that the logarithm of the underlying asset follows a Brownian motion with drift. The value of an asset follows a GBM for continuous time if it is described by the following differential equation:

$$\frac{dS_t}{S_t} = \mu dt + \sigma dW_t \tag{3.1}$$

Here, S_t is the asset value, σ is the volatility of S_t, d_t is the time increment and mu is the expected drift that describes the long term movement of the asset value. dW_t is the time increment of a Brownian motion, also referred to as Wiener process. The Wiener process is a Markov chain, and is supposed to model *white noise*, the uncertain factors of market movement. Typically, the Wiener process is modeled as a random variable with a standardized normal distribution.

Thus, the motion of the asset value is independent of the current state, which makes GBM path independent.

3.1.3 Mean-Reverting Process

A possible outcome when using GBM to model a future value, is that the asset value get unreasonably high or low with time. Such movement behavior can be avoided by letting the drift revert back to a long term mean value. This is known as a mean-reverting process, and it is described by the Ornstein-Uhlenbeck process in the equation below:

$$dS_t = \kappa(\alpha - S_t)dt + \sigma dW_t \tag{3.2}$$

Here, α is the long-term mean value and κ is the rate of reverting to the mean value. The other variables are as described in Equation 3.1. The price movement depends on previous states, and thus, the process is path dependent. An example in which the process of mean-reverting is relevant includes the dynamics of supply and demand of commodities. A higher demand implies a higher price and gives suppliers an incentive to increase their production rate. Increasing supplies will eventually force the prices to drop until additional supply is no longer attractive for the supplier. In other words, we have reverted back to a mean value due to a balance between supply and demand. Such cycles are well known within shipping as it affects the spot rates (Stopford, 2009). Sødal et al. (2008) investigate the real option value of switching between wet and dry bulk for a combination carrier. The value is estimated by an analytical solution to the mean-reverting process.

The mean-reverting process may be a good model for cyclic processes. However, markets that occasionally experience drastic price movements are less accurate modeled with the mean-reverting process. As an example, oil price prediction by using mean-reverting fails to model jumps in the price movement due to extraordinary events. Studies have shown that oil price prediction of more than three months has a low plausibility when using the mean-reverting process (Meade, 2010). Hence, the same may be assumed for fuel price prediction.

3.1.4 Jump-diffusion process

In order to model sudden market changes, the jump-diffusion process is a possible candidate. It was a suggested approach by Merton (1976) for valuation of options when the underlying asset is discontinuous. Sudden market changes can be identified as trend breakers, meaning that the smooth continuation of the recent past is disrupted. Various trend breakers include elements as economic crises, political shifts, game changing technology and new market conditions (Neufville & Scholtes, 2011). Figure 3.1 illustrates various sudden price changes in the oil price commodity, here by the spot price of brent crude oil.

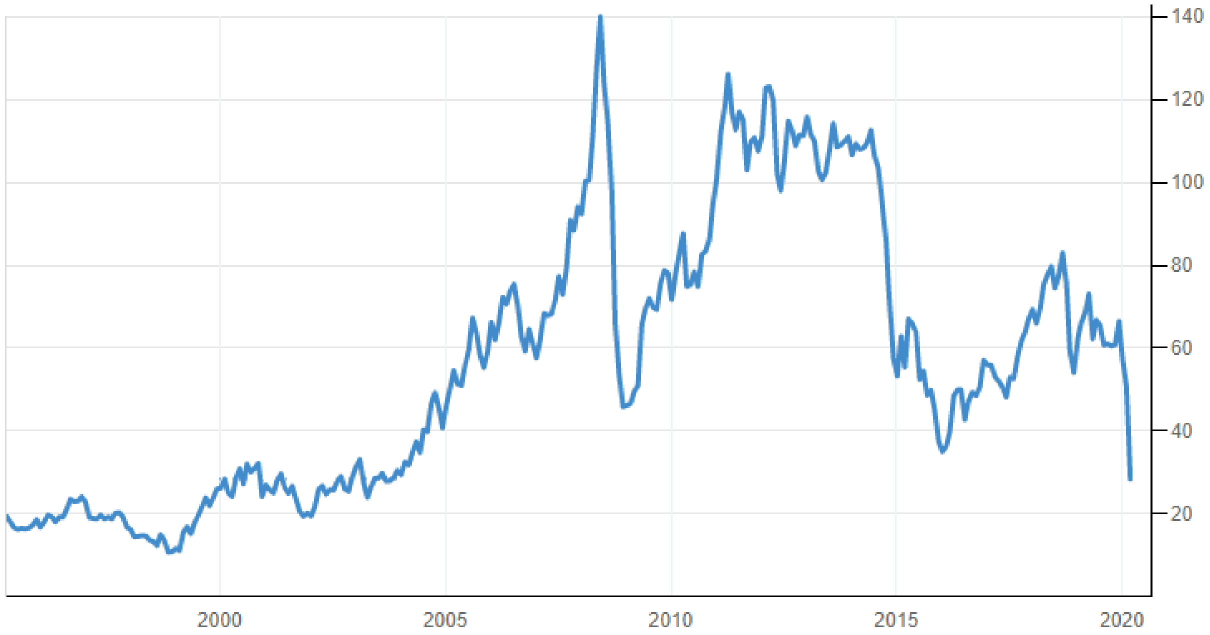


Figure 3.1: 25-year price chart [USD/bbl] for brent crude oil. The chart illustrates the occurrence of sudden price jumps in the oil price market (Trading Economics, 2020a).

Sudden price changes are seen from mid 2008 due to the financial crisis, from late 2014 due to overproduction of oil and recently from late February due to oversupply of oil in the market and the coronavirus. The changes in the price development are so drastic that a possible approach is to model the price development as discontinuous by using the jump-diffusion process. Generally, the underlying asset in a jump-diffusion process follows a Brownian motion with drift punctuated by jumps, and the underlying asset should satisfy the following equation in order to follow the process:

$$\frac{dS_t}{S_t} = \mu dt + \sigma dW_t + (J-1)dN(t) \tag{3.3}$$

Here, J is the multiplicative jump size, commonly modeled using a log-normal distribution, while $N(t)$ represents the number of jumps that have occurred up to time t. The jump frequency is typically modeled by a Poisson process. The remaining variables are as explained in Equation 3.1.

3.2 Uptake of New Technology

New technology can be an essential factor when modeling the future from an engineering point of view. The uptake of emerging technology is often decisive for the availability, supply, demand and the price of the given technology, which further could be crucial for the stands of a decision maker. A technology lifecycle can be modeled by the use of the s-curve concept, which is represented as a function of time t in Equation 3.4 and illustrated in Figure 3.2 below.

$$S(t) = \frac{1}{1+e^{-t}} \tag{3.4}$$

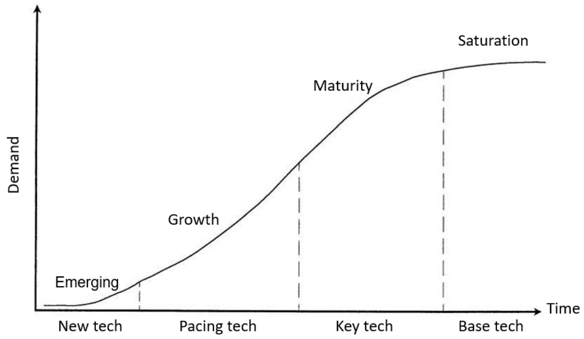


Figure 3.2: S-curve illustrating the demand of a technology through its lifetime, based on Gao et al. (2013).

Generally, technology uptake can be divided into the emerging, growth, maturity and saturation period. For a decision maker, it is important to identify which period that as applicable for the technology under consideration. This is due to that the unit cost of the given technology changes between different periods. Typically, new emerging technology are embraced by early adopters. The low demand in this period does not require high production volumes, and thus, the unit cost of emerging technology is often high compared to more conventional technology choices. As the given technology uptake increases, higher production volumes are reached. As a result, the unit cost may stabilize at a lower level. Examples of this are seen in DNV GL (2019c) during the discussion of unit cost development of different types of energy production. The predictions can be seen below in Figure 3.3.

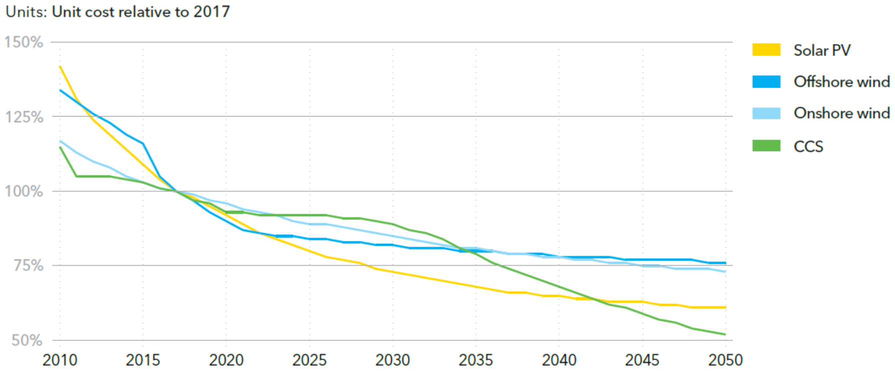


Figure 3.3: Predictions of decreasing unit cost for different technologies (DNV GL, 2019c).

An example of using the s-curve to model the future is seen in Cardin et al. (2015). The study projects LNG demand through a time period of 20 years. When comparing the projection with the actual realized demand of LNG at 25 different sites, it can be seen that the s-curve approximation captures the reality.

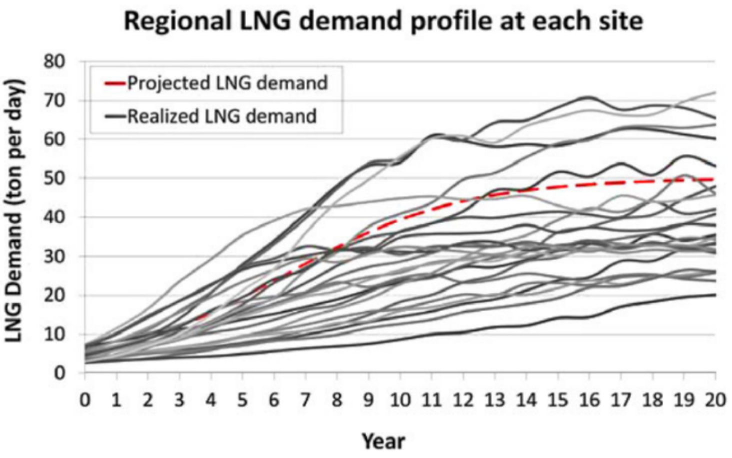


Figure 3.4: Modeling LNG demand as an s-curve (dashed line) versus twenty-five realized scenarios (Cardin et al., 2015).

3.3 Flaw of Averages

Flaw of averages refer to the common assumption that project evaluation under average conditions is a reliable source for decision making. Typically, such designs are made while considering a most likely-scenario, and such scenario-thinking can be problematic. A focus on the most probable situation neglects possible extreme conditions, which are the biggest risk and opportunities associated with a project. Consequently, designs based on average assumptions miss out on the possibility to take advantage of good situations, while the designs at the same time does not obtain any insurance against risk and possible losses (Neufville & Scholtes, 2011).

A simplified example illustrates how wrong such valuation can get. Assume a company has on average a yearly sale of 1,000 units of a certain type. Based on the sales from previous years, the company produces 1,000 units which are sold at a price of \$ 10 per unit. When asked about the expected value of the project, the company states that they on average sell for \$10,000 each year, and thus, that is the expected income. As they produced the amount of units that were expected to be sold, this must be wrong. \$10,000 is the maximum value of the project as they only produced the average number of units sold each year. Thus, the company miss out on any upside potential while the company is still affected if a lower demand than average occur.

4 Real Option Analysis

The purpose of performing a real option analysis is to quantify the value of a real option. There exists various methodologies for option pricing, and this section elaborates relevant methods for pricing of real options. In addition, a distinction between the pricing of real options *on* and real options *in* projects is made.

4.1 Three-Building Methodologies

Three-building methodologies is the provider of several possibilities to value options. Common for all of them is that they are built by discrete steps, reflecting the various pathways a project may take. The different pathways are often assigned with a probability. Further, trees can be modeled with two or more end states, referred to as binomial and multinomial trees, respectively. Another distinction is made if the tree is able to recombine or not. If they are, the trees are referred to as lattice.

4.1.1 Binomial Option Pricing Model

The binomial option pricing model (BOPM) was introduced by Cox et al. (1979), providing a powerful tool for the pricing of various types of options, including American and European options. The BOPM uses discrete time and discrete variables, and the model is a commonly used method to value real options *on* projects. The principle of the method is to construct a replicated portfolio by dynamically balancing a portfolio consisting of cash and the underlying asset, reflecting the exact price of the option. Thus, under the assumption of no arbitrage in the market, the price of the portfolio can be used to price the option. Assuming that the replicated portfolio follows a binomial process, the replicated portfolio can be illustrated as in Figure 4.1 below.

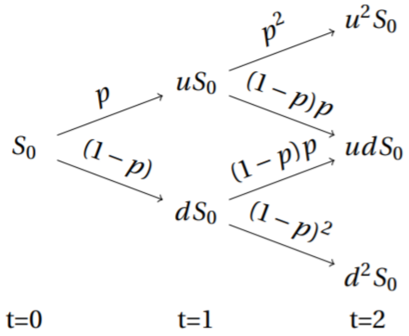


Figure 4.1: Two period recombining binomial lattice of the risk-free replicated portfolio S_0, based on Wijst (2013).

As shown in Figure 4.1, the replicated portfolio S_0 has two possibilities at t=0. S_0 either follows an upward movement of probability p or a downward movement of probability $(1 - p)$. The probabilities are risk-neutral, meaning that they are adjusted for risk. Following, S_0 either increases with a factor of u or decreases with a factor of d, given an upward or downward movement, respectively. The parameters of the binomial process are defined in the equations below:

$$u = e^{\sigma\sqrt{\Delta t}} \tag{4.1}$$

$$d = e^{-\sigma\sqrt{\Delta t}} = \frac{1}{u} \tag{4.2}$$

$$p = \frac{e^{r\Delta t} - d}{u - d} \tag{4.3}$$

r represents the risk-free interest rate, Δt is the time to maturity divided by number of steps in the binomial model, while σ is the standard deviation of S_0.

To calculate the option value, the lattice of the replicated portfolio must be solved from the end and backwards, working recursively. Depending on whether the option is a call or put, the option value is calculated by evaluating the difference between the portfolio value at period n, S_n, and the strike price, X, as followed:

$$O_{call} = \max[0, S_n - X] \tag{4.4}$$

$$O_{put} = \max[0, X - S_n] \tag{4.5}$$

Following, the option value at the earlier nodes are found by using the previously calculated nodes as in the formula below:

$$O_{node} = e^{-r\Delta t}(pO_{up} + (1-p)O_{down}) \tag{4.6}$$

The iteration process stops at the leftmost node, which is the calculated binomial option price. However, as mentioned earlier, certain option styles can be exercised prior to the expiration date. In order to take the possibility of early exercise into consideration, the nodes in the binomial lattice must be evaluated by the following criteria:

$$O_{node} = max[dead, alive] \tag{4.7}$$

Dead is the equivalent of exercising the option, while *alive* means to keep the option. When evaluating projects containing real options that can be exercised early, this step is crucial in order to calculate the true option value.

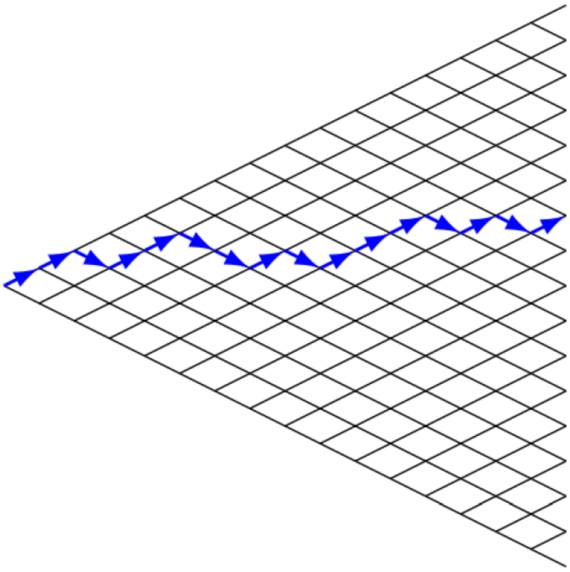


Figure 4.2: Binomial lattice illustrating a GBM sample path (Wijst, 2013).

When using the BOPM to calculate the value of an option, the output is a single value which is identical for all possible paths. This means that the option value is path-independent. Thus, for real options *on* projects, the model can deliver reasonable results. However, for real options *in* projects this may be an over-simplification which may not hold (Wang & de Neufville, 2005). This is due to that *in* options in general have a more complex structure, and the circumstances of the project may change during different paths. Additionally, revenue is path dependent, meaning that the lattice will not recombine (Wang & de Neufville, 2005).

4.1.2 Decision Tree

A decision tree is another available tree-building methodology designed for decision support. Commonly, a decision tree is built up by different types of nodes, such as decision nodes, chance nodes and end nodes. As an example, the decision node can represent an investment, the chance node can represent a probability of different outcomes and each outcome leads to the end node with a corresponding expected value of the outcome.

Decision trees does not provide any accurate valuation of real options. However, by creating a decision node of the choice between a flexible and an inflexible system, the value of flexibility can be approximated. This is done by taking the difference of the expected values between the two choices. Figure 4.3 illustrates a decision tree example.

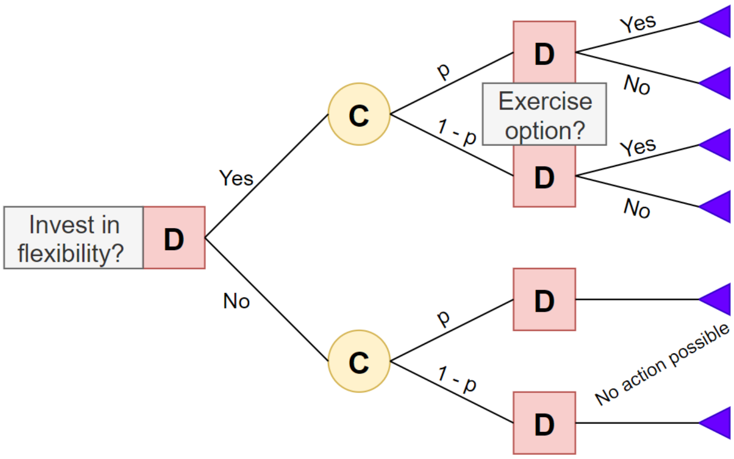


Figure 4.3: Illustrative case for flexibility valuation by the use of a decision tree.

The decision maker is provided with an initial choice to invest in a LNG dual fuel engine system. After t years there are two possible market outcomes, either a high or low global availability of LNG bunkering stations. The two outcomes have the probability p or $(1-p)$, respectively. Further, given the market condition, the decision maker has the option to perform a fuel switch from HFO/VLSFO to LNG. Essential parameters for the option decision are identified to be fuel price and local availability of LNG for the relevant trade at time t. By evaluating the difference in expected value between the two decisions, an approximate value of flexibility for a dual fuel engine system can be quantified.

4.2 Analytical Solutions

In terms of option pricing, an analytical solution is the exact solution to a differential equation that express how the given option value changes relative to the variables affecting its value (Alizadeh & Nomikos, 2009). A closed-form solution is elaborated in the work of Black & Scholes (1973), and the work is seen as in important breakthrough in options pricing theory. By letting the number of time steps in the BOPM become infinite, the time steps will be infinitesimal. Thus, the option can be priced in continuous time having an infinite number of end-nodes. By this, the BOPM converges to the same results as the Black-Scholes formula. The Black-Scholes formula defines an exact valuation for European options:

$$BS_{call} = S_0 N(d_1) - Xe^{-rT} N(d_2) \tag{4.8}$$

$$BS_{put} = Xe^{-rT} N(-d_2) - S_0 N(-d_1) \tag{4.9}$$

$$d_1 = \frac{ln(S_0/X) + (r + \frac{1}{2}\sigma^2)}{\sigma\sqrt{T}} \tag{4.10}$$

$$d_2 = \frac{ln(S_0/X) + (r - \frac{1}{2}\sigma^2)}{\sigma\sqrt{T}} = d_1 - \sigma\sqrt{T} \tag{4.11}$$

An advantage of analytical solutions is that they are relatively simple to compute. However, the characteristics of real options are more complicated than compared to traditional financial options. As a consequence, the parameters of the option valuation as volatility, value of the underlying asset and time to maturity, may be difficult to determine and an analytical solution is therefore often hard to obtain. Traditionally, GBM is the preferred stochastic process to model the value of the underlying asset when using the Black-Scholes formula. However, other approaches occur, but they tend to get quite messy and complicated.

4.3 Monte Carlo Simulation

The use of Monte Carlo simulation as a method to value options was first introduced by Boyle (1977) for European style options, while a technique to value early-exercise options was introduced by Carriere (1996). In cases when analytical solutions are difficult or impossible to obtain, Monte Carlo simulation (MCS) can be a suitable approach to determine option value. Thus, as real options *in* projects often have a complex and path-dependent nature, MCS can be used to approximate the value of such options. Additionally, the implementation of other stochastic processes than GBM is facilitated when using MCS compared to analytical solutions. Thus, modeling approaches such as mean-reverting processes, jump-diffusion and seasonality dependencies are often easier implemented. There exists various MCS algorithms, but generally MCS follows the pattern illustrated below.

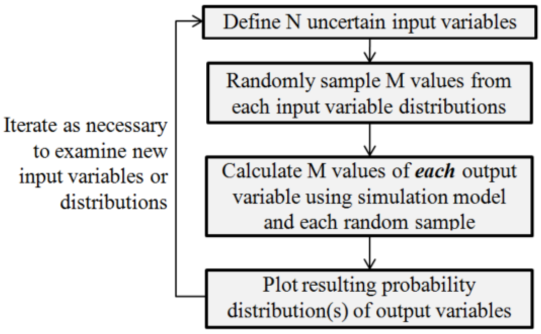
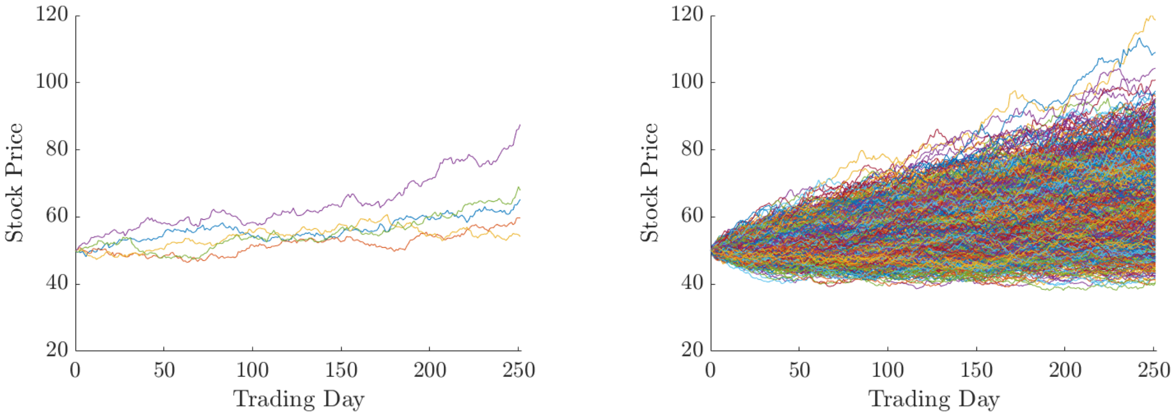


Figure 4.4: Monte Carlo Simulation process (Rader et al., 2010).

When using MCS for option valuation, the path of the underlying asset, i.e. the value development, is defined by stochastic processes with probability distributions representing the uncertain variables. In order to value an option, possible path developments should be simulated. The number of simulations depends on the complexity of the option. Typically, at least 10,000 simulations are needed (Alizadeh & Nomikos, 2009). A payoff distribution for the option is obtained by calculating the value at expiration. Following, the average of the simulated option values is discounted at the risk-free rate to approximate the present value of the option. The standard valuation error is obtained by $\frac{sd}{\sqrt{n}}$, where sd is the standard deviation of the payoff distribution and n is the total number of simulations. In other words, to double the accuracy of a valuation, the number of simulations must be increased by a factor of four. Finally, the value of flexibility is calculated by comparing the NPV of a project with and without an option, where the expected value of flexibility is the NPV difference:

$$E(V) = E(NPV_{flex}) - E(NPV_{rigid}) \tag{4.12}$$

Implementation of real options in MCS are typically by the use of *if*, *else* and *then* programming statements. As an example, pseudo-code for valuing the real option to switch fuels can be expressed as "*IF* the expected OPEX with LNG consumption added by the expected cost of performing a fuel switch is less than the expected OPEX with VLSFO, *THEN* exercise the real option to switch fuel type, *ELSE* continue to use VLSFO." If further system configurations are suggested, the MCS is easily modified by programming statements and the value of the changes can be simulated and evaluated.



(a) Five simulation paths.

(b) 2000 simulation paths.

Figure 4.5: Monte Carlo simulations of the underlying value of an option, in this case the stock price, during 252 trading days. GBM is used as the stochastic process with $\mu = 0.001$ and $\sigma = 0.01$.

4.4 Numeric Example: NPV vs Real Option Analysis

When a project is evaluated and the DCF model estimates an expected NPV of below zero, a reasonable thought may be to neglect the project. However, as already stated, the DCF model struggles to adapt to managerial flexibility and uncertain cash flows. The inclusion of real option analysis may change the outlooks of a project. Projects that are assumed to be loss-making may instead be profitable. In order to illustrate this effect, a simplified, yet illustrative example from Alizadeh & Nomikos (2009) for an investment decision is given.

An old ship is sold in the market for \$ 10 million. The decision makers assume that the expected operating profit of the ship is \$1.5 million annually. Further, at the end of the sixth year of operation, the ship is sold for scrapping, with an expected value of \$4 million. The cost of capital is estimated at 6.5 %, by a risk-free rate of 5 % and a risk premium of 1.5 %. Thus, the present value of cash flows can be estimated to calculate the NPV of the project.

Table 4.1: Discounted cash flows and NPV of shipping project decision example [US$m].

Year	0	1	2	3	4	5	6
Purchase Price	-10.0						
PV of operating profit		1.41	1.32	1.24	1.17	1.09	1.03
PV of scrap value							2.74
NPV	0						

The project estimations give an expected NPV of approximately zero, an estimation that would attract few investors. However, if the decision makers use a real option approach to value the project, the outcome may be different.

A reasonable assumption is that the acquired vessel can be resold in the market during the lifetime of the project. This is referred to as the option to abandon the project and can be modeled as an American put option. By assuming a risk-free rate of 5 % and a vessel price volatility of 30 %, the value of the put option can be calculated through the BOPM. If the option to abandon the project is evaluated once per year, six steps can be used in the model. Under these assumptions, an option value of $ 91,850 is calculated by using the BOPM. Thus, an investment that originally seemed unprofitable is proven to have value when including real option valuation. The calculations for the numeric example are found in Appendix A.

Table 4.2: Comparison of the DCF model and real option analysis to value the project example.

	DCF Model	**Real option analysis**
NPV	$ 0	$ 91,850

It should be noted that this example is simplified and for illustrative purposes. The underlying value of the option is here the secondhand vessel price, which is assumed to be volatile. Yet, the expected operating profits are assumed to be static. A volatile secondhand value should also indicate volatile earnings, and the assumption of static operating profit can therefore seem somewhat off. However, the example forms a good basis on how real option analysis can be used to determine project decision and is therefore seen as relevant to include.

4.5 Miscellaneous Aspects of Flexibility Valuation

4.5.1 Compound Options

Compound options are options on previous options, and for systems of high complexity such options can be highly relevant. As most ships have a long expected lifetime of around 30 years, flexibility in design is a suitable way to meet an uncertain future. However, flexibility introduction can be distinguished between whether to invest in flexibility from the beginning or to design in order to facilitate the flexibility introduction on a later stage. In other words, flexibility can be introduced as a real option itself. A typical compound real option in shipping is the option to design a ship as LNG ready. Initially, there is a call option for design flexibility, which further is followed by another call option on whether to actually install the engine modifications needed in order to combust LNG. Factors as technology uptake, fuel prices and construction costs vary with time, and thus, the value of such options are highly dependent on the exercise time.

4.5.2 Option Valuation for Combined Options

Another aspect that should be noted is the option valuation when options are combined. Project decisions of complex systems tend to include multiple different real options. An intuitive approach to determine the combined option values of a project would therefore be to calculate each real option separately followed by summing up the different real option values. However, this approach is wrong when the different real options are interacting with each other (Wijst, 2013). By exercising a real option, the underlying value of the option is affected. Consequently, the specifications of real options at later project stages are changed, and therefore also their value. In other words, the modeling complexity of option valuation increases with the amount of combined options. Typically, combined options are accounted for by the use of decision rules in MCS. When using the BOPM, both value trees must be considered in each node when calculating the option value recursively.

4.5.3 Game-Theoretic Extension

In cases when the value of the underlying asset is influenced by the actions of competitors, the discussed methods for real option valuation may be insufficient (Wijst, 2013). Thus, as proposed by Smit (2004), a game-theoretic extension can be made for real option analysis. Game theory studies strategic decision making in situations when the outcome is dependent on others. Liang et al. (2009) discuss the introduction of game theoretic extensions in marine systems design.

5 Future Operating Context of Product Tankers

A real option approach in order to value flexibility in ship design is evaluated through a case study. The case study investigates project decisions for a product tanker, specifically. In order to perform a real option analysis, a proper model must be built, and the model requires knowledge about both the current and the future operating context of product tankers. Important factors in the product tanker market can be identified and understood through evaluation of ongoing trends and by analyzing available data. Following, assumptions regarding the future operating context can be made. Thus, this section will cover the current market and market outlook of shipping, with a specific focus on the product tanker segment. Further, the current emission regulation status and regulation development is assessed. Additionally, technological aspects are considered, focusing on possible alternative fuel configurations that are suitable to face the expected future emission regulations.

5.1 Current Market and Outlook

Initially, the performance of international shipping in general is presented. Figure 5.1 below illustrates the magnitude of international shipping. As seen in the figure, there have been a gradual increase in the amount of cargo that is shipped. The aftermath of the 2008 financial crisis is an exception. In general, the growth of maritime trade follows a linear trend.

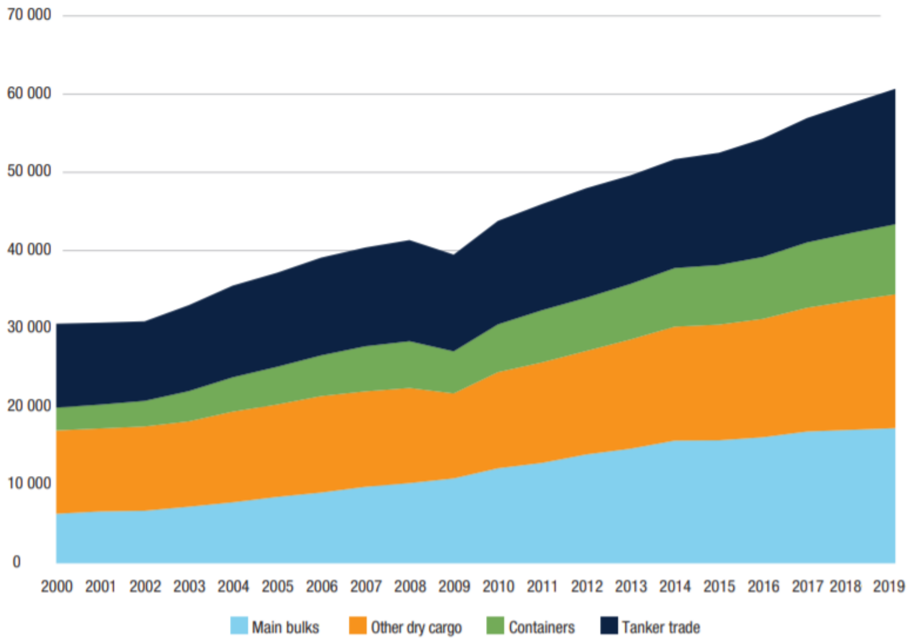


Figure 5.1: International maritime trade measured in billion cargo ton-miles from 2000 to 2019. Main bulks include iron ore, grain, coal, bauxite and phosphate. Tanker trade includes crude oil, gas, refined petroleum products and chemicals (UNCTAD, 2019).

The tanker trade, including crude oil, refined petroleum products, gas and chemicals, loaded 3194 million tons of cargo in 2018, which accounts for 29 % of the total amount of loaded cargo in 2018 (UNCTAD, 2019). Though, with a constantly increased interest of green technology, the demand for such products may decrease in the future. A shift away from an oil-based economy towards a higher uptake of green technology is identified to be an important long-term risk. To what extent the tanker segment is affected is challenging to predict, but a decrease in demand for oil related products may slow down the tanker trade accordingly, and correspondingly the world fleet growth. Thus, UNCTAD (2019) projects an expected annual cargo growth within the tanker trade of only 1.5 % in the period towards 2026, while Clarksons Research (2019b) are more optimistic and suggest an annual growth of 2.6 % for the same period. In comparison, Clarksons Research (2019a) and UNCTAD (2019) estimate an annual growth within the dry bulk segment of 1.3% and 3.1 % respectively towards 2026. This illustrates the substantial differences in estimates depending on the publisher of the report, and thus, such long-term estimates can better be defined as guesstimates.

The shipping market as a whole faces major risks the coming years. Slow economic growth is identified to be a significant short term risk. IMF (2020) have given warnings about the possibilities of a proceeding global recession. Though, the report specifies that the future predictions regarding the world economy is associated with extreme uncertainty. This is reflected in Figure 5.2, which displays the CBOE Volatility Index (VIX). VIX is popularly referred to as the fear index, and the index is a measure of the volatility of S&P index options. Since those option prices reflect the market's expectation of 30-day forward-looking volatility, increased market uncertainty increases the VIX index. With a VIX index approaching the levels of what was seen during the financial crisis, the world economy as a whole is indeed highly uncertain.

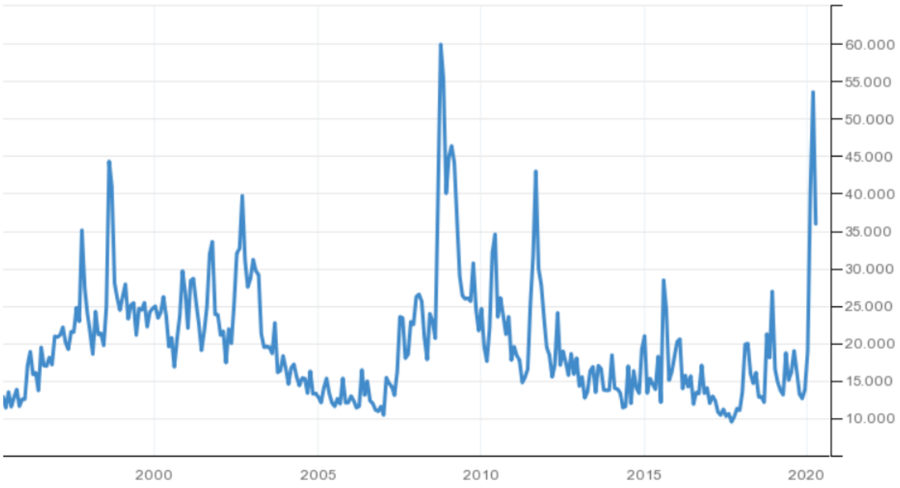


Figure 5.2: 25-year chart for CBOE Volatility Index (VIX) (Trading Economics, 2020b).

5.1.1 Product Tankers

The case study evaluates project decisions for a product tanker, and thus, the current market of the product tanker segment and its outlook is elaborated in this section. Product tankers are designed to transport refined products from refineries to the consumer market, and they are classified by size. Their size classification is seen in Table 5.1. Following, available market data for the product tanker segment are presented. Statistics and numbers presented are based on reports delivered by UNCTAD, Danish Ship Finance and Clarksons Research.

Table 5.1: Size breakdown for product tankers.

Classification	Deadweight
MR1	30,000 - 44,999
MR2	45,000 - 54,999
LR1	55,000 - 79,999
LR2	80,000 - 159,999

As the statistics in Figure 5.3 illustrates, the spot market gained pace towards the end of 2019 with an increase in earnings of almost 170 % from October towards the end of 2019. A likely reason for the increase in earnings is the combination of seasonality and the approach of IMO 2020. Tonnage was taken out of the market for scrubber installations, lowering the supply side, which resulted in stronger freight rates. However, the beginning of 2019 was rough due to surplus capacity after introduction of new vessels and weaker growth in cargo volumes than expected.

The beginning of 2020 provided the tanker market with declining rates. However, from the beginning of March 2020 disputes within OPEC and Russia triggered an oil price war with several countries overflowing the market with oil. The combined effect of declining demand due the the coronavirus and extreme levels of oil supply, consequently lead to skyrocketing tanker rates. This especially accounted for VLCC, but also smaller tank sizes as LR2, LR1 and MR benefited from the price war.

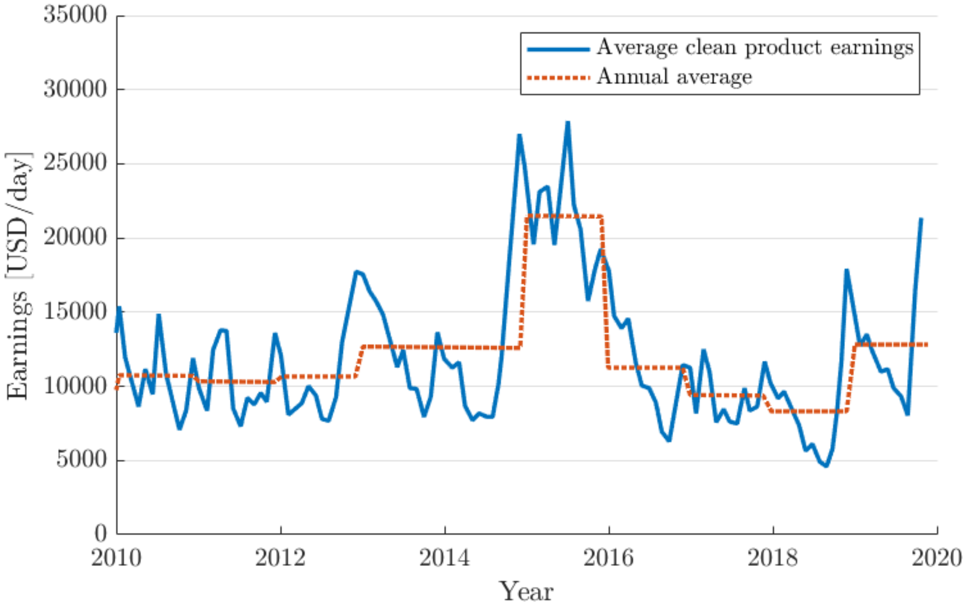


Figure 5.3: Average clean product earnings from 2010 to 2020 (Danish Ship Finance, 2019).

The one-year timecharter (TC) rate increased steadily during 2019, even though cargo volumes were low in the first half of 2019. The expectations of charterers to see higher freight rates due to lower capacity prior to the implementation of IMO 2020 is a possible reason. As Figure 5.4 illustrates, the TC rates have been increasing more or less continuously throughout 2019, and the biggest increase can be seen within the LR2 segment. From January 2019 towards the end of the year, the one-year TC rates increased by 44 %, 22 % and 18 % for LR2, LR1 and MR, respectively.

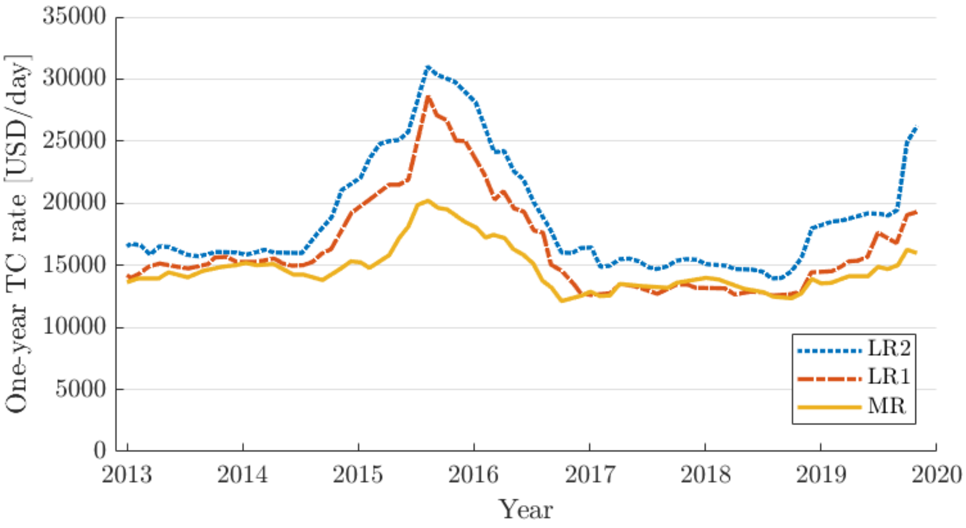


Figure 5.4: Average one-year time charter rate for LR2, LR1 and MR product tankers from 2013 to 2020 (Danish Ship Finance, 2019).

In 2019, the number of transactions of secondhand ships reached the highest level since 2005. During the first ten months of 2019 a total of 137 product tankers changed owners. However, future uncertainty regarding environmental regulations and market demand favors vessels that are relatively old. Consequently, the average age for sold vessels is 13 years, which supposedly is the highest on record. In general, the difference between newbuild and secondhand prices is a decent indicator of the market temperature. Further, the difference between TC rate development and secondhand prices reflects expectations regarding freight rates. Typically, when secondhand prices of vessels outperform the one year TC-rate, the market expects future earnings to rise, something which could be seen in 2019. While the one-year TC rate for a LR2 increased with 2 million USD, secondhand prices for five year old vessels increased with 3 millions USD. Secondhand price development for 5-year old product tankers are displayed in Figure 5.5.

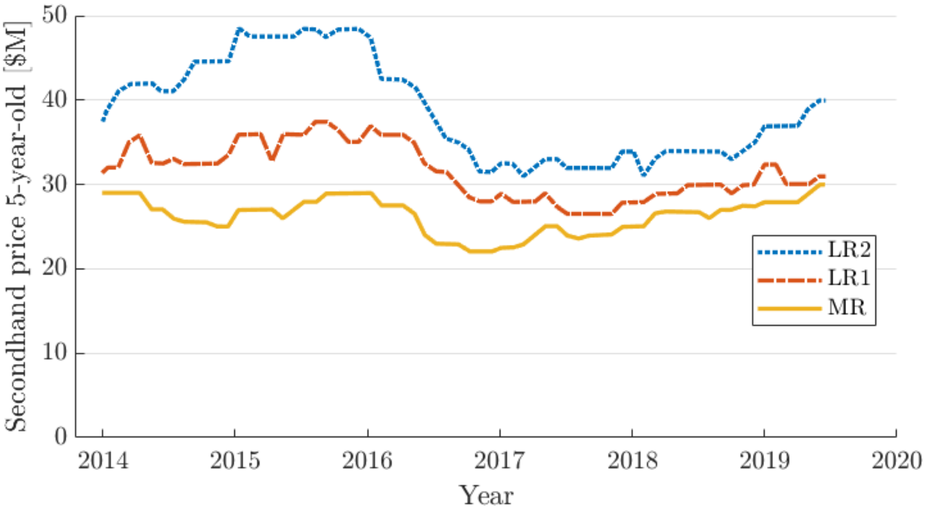


Figure 5.5: Average secondhand price of a five-year-old product tanker from 2014 to 2020 (Danish Ship Finance, 2019).

The fleet composition of the product tanker fleet is seen in the bar chart in Figure 5.6, separating between the LR2, LR1 and MR segment. As seen, the orderbook corresponds to 7 % of the total fleet tonnage, and the fleet as a whole is considered to be relatively young. Projected growth for the following three years within the LR2 and MR segment is strong and estimated to 9 % and 7 %, respectively. Fleet growth for the LR1 segment is projected to be limited to only 2 %. Thus, in general, the fleet growth for product tankers is considered strong. However, lower demand expectations implies little room for major fleet expansion, which can be considered a medium/long-term risk.

Historic data for fleet growth can be seen in Figure 5.7, which illustrates the development of deliveries and scrapping over the last decade. The fleet growth of the first ten months of 2019 was high, but the growth was mainly driven by low scrapping frequency. Probably, scrapping was postponed in order to benefit from the IMO 2020 effect on freight rates. Further, the disputes regarding the oil price during spring 2020 are likely to prolong the low scrapping frequency if earnings remain high.

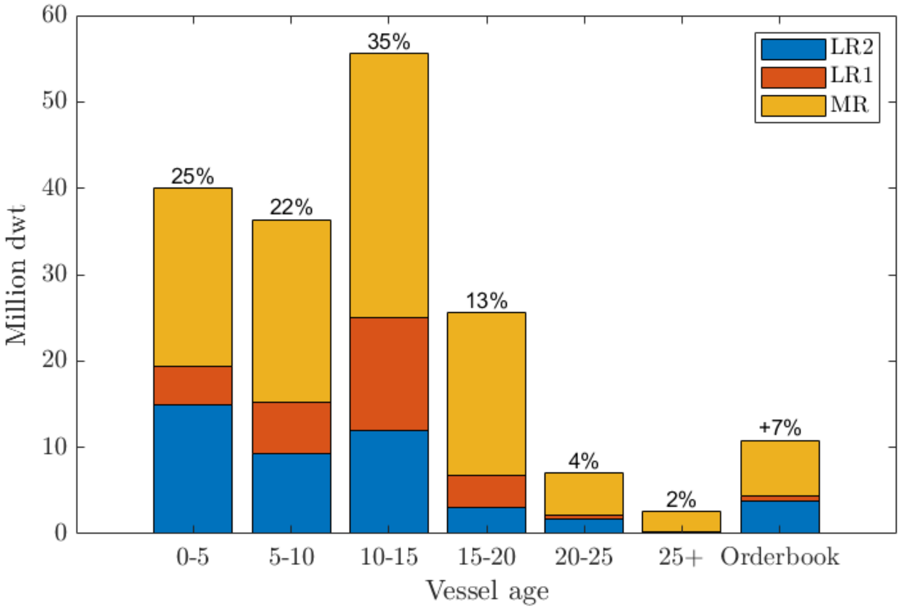


Figure 5.6: Product tanker fleet composition, sorted by vessel age and combined total capacity in million dwt. The last column displays the size of the orderbook relative to the total capacity of all product tankers (Danish Ship Finance, 2019).

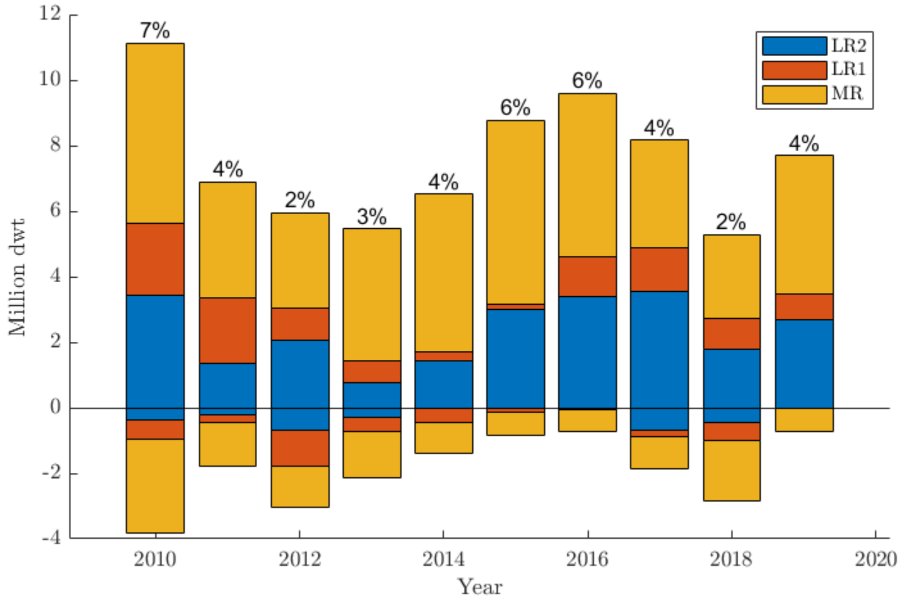


Figure 5.7: Fleet growth for product tankers from 2010 to 2019, though only from January to October for 2019. Values below zero indicate the total tonnage of scrapping for each tanker segment, while positive values indicate deliveries. The percentage mark on top of each bar indicates the annual fleet growth of the respecting year for product tankers in general. (Danish Ship Finance, 2019).

5.2 Future Environmental Regulations

In order to limit pollution of the environment, the shipping industry must adapt to various regulations and conventions. Naturally, the regulations are changing gradually and develops stricter with time. Given the long operational lifetime of a ship, stakeholders must take both current and future environmental regulations into consideration during evaluation of project decisions. Initially, forthcoming emission regulations that may be decisive for current ship design are presented. It is assumed that the reader is familiar with important current emission regulations, including global sulphur cap, Ship Energy Efficiency and Management Plan (SEEMP), and emission control areas (ECA) of SO_x, NO_x and PM. Thus, these regulations are not elaborated in this thesis. However, current regulations are obviously also needed to consider in order to determine future proof project decisions. Following, possible pathways to cope with the expected future emission regulation are discussed.

5.2.1 Energy Efficiency Design Index

The Energy Efficiency Design Index (EEDI) aims to reduce CO_2 emissions from shipping and is applicable to newbuild vessels. The emission reduction is done by gradually tightening the maximum required level of CO_2 emissions per tonne mile, referred to as carbon intensity. Thus, the regulation can be satisfied through ships of higher energy efficiency or through implementation of propulsion with a lower carbon profile. The regulation provides ship owners with the flexibility to choose the technology that best fits their economy, trade and vessel, as long as the required carbon intensity is lower than the requirement levels. The maximum EEDI value is dependent upon size and ship type. The required EEDI value decreases during different implementation phases, as reflected in Figure 5.8. As of 2020, the EEDI is in Phase 2. Thus, compared to a ship delivered before 2015, a newbuild delivered today must comply with a 15-20 % lower carbon intensity, depending on size and type.

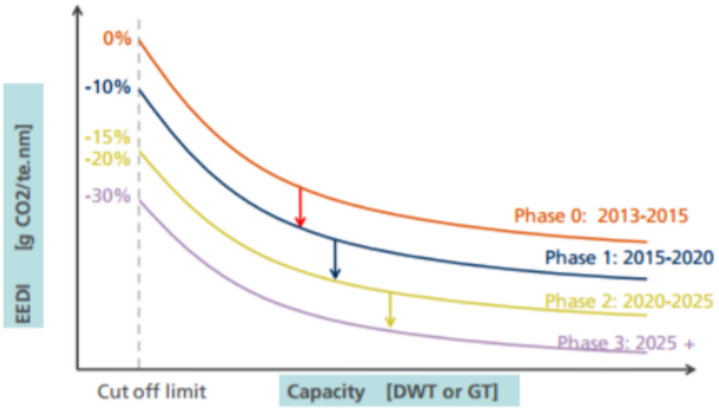


Figure 5.8: Baselines for the different phases of the EEDI. The cut off limit (dashed line) reflects that smaller vessels are exempted from a required EEDI (IMO, 2016).

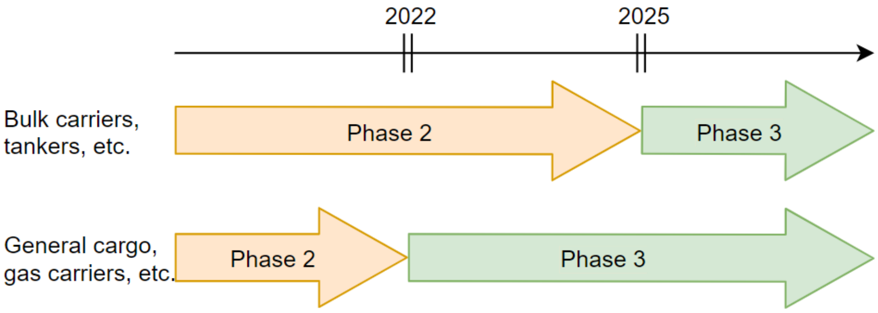


Figure 5.9: Earlier EEDI Phase 3 for certain ship types.

While the EEDI is only applicable to newbuilds, there have been proposed to implement an EEDI for existing ships, until further referred to as Energy Efficiency Existing Ship Index (EEXI) (Nyhus, 2019). Suggested emission reduction percentages are shown for different ship types in table 5.2.

Table 5.2: EEDI for existing ships: EEXI. Required EEXI value is shown as a percentage difference from an EEDI baseline.

Ship type	**Required EEXI**
General cargo, LNG carrier, cruise ship	Δ30 %
Bulk carrier, tanker, ro-ro, combination carrier	Δ20 %
Container ship	Δ 30-50 %
Gas carrier	Δ 20-30 %
Reefer	Δ 15 %

5.2.2 Expansion of ECA zones

Starting from 1st January 2021, the North Sea and The Baltic Sea will be a designated ECA for NO_x (IMO, 2019). Hence, if a vessel is built after this date and sails in the specified area or in the North American ECA, the vessel must be NO_x Tier III compliant.

5.2.3 Reduction Goals for GHG Emissions

In April 2018, IMO adopted an initial greenhouse gas (GHG) reduction strategy. The vision of the strategy is to gradually phase out carbonized fuels and to peak GHG emissions from international shipping as soon as possible. The long-term goal is to reduce total GHG emissions from shipping by at least 50 % within 2050. This is a challenging goal, which puts pressure on ship owners and other relevant stakeholders. An expected fleet growth towards 2050 increases the difficulty of the goal even further. According to UNCTAD (2019), the world fleet reached a capacity of 1.97 billion dwt in January 2019. This corresponds to an approximate 2.6 % increase compared with the previous year, which is the lowest fleet growth this decade. The report projects an annual fleet growth of 3.4 % in the period 2019-2024. Assuming an equal fleet growth from 2025-2030, the world fleet will reach a total capacity of approximately 2.9 billion dwt in 2030. This is equal to a total fleet growth of almost 50 % from 2019-2030. In other words, the difficulty of a 50 % GHG emissions reduction may increase with time and is dependent upon the size of the world fleet. However, as most long-term predictions, the expected fleet growth is highly uncertain. In addition to reduce the GHG emissions in general, there are specific goals required for CO_2 emissions, which is the biggest contributor to GHG emissions globally. The average carbon intensity, CO_2 per tonne mile, must to be reduced by 40 % within 2030 and 70 % within 2050 in order to satisfy the goals of IMO. All mentioned reduction goals are relative to a 2008 baseline. Though, the baselines remain to be quantified. Estimations for current CO_2 emissions and carbon intensity from shipping is seen in Figure 5.10 below.

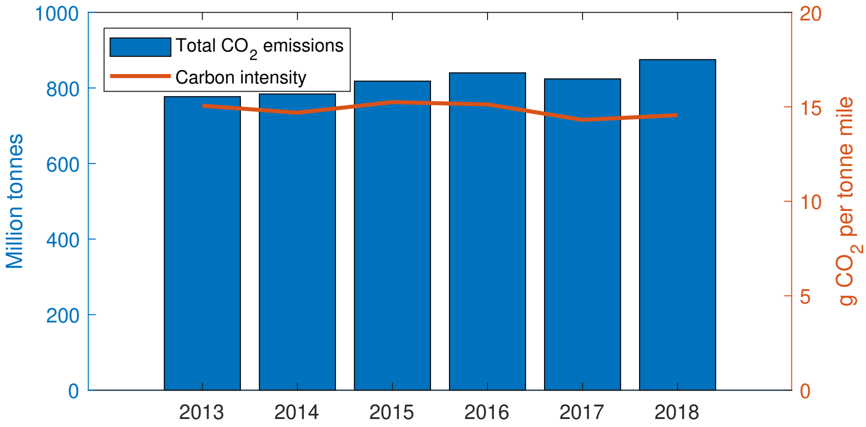


Figure 5.10: Average carbon intensity and CO_2 emissions from the world shipping fleet seen from 2013-2018. Emission statistics are gathered from DNV GL (2019c).

It should be noted that the IMO GHG strategy is yet to be concretized and put into regulation. Currently, the formulation of the strategy is somewhat vague and details regarding the implementation strategy are needed. In order to exemplify, the measured carbon intensity of a vessel depends on how the emissions are calculated. So far, a definition for such calculations is lacking, and there may be huge differences in carbon intensity whether only tank-to-propeller emission is included in the calculations in comparison with an inclusion of well-to-tank emissions as well. The process of the total GHG emission reduction also raises some doubts. Whether a ship owner can reduce its GHG emissions of the fleet as a whole, or if the reduction must be specific for each vessel needs to be determined. Additionally, too strict requirements may lead to a too low capacity of the world fleet if the requirements drastically increase the scrapping frequency. Thus, gradual increasing requirements may be needed to phase out old vessels in a decent pace. However, this may lead to a possible unwanted effect by making it more attractive to buy old vessels than to invest in newbuilds. Hence, the implementation strategy needs to be balanced accordingly.

More precise formulations of the strategy are expected to be included in the Fourth IMO GHG study, which is supposed to be ready by Marine Environment Protection Committee's 76th session (MEPC 76) during Autumn 2020. If a regulation amendment is approved at MEPC 76, an adoption can take place at MEPC 77, no earlier than Spring 2021. In that case, new regulations can entry into force by the end of 2022.

5.3 Fuels of the Future

The project thesis of Rudi (2019) evaluates possible pathways to reduce the GHG emissions for a deep-sea shipping fleet. An alternative fuel study was conducted in addition to investigation of innovative solutions as wind-assisted propulsion. Key findings from the study are hereby presented, and possible pathways to comply with future regulations are discussed.

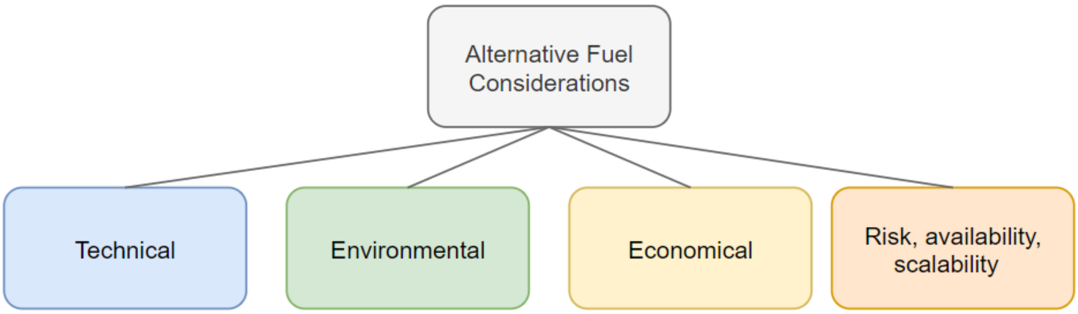


Figure 5.11: Key aspects during consideration of alternative fuels.

5.3.1 Compliance with Future Environmental Regulations

The implementation of fuel alternatives with a lower carbon profile is important to decrease the carbon intensity enough to fulfill the IMO goals, and there are several alternative fuels commercially available. Several aspects should be addressed when considering different fuel alternatives. Initially, the technology must be proven with low downtime and to be easily maintainable. On an environmental level, current and expected regulations must be fulfilled. Further, in order to stay competitive, the alternative fuel must be cost-efficient. Additionally, various aspects regarding risk, logistics/availability and scalability should also be considered.

Possible alternative fuels include methanol, LPG, LNG, biofuels, ammonia and hydrogen. Referring to Figure 5.12, a separation for the mentioned alternative fuels is done in terms of steps. The steps are supposed to illustrate the concept of fuel bridging, leading to a higher reduction with time. Given limited or no experience for ammonia and liquid hydrogen as marine fuels, the technology-readiness level is lower than for the fuels categorized in step I. In Step I, LNG is the fuel with the highest uptake frequency. Reportedly, almost 400 ships are today running on LNG (DNV GL, 2020). In turn, methanol and LPG is the preferred fuel of 24 and 25 vessels, respectively.

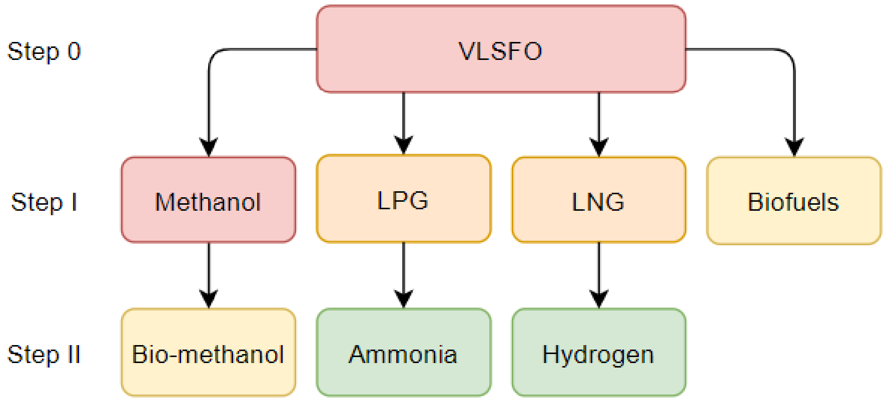


Figure 5.12: Alternative fuel pathways for compliance with future environmental regulations.

The different alternative fuels have a varying potential of GHG emission reduction, and estimations of their potential reduction vary between different studies. Reduction estimates of the alternative fuels are given in Table 5.3. The reduction potential is given relative to GHG emissions from HFO, due to that the IMO goals is based on a 2008 baseline.

Table 5.3: GHG reduction potential for various alternative fuels, relative to HFO and measured from tank-to-propeller (Brynolf et al., 2011; DNV GL, 2019b; DNV GL, 2019a).

Fuel Alternative	Reduction potential	Fuel bridging	Total reduction
Methanol	5-10 %	Bio-methanol	50 %
LPG	15-25 %	Ammonia	100 %
LNG	20-30 %	Hydrogen	100 %
Biofuels	50 %	-	50 %

By examining the estimations in Table 5.3, it can be seen that the information given in the table corresponds with the colors used in Figure 5.12. The colors represent the capability of a fuel to be compliant with future GHG emission regulations, with the scale being ranged by the order red-orange-yellow-green, in which red is the least capable of sufficient GHG reduction of the assessed alternative fuels.

The pathways providing the lowest GHG emissions is through LNG and LPG, leading to ammonia and hydrogen. However, the issue of methane slips should be kept in mind, as methane is assumed to have a remarkably higher global warming potential than CO_2. Further, it can be seen that methanol has a lower GHG reduction potential than the other fuels listed. Currently, methanol is performing well against the regulations, having very low emission of particulate matter and sulphur- and nitrogen-oxides. However, in a long-term perspective, with expectations of more strict CO_2 regulation, methanol as a marine fuel may struggle to comply with the regulations, unless the methanol is produced from biomass. Like certain biofuels, bio-methanol has a good potential in terms of CO_2 emission reductions.

Biofuels is an umbrella term containing fuels produced from biomass, but the characteristics of various biofuels can be quite different. Hydrotreated vegetable oil (HVO) can be used in conventional diesel engines, while liquefied biogas (LBG) can be used as a drop in fuel in LNG engines. Both fuels are provided with a strong potential of emission reduction, while FAME's emission reduction potential is more limited. Anyhow, issues regarding sustainability are associated with large scale production given that biomass resources often compete with food crops. Another obstacle with biofuels is the relatively high fuel cost.

5.3.2 Economical and Technical Aspects

The fuel cost is a decisive parameter regarding the choice of future alternative fuels. However, fuel prices are not always straight forward to compare. The energy content per tonne varies significantly, and thus, to compare the different fuels by price per tonne is insufficient. Further, prices may be given per gross calorific value, which again may have varying standards of calculations. By these reasons, some assumptions are needed in order to perform a proper comparison of fuel prices, and a common unit is needed. Thus, the fuel price is given in terms of tonnes per MGO equivalent. Essentially, this is done by comparing the lower heating value (given in megajoules per kg) of the alternative fuels. Figure 5.13 displays the fuel price development from 2013-2020 for selected fuel types. The prices are updated quarterly.

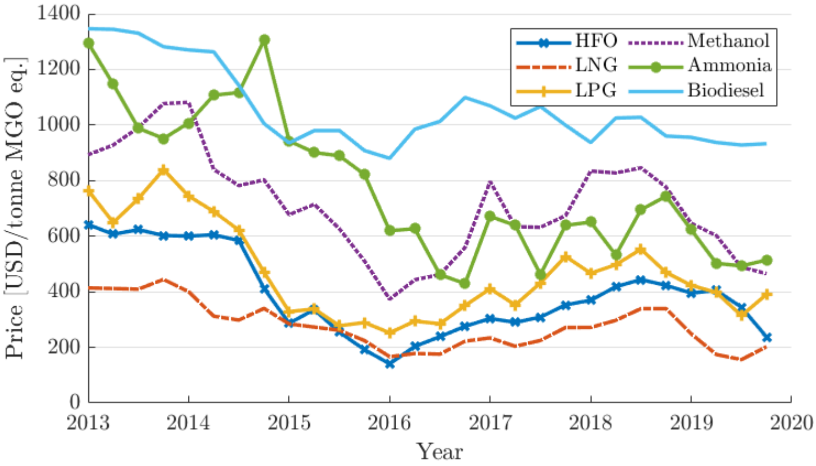


Figure 5.13: Fuel price for various fuel types from 2013-2020. The prices are updated each quarter and are estimated as USD per tonne MGO equivalent. Statistics are gathered from (DNV GL, 2020).

Figure 5.13 illustrates the high fluctuation of fuel price differences. As an example, the ratio between MGO and LNG is approximately four when measured in 2011. The same ratio is reduced to nearly one in 2015. Thus, the fuel price of today can not determine the payback time of a future investment without great uncertainty. The plot identifies biodiesel and methanol to be of high cost per energy content, compared to LNG and LPG. Unfortunately, sufficient historical price data for hydrogen, ammonia and certain biofuels were not retrieved.

Further, the relation between energy, weight and volume is of interest due to product tanker shipping being space critical. A bigger required volume for fuel tanks implies less space for cargo, and thus, lower earnings. Hence, a fuel of high volumetric density is desired. Figure 5.14 illustrates the relation between energy, weight and volume for selected alternative fuels. The required volume needed for a certain amount of energy, is decreasing from the bottom and up, while the energy amount per unit mass is increasing from left to right. In other words, bottom left is least desirable and upper right is most favorable.

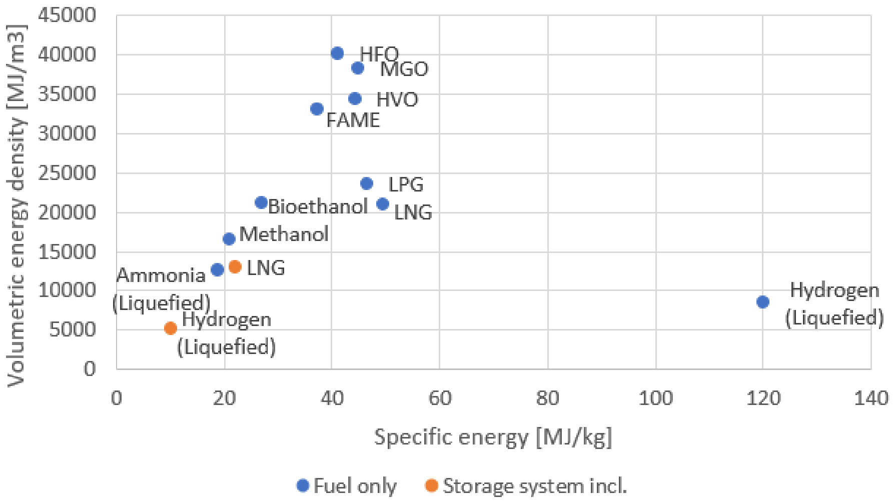


Figure 5.14: Relation between energy, weight and volume for selected alternative fuels. Data gathered from Aatola et al. (2008); Balcombe et al. (2019); Portin (2019); DNV GL (2019b).

At first sight when examining Figure 5.14, liquefied hydrogen stands out with a high specific energy, while HFO and MGO stand out as the most volume effective fuel alternatives. However, the blue circles in the scatter plot show only the relation of the thermodynamic properties of different fuels. Additional system configurations as tank insulation and onboard boil-off handling is not taken into account. Considering hydrogen needs to be refrigerated below -253°C to be liquid, the increase in thickness of tank insulation is significant. Given the low density of hydrogen, a heavy storage system will affect the specific energy correspondingly. Thus, when the storage system is included, the hydrogen fuel system's energy per unit mass is decreased by up to 90 %. In general, fuels that are liquid under ambient temperature and atmospheric pressure are easily integrated on a vessel, while gaseous fuels require insulation and pressurization, either combined or alone. Anyhow, structural changes are required. Consequently, retrofitting of gaseous fuels can accumulate to high costs. Insulation requirements for gaseous fuels lead to smaller fuel tanks, which may limit the operational range of a vessel. Insulation requirements are strict for liquid hydrogen and LNG, and the two fuels performs significantly lower when the storage systems are taken into account. The same accounts for ammonia and LPG if the use of refrigerated tanks. Though, pressurized tanks is a more common configuration for ammonia and LPG. When under pressure, insulation requirements are lower. Consequently, LPG storage requires less volume than LNG.

Another important consideration when evaluating alternative fuels is the cost differences associated with capital expenditures. A 75,000 dwt LR1 tanker case study is evaluated in DNV GL (2016), and the report evaluates several different fuel configurations. The configurations are presented below in Table 5.4, together with the additional CAPEX of each configuration in 5.15. Engine upgrades, fuel supply system and fuel storage in addition to installation and engineering costs are reportedly included in the given CAPEX.

Table 5.4: Different fuel configurations alternatives from DNV GL (2016) LR1 case study.

Configuration	Inside ECA	Outside ECA
MGO/VLSFO	MGO	VLSFO
LNG/VLSFO	LNG	
LPG/VLSFO	LPG	
Methanol/VLSFO	Methanol	
LNG	LNG	LNG
LPG	LPG	LPG
Methanol	Methanol	Methanol

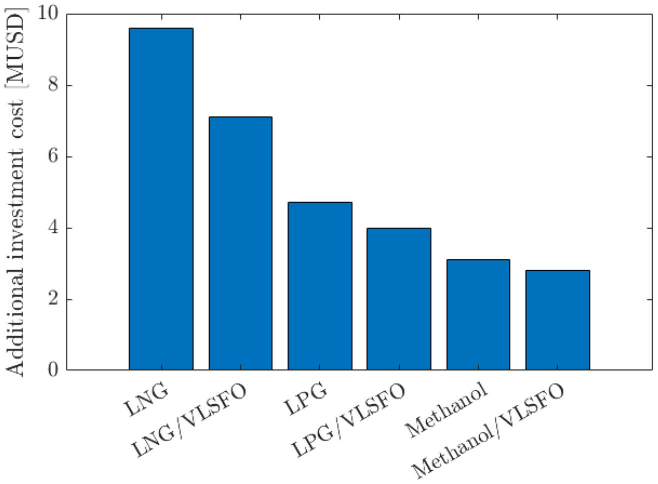


Figure 5.15: Additional investment cost for the different fuel configurations seen in Table 5.4. The numbers are from a 75,000 dwt LR1 product tanker case study (DNV GL, 2016).

As shown in Figure 5.15, the added cost for the LNG configuration is twice as high compared to LPG, while the additional CAPEX of methanol is a third of additional CAPEX for LNG. At first sight, it can seem odd that the LNG configuration is more expensive than the LNG/VLSFO configuration. However, the configuration of LNG/VLSFO is assuming VLSFO consumption outside any ECA, and thus, the LNG configuration is on a smaller scale with less insulated tanks etc. Anyhow, VLSFO is unlikely to comply with future GHG emissions. Therefore, the CAPEX for LNG, LPG and methanol configurations are the interesting ones.

5.4 Fuel Saving Technology as a Measure for Future Compliance

A simple way to comply with future GHG emissions and carbon intensity requirements is through implementation of fuel saving technology. A wide variety of technologies exist with the objective of lowering the fuel costs. Measures and their respecting fuel saving potential is presented in Table 5.5. Some of the measures can be re-combined with each other, providing substantial cumulative fuel savings. Thus, by combining fuel saving technology measures with the use of alternative fuels, compliance with future GHG emission regulations are facilitated.

Table 5.5: Estimations of potential fuel savings for implementation of technology measures or structural changes. Numbers based on DNV GL (2019b); Traut et al. (2014); Norsepower (2019).

Technology measure	Potential fuel savings	
	Main engine	Auxiliaries
Hull form (newbuilding)	12 - 17 %	-
Hydrodynamics (retrofit)	13-20 %	-
Machinery improvements	4-8 %	12-23 %
Waste heat recovery	0-8 %	-
Operational measures	3-11 %	-
Air lubrication	3-5 %	-
Flettner rotor	5-10 %	-
Kites	5 %	-
Cold ironing	-	30-70 %
Hybridization	3-15 %	

5.5 Potential Future Technological Game Changers

Given an uncertain future, there is a possibility for the introduction of new game changing technology. An interesting topic is the introduction of carbon capturing systems (CCS) on-board vessels. If made financially feasible, the transition away from fossil-fuels may become unnecessary. If so, the benefit from introduction of fuel flexibility is somewhat limited. If it is possible to comply with emission regulations without the use of alternative fuels, additional CAPEX is avoided. Though, any advantage from fuel prices fluctuation is not made without fuel flexible engines.

As mentioned earlier, a major challenge with the introduction of low-carbon fuels as ammonia and hydrogen is associated with their low volumetric energy density. Fuel capacity problems or fuel tanks occupying space that could have been used for cargo are aspects that argues against the introduction of such fuels. However, if future technology can limit these challenges, this will be a potential game changer. Bunkering stations mid-ocean, tanks on deck or fuel storage facilities on tow at the aft of the ship can all increase the feasibility of low-density fuels. These solutions are radical and may seem unrealistic as of now, but they should not be disregarded.

Further, another potential game changer is a future reduction in size for battery solutions and maturity of fuel cells. This can make electricity and hybrid configurations more interesting from a commercial point of view, and not be limited to ferries and other similar small vessels. Fuel cell development is decisive to what degree hydrogen may become a feasible alternative or not.

The implementation of carbon taxes or incentives that reward the uptake of alternative fuels can potentially drive the development in a clear direction. However, there is a possibility that the costs of a carbon tax will be pushed towards the consumer. Hence, financial incentives are more likely to be creators of change.

6 Case Study: Flexibility Valuation for a MR2 Product tanker

The purpose of the case study is to evaluate if implementation of engine flexibility in deep-sea shipping is a suitable approach to face the uncertain future context of shipping. Mainly, the study evaluates the expected value of a dual fuel engine, based on the value achieved from fuel switching. Additionally, a comparison is made between the implementation of fuel flexibility from the beginning versus the option to retrofit on a later occasion, in order to comply with future environmental regulations. Possible environmental regulations are suggested during an uncertainty identification. Further, the market outlook of the case study is based on available historic price data, combined with the use of stochastic processes to model the future. Relevant market conditions such as earnings and fuel prices are simulated to form a basis for the economics of the project decisions. Finally, decisions regarding engine flexibility are valued through a real option approach.

6.1 Characteristics and Parameters of the Case Study

Relevant parameters and characteristics of the case study is established and a description of the case study is elaborated in this section. The ship under consideration in the case study is a MR2 product tanker, and its dimensions are listed in Table 6.1. Typically, the vessel trades between the Gulf of Mexico and countries in the Far East. Thus, the dimensions of the ship are naturally restricted by the size of the Panama canal.

Table 6.1: Ship dimensions in the case study. Lengths in meters and weight in tonnes.

Loa	Lpp	Beam	Depth	DWT	Lws
183.20	174.10	32.20	18.80	48,000	10,374

The product tanker is ready to be put into the trade from the beginning of 2020, and the purchase price of the ship is \$ 35 million. The purchase price is set equal to the last known sale according to the numbers of Clarksons Research (2020). The price history for MR2 product tankers of approximately 50,000 dwt is shown in Figure 6.1. In order to enable the purchase, it is assumed that 70 % of the purchase price needs to be financed through a loan. Loans in the case study are given with an interest rate of 8.5 %, while the discount rate is set equal to 5 %. Further, it is assumed that the product tanker has a lifetime of 20 years. By the end of the twentieth year, the ship is sold for scrapping. The scrap price is determined as the product of the steel price and the lightship weight, with the steel price being set to \$ 600 per tonne.

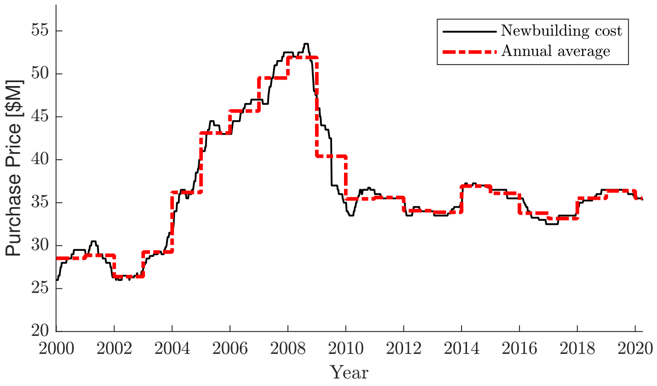


Figure 6.1: Historical newbuilding cost for a MR2 product tanker of approximately 50,000 DWT (Clarksons Research, 2020).

The following parameters are estimated and determined on the basis of discussions with subject-matter experts (Personal communication, Tore Haugen, 28.04.2020). Thus, daily operational expenditures (excluding fuel costs and port fees) for the product tanker in the case study is set to \$ 6,500 per day. Though, the OPEX is assumed to increase 2 % annually. Further, it is assumed that the average consumption level is equal to 28 tons per sailing day, while the number of sailing days per year is set to 260. Thus, no earnings are generated for 105 days each year. The mentioned parameters of the case study are summarized in Table 6.2.

Table 6.2: Defined parameters of the MR2 product tanker case study

Purchase price USD	Consumption $\frac{\text{tonne}}{\text{day}}$	Sailing $\frac{\text{days}}{\text{year}}$	OPEX $\frac{\text{USD}}{\text{day}}$	Debt -	Discount rate -	Interest rate -
\$ 35,000,000	28	260	\$ 6,500	70 %	5.0 %	8.5 %

6.2 Uncertainty Identification and Case Options

The future operating context, which is discussed and elaborated in section 5, is used in order to identify the relevant uncertainties of the case study. The identified uncertainties are summarized below in Table 6.3.

Table 6.3: Uncertainties highlighted as especially relevant for the case study.

Type	**Uncertainties**
Market	Fuel prices, freight rate, technology cost, newbuilding cost
Regulations	GHG emission reduction, future ECA, EEDI/EEXI
Technology	Fuel saving technology, alternative fuels, potential technological game changers
Political	Financial incentives, carbon tax

Some of the identified uncertainties in the case study can be categorized as exogenous, which means that they are independent from project decisions. In general, the market related uncertainties are outside the control of a shipowner. That is also the case for regulation implementations, political initiatives and technology development. However, actions can be made in order to be better prepared for different outcomes of the uncertainties.

The future uncertainties related to regulations, fuel prices and feasibility of alternative fuels are essential to take into account when building new vessels. Engine flexibility is suggested as a measure to avoid non-compliant vessels. A flexible engine provides the ship owner with freedom to change fuel in order avoid availability issues, and simultaneously, the option to perform a fuel switch towards a cheaper or more well-developed fuel is made possible. Another important purpose of implementation of fuel flexibility is to be better prepared towards stricter emission regulations.

If the GHG reduction goals of IMO are to be accomplished, stricter regulations will be implemented. However, as of now, it is challenging to predict when regulations are becoming more strict and also the degree of strictness. In order to satisfy the goal of a 40 % reduction in carbon intensity within 2030, it is reasonable to assume there will be a shift from VLSFO to fuels with a lower carbon content. It is believed that both LNG and LPG are sufficient fuel alternatives in the first phase towards low-carbon shipping. They both allow for a further transition towards zero-carbon fuels as fuel bridging from LNG and LPG to hydrogen and ammonia respectively is considered to be a possible pathway. Additionally, the technology readiness level of both LPG and LNG is considered to be sufficient as of today. As mentioned in section 5, the volumes required for a LNG system is substantial due to the low temperatures needed in order to liquefy the gas. Hence, if an LNG system is installed on a ship, the amount of cargo that can be loaded is likely to decrease. In turn, an LPG configuration has lower volume requirements due to the fact that the gas can be pressurized to obtain liquid form. Thus, the case study evaluates the change from VLSFO towards LPG. Future availability and scalability of LPG as a marine fuel can be an obstacle. However, this is disregarded in the case study, but these issues should be kept in mind by the reader.

Now that LPG has been identified as the case study candidate to face future emission regulation, different future scenarios are introduced. The scenarios forms the basis for the calculations used to value fuel flexibility. The strictness of future GHG emission regulations is currently unknown. However, an assumption is made that the inclusion of an LPG configuration is sufficient in order to comply with future GHG emission regulations. Thus, for a ship delivered today, two different choices can be made to cope with the expected regulations.

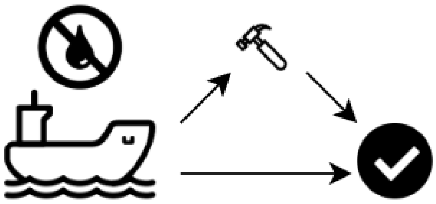


Figure 6.2: Flowchart illustrating two possibilities of emission regulation compliance, either fuel flexibility from the beginning or retrofit on a later occasion.

The choices can be separated as either a proactive or a reactive approach. The proactive approach represents to order a product tanker that is equipped with a dual fuel engine providing the option of switching between LPG and VLSFO. Until regulations are implemented, the cheapest of the two fuels is the preferred fuel. When the regulations are put into effect, the transition is uncomplicated and easily performed. In turn, the reactive approach represents the option to wait until it is known whether new emission regulations are implemented or not, and if they are, a retrofit of an LPG configuration can be made before the regulations are put into effect. Table 6.4 shows differences in purchase price and space available for cargo between a conventional MR2 product tanker and one equipped with a dual fuel engine capable of both LPG and VLSFO consumption. The cargo reduction affects the earnings correspondingly.

Table 6.4: Differences between the conventional product tanker and a product tanker with an LPG/VLSFO dual fuel engine.

Configuration	**Purchase price**	**Cargo reduction**
Conventional	$ 35,000,000	0 %
Dual fuel	$ 41,000,000	2 %

It is assumed that a retrofit which is made in order to enable an LPG configuration is of a higher cost than the $ 6 million extra that were presented in table Table 6.4. This is due to that such a retrofit is a complicated installation and requires thorough engineering and planning in advance. Thus, the cost of the retrofit is assumed to be 25 % higher than installing a dual fuel engine from the very start. In addition, the cost of the retrofit is assumed to increase with 2 % annually. The difference in retrofit is displayed in Table 6.5. The retrofit also requires drydocking, and thus, there is a loss in earnings during the drydocking period. Further, the time to retrofit must be determined, and a distinction is made between none implementation, soft, moderate and strict implementation. They all represent possible future scenarios of emission regulation. The scenario without implementation of new emission regulations indicates that no transition from VLSFO is needed, and the vessel can run on VLSFO its whole operational lifetime. It can be argued that this is unlikely. However, the aforementioned game changers in subsection 5.5 can make this scenario a possibility. The soft, medium and strict scenario all describe an identical needed switch from VLSFO to a fuel of a lower carbon profile, as for example LPG. The difference between the scenarios is the time of implementation. The strict, moderate and soft scenario indicates an implementation in either 2025, 2030 or 2035, respectively. It is assumed that a further fuel transition is not applicable for the case study, given that the product tanker is scrapped after 20 operational years. However, measures of fuel savings may be needed, but this is not further discussed in the case study.

Table 6.5: Cost associated with retrofit of LPG configuration

Scenario	Retrofit year	Retrofit cost	Days in drydock
Strict	2025	$ 8,300,000	30
Moderate	2030	$ 9,150,000	30
Soft	2035	$ 10,100,000	30

6.3 Historical MR Product Tanker Earnings

The different choices already explained affect the profitability of the product tanker during its operational lifetime. In order to evaluate to what degree the profitability is affected by a given decision, it is beneficial to form an adequate picture of expected earnings and lifecycle costs.

Historical earnings for the MR product tanker segment of approximately 50,000 DWT have been retrieved from the database of Clarksons Research (2020). Daily earning rates are reported and updated correspondingly on a weekly basis and expressed as the average daily earning of all reported numbers. The earnings are estimated from the freight rates, subtracting voyage related costs as bunker and port fees. Other operational expenditures such as crew, insurance and lubeoil are not taken into account in the earnings statistics. The given time series spans from the beginning of 1990 until the middle of April 2020 and can be seen in its entirety in Figure 6.3. The occurrence of volatile earnings in the tanker market is clearly visualized, and periods of remarkable high earnings are identified in the years prior to the financial crisis, in addition to the year of 2015 and also recently, in the end of 2019 and beginning of 2020. It can be hard to evaluate a highly volatile time series visually, and thus, the corresponding histogram of the time series is provided in Figure 6.4 in order to easier illustrate how often different earnings occur during the examined period.

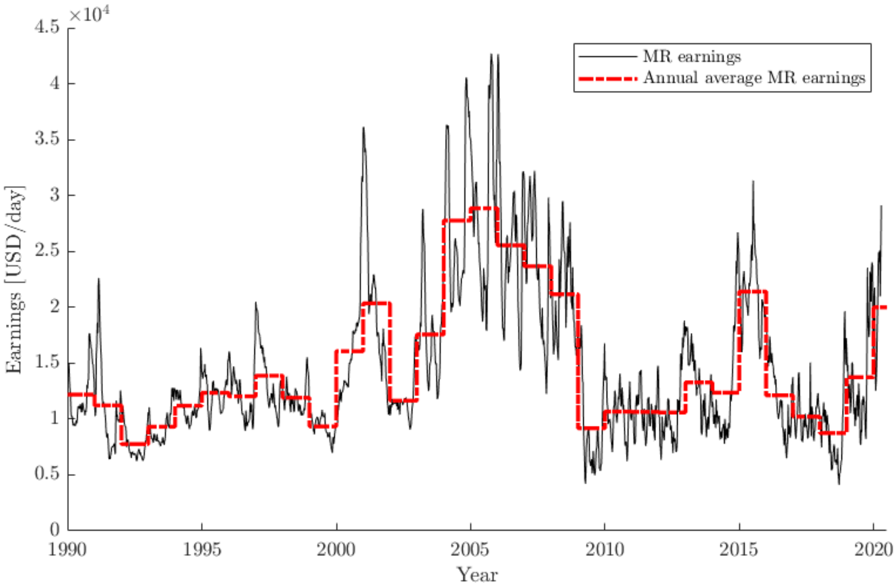


Figure 6.3: Historical spot earnings for MR product tankers of approximately 50,000 DWT, from 1990 to mid-April 2020.

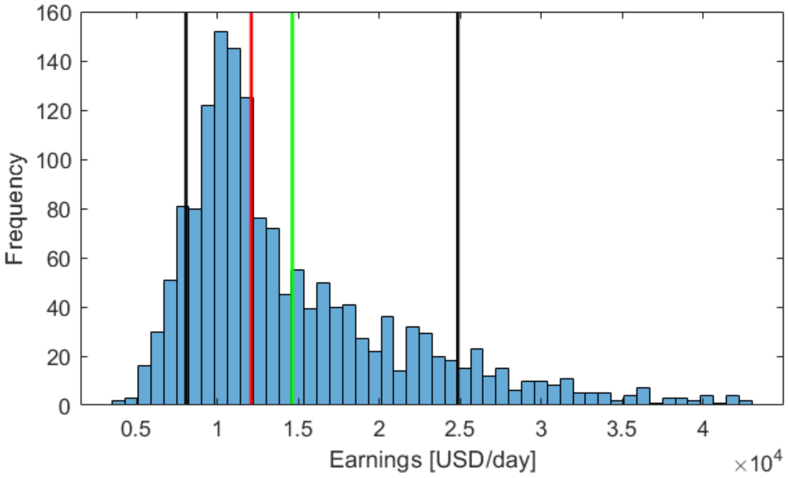


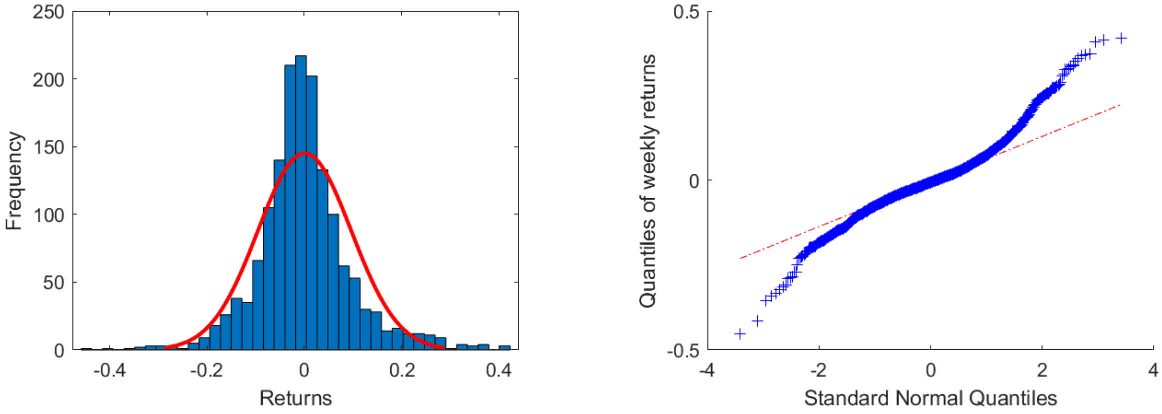
Figure 6.4: Histogram for historical MR product tanker earnings. Going left to right, the vertical lines represent the 10th percentile, median, mean and 90th percentile of the data set.

By evaluating the histogram given in Figure 6.4, it can be stated that a normal distribution is an inappropriate distribution in order to describe the MR product tanker earnings. Extreme observations occur at a higher rate than what would fit to a normal distribution. The shown distribution has a significant right-side tail, with the average earnings being greater than the median earnings. Hence, the distribution of the data set is asymmetrical and it has a positive skewness. Further, if the data set followed a normal distribution, the kurtosis would be approximately three. The observed kurtosis of the earnings distribution is significantly bigger than three, and thus, the distribution is leptokurtic. Relevant descriptive statistics for the MR earnings data set are given in Table 6.6.

Table 6.6: Descriptive statistics of MR product tanker earnings data set. Percentiles, median and average given in USD per day.

Data points	Median	Average	Skewness	Kurtosis	Percentile	
					10th	90th
1,581	\$ 12,082	\$ 14,611	1.411	4.834	\$ 8,045	\$ 24,830

According to Black & Scholes (1973), earnings are normally assumed to be *log-normal* distributed. If so, the corresponding return on the earnings should be normally distributed. Figure 6.5a shows the distribution of the returns and compares it with a normal distribution. By examining the plot, it is clear that the returns are not normal distributed, and thus, the earnings are not log-normal distributed. This is in accordance with Alizadeh & Nomikos (2009), who state that freight rates and earnings in shipping usually are leptokurtic with a far higher probability of extremely high or low values than what log-normal distribution would imply, and that returns are non-Gaussian. This does again correspond well with what is already observed in the earnings histogram in Figure 6.4. Additionally, the occurrence of high fluctuations is observed in the QQ-plot of the returns in Figure 6.5b.



(a) Histogram of returns.

(b) QQ-plot of returns.

Figure 6.5: Normality plots for historical MR product tanker earnings. Red lines are theoretical values of the normal distribution, while blue is for the sample data.

Through investigation of earnings time series from 1978 to 1996, Kavussanos & Alizadeh-M (2002) identify the occurrence of deterministic seasonality within the tanker market for certain segments. As an example, the heating oil consumption in the Northern Hemisphere increases every winter and declines every summer, with seasonal peaks reached in November and December pushing the rates up, followed by declining rates until April. At this point, the seasonal dependencies are not included in the model used in the case study. However, seasonal dependencies in earnings may affect the timing of e.g. drydocking.

6.4 Future Predictions of Earnings

A major uncertainty for the profitability of a MR product tanker is its future earnings, and thus, the case study is vulnerable to claims regarding future earnings. It can be argued that the challenge to predict the market increase with the length of the period under consideration. Financial instruments as futures and forwards may give a sufficient indication to future earnings in the near vicinity, However, for long-term predictions, the errors of predictions based on financial futures and forwards may be high. This is due to possible unforeseen game-changing events in the market conditions. Recent events illustrating this include the bombing of Saudi Aramco's oil processing facilities in September 2019 and the plunging oil demand during the spring of 2020 due to the corona pandemic. In the first case, earnings increased due to concerns regarding lack of oil supply, while the latter case pushed the earnings upwards due to an over-supply of oil leading to full storage facilities and low oil prices. If the time span of the future period under consideration increases, the probability of a market shock within the given period would also increase. By this reasoning, it is argued that deterministic predictions of earnings, as modeling through financial futures, forms a weak basis for further analysis. This is especially due to the long time periods under consideration in this case study.

6.4.1 Stochastic Processes to Predict Future Earnings

Dixit & Pindyck (1994) state that the dynamics of mean reversion is applicable to certain asset prices, including shipping earnings. If the rates are higher than the long-term mean of a time series, new suppliers are attracted to the market. Eventually, the increased supply will push the rates down. If pushed too far, suppliers may withdraw from the market. Consequently, there may eventually be a lack of supply again, pushing the rates up, and the cycle repeats. Hence, the ongoing process to balance the supply with the demand will push the rates towards a long-term mean. An attempt to predict the future earnings is therefore done through simulation. The model used in the simulation is the Ornstein-Uhlenbeck process, a Brownian motion with mean-reverting drift. The stochastic process is previously explained in section 3.1.3. It should be noted that the model uses the geometric version of the Ornstein-Uhlenbeck process. By doing this, negative values for simulated earnings are avoided. As stated in Tvedt (1997), lay-up of the vessel would be the preferred option if facing negative earnings, and thus, negative values should be avoided in the model of the case study.

In order to estimate the parameters of the mean-reverting process, the previously used data set containing historical MR product tanker earnings is examined. Recalling from Equation 3.2, κ is the rate of reverting to the mean, α is the long-term mean value and σ is the volatility of the time series. A linear fit between the log prices of the historical earnings and their first difference scaled by a weekly time interval is performed, and the retrieved estimated parameters are shown below in Table 6.7. The calculations to estimate the parameters is not elaborated any further. The relevant MATLAB code for the calculations is found in Appendix B.4.

Table 6.7: Estimated parameters for the mean-reverting process used to simulate future earnings.

Parameter	α	κ	σ
Estimation	9.509	1.249	0.690

Since the parameters are estimated using the log earnings, it means that the actual mean-reverting level can be found by taking the exponential of the α parameter. Thus, the simulated earnings reverts to a long-term mean of approximately \$ 13,500 per day. Looking back to the descriptive statistics of the historical data in Table 6.6, it is confirmed that the mean-reverting level is somewhere in between the median and the mean of the historical data. Thus, the long-term mean value is verified to be a reasonable estimation.

6.4.2 Earnings Simulations

Monte Carlo simulation is performed using the estimated parameters of the mean-reverting process, generating multiple log earning paths. Thus, to visualize the actual earning paths, the simulated log earnings are exponentiated. Reproducibility is ensured by setting the simulation seed to a default value. The simulated earning paths are updated on a weekly basis like the historical earnings, and each simulation path last for 20 years in total. Example simulations are presented in the time series below, plotted together with the known historical earnings. The historical data set ends in mid-April 2020, and the earnings simulations start at this point in time. The starting point in the simulated earnings is equal to the ending point of the historical earnings.

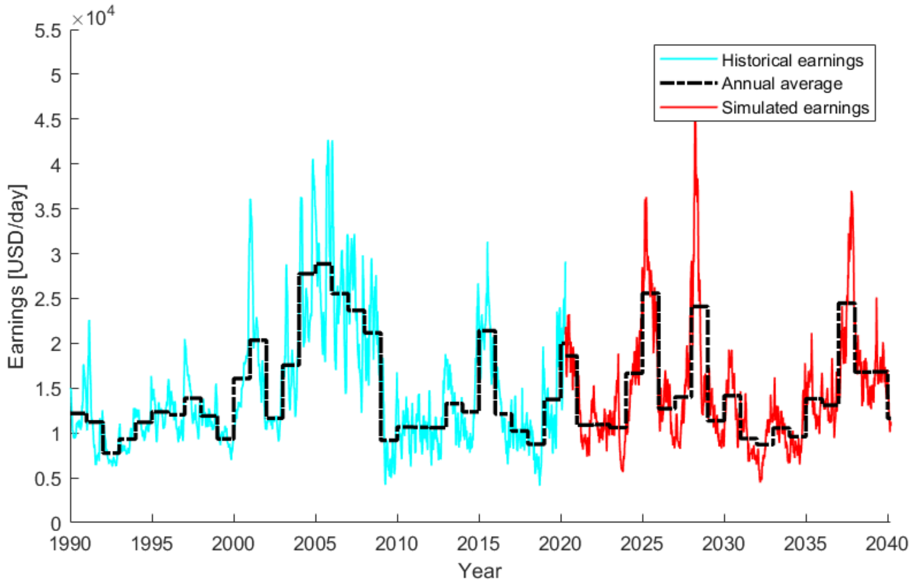


Figure 6.6: Simulation path number one out of ten thousand illustrating future earnings.

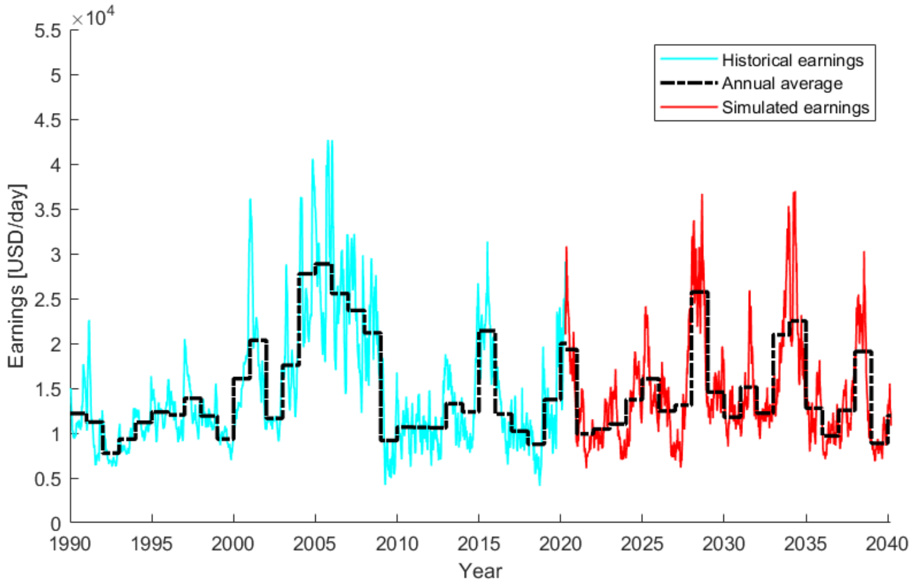


Figure 6.7: Simulation path number two out of ten thousand illustrating future earnings.

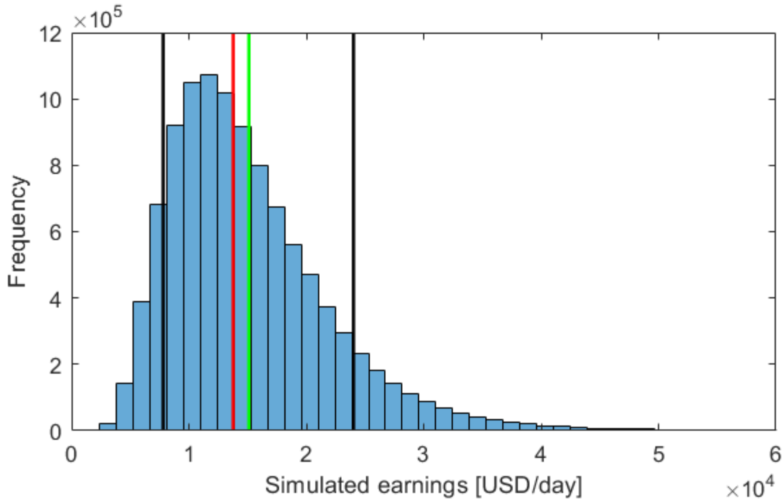
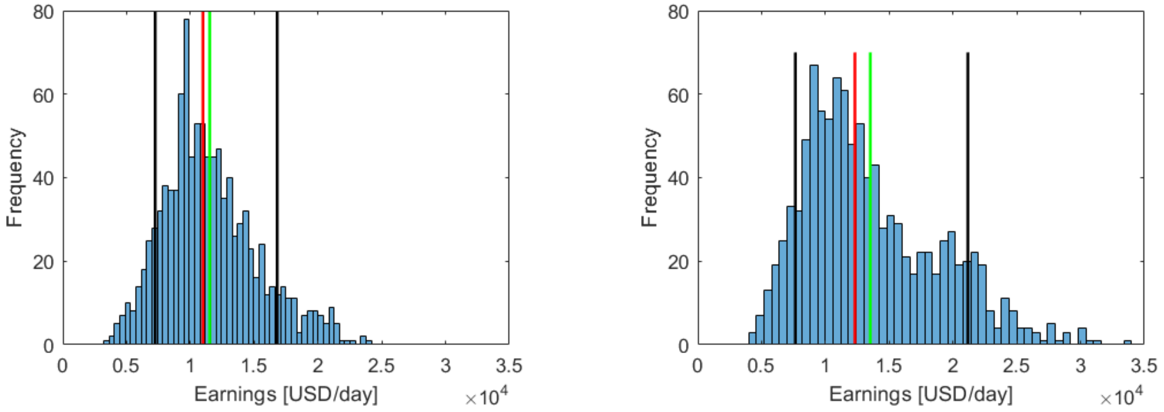


Figure 6.8: Earnings histogram of 10,000 simulation paths. The paths are updated on a weekly basis, for 20 years in total. Going left to right, the vertical lines represent the 10th percentile, median, mean and 90th percentile.

Table 6.8: Comparison of descriptive statistics of historical and simulated earnings. 10,000 simulation paths are updated on a weekly basis for 20 years. Percentiles, median and mean earnings given in USD per day.

Earnings	Data points	Median	Mean	Skewness	Kurtosis	Percentile	
						10th	90th
Historical	1,581	$ 12,082	$ 14,611	1.411	4.834	$ 8,045	$ 24,830
Simulation	10,450,000	$ 13,771	$ 15,115	1.433	6.937	$ 7,801	$ 24,020

The earnings distribution seen in Figure 6.8 can be fitted to a log-normal distribution of mean equal to 9.527 and standard deviation equal to 0.439, for the logarithmic values of the data set. Recalling from the discussion regarding the historical data set, it was stated that the historical earnings have a higher possibility of extremely high values than what a lognormal distribution would imply, referred to as fat-tail properties. It is therefore possible to doubt the goodness of the simulated earnings. However, it is important to keep in mind that the distribution consists of 10,450,000 data points. If each simulation is isolated into its own distribution, the earnings rarely follow any lognormal distribution. This is illustrated in Figure 6.9, which illustrates the earnings distribution for the simulation paths shown in Figure 6.6 and 6.7. The descriptive statistics of all simulation paths are stated in Table 6.8, and by comparing the simulated earnings with the historical earnings, the simulation statistics approximate the statistics of the historical data set. A critic to the earnings simulation paths is the lack of persistent high levels. In cases where the earnings reach high levels, the process of mean-reversion often decreases the earnings quickly. Anyhow, the earnings simulation paths are evaluated to be satisfactory for this case study.



(a) Histogram for simulation number one.

(b) Histogram for simulation number two.

Figure 6.9: Histogram for different earnings simulation example paths. Going left to right, the vertical lines represent the 10th percentile, median, mean and 90th percentile of the data set.

6.5 Future Fuel Prices

In order to obtain the value of being able to perform fuel switching, future fuel prices must be determined. The value of a dual fuel engine capable of switching between VLSFO and LPG is evaluated. Thus, future fuel prices for VLSFO and LPG are needed. To begin with, future fuel prices are predicted through the mean-reverting stochastic process, similar to what was done to simulate different future earnings paths. Geometric mean-reversion is preferred to regular GBM, in order to avoid the occurrence of either extremely high or extremely low fuel prices. With GBM simulations, the VLSFO price occasionally went as low as \$ 50 per tonne, and such low fuel prices are evaluated to be unrealistic.

The retrieved data for historical fuel prices, which were shown earlier in Figure 5.13, are less detailed than the data set containing historical earnings. It can be questioned whether the data set of the historical fuel prices contains enough accuracy to estimate sufficient parameters of the mean-reverting process. Thus, it is chosen not to carry out any estimation process. The choice of parameters is based upon an iteration process, in which the fuel prices are checked to what extent they reach reasonable values. The sensitivity in the modeling of future fuel prices are elaborated and discussed in section 6.8.2.

Table 6.9: Parameters of the mean-reverting processes used to simulate future fuel prices.

Parameter	VLSFO_{start}	LPG_{start}	α_{VLSFO}	α_{LPG}	κ	σ
Value	\$ 300	\$ 400	5.704	5.991	0.30	0.30

The chosen long-term mean value of the mean-reverting processes are set to be the logarithmic value of the fuel prices at the time of simulation start. Thus, the starting values of the fuel prices, and also the long-term mean value, are \$ 300 and \$ 400 per tonne, for VLSFO and LPG respectively. The fuel prices are given in MGO equivalents. The plot in Figure 6.10 illustrates the first simulation of fuel price developments.

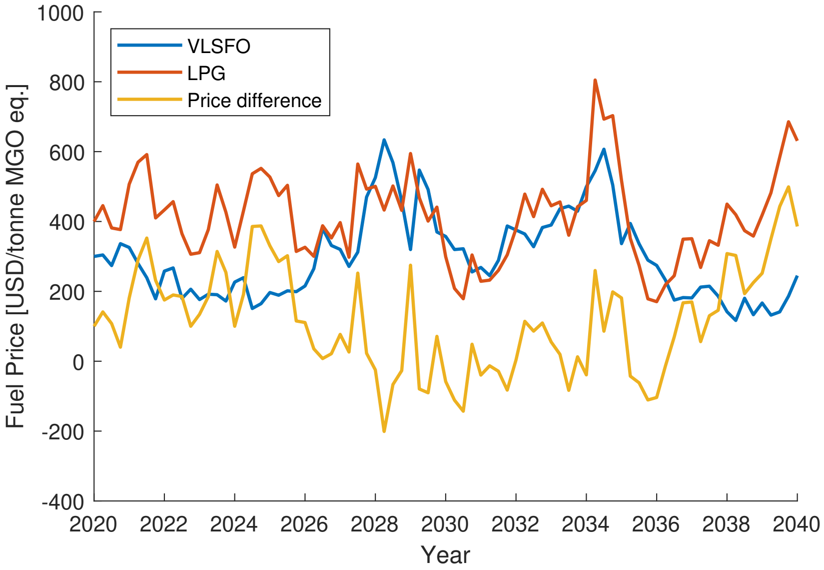


Figure 6.10: Example of fuel price simulation paths.

By examining Figure 6.10, it can be seen that the price paths of LPG and VLSFO are crossing on several occasions. Thus, if a vessel is capable of running on both LPG and VLSFO, every crossing represents a potential to lower the fuel costs.

Recalling from section 6.3, voyage related costs are already included in the earnings. Thus, the simulated earnings do also take the fuel cost into consideration. Consequently, it can be argued that the fuel price development should be modeled with a certain correlation to the simulated earnings. However, this is not straight forward either. The fuel prices do correlate with the oil price, but the freight rates in the tanker market can go up both if the oil price increase or decreases, which makes it difficult to determine a clear correlation. Thus, the choice to avoid an implementation of correlated values is justified. With the fuel prices already included in the simulations of earnings, the purpose for fuel price simulations is to simulate the price difference between two fuels.

10,000 simulation paths are generated for both VLSFO and LPG. The fuel price is updated quarterly and all simulations last for 20 years, which is the time frame of the case study. Descriptive statistics of the obtained fuel price differences is seen in Table 6.10. A negative fuel price difference indicates that LPG is cheaper than VLSFO, and a positive value states the opposite. The simulation can easily be expanded to include other fuel alternatives, but this is not done in this case study. The MATLAB code used for fuel price simulations is found in Appendix B.5.

Table 6.10: Descriptive statistics of the simulated fuel price difference between VLSFO and LPG. Negative values occur when LPG is cheaper than VLSFO. Percentiles, median and average given in USD per tonne.

Data points	**Median**	**Average**	**Skewness**	**Kurtosis**	**Percentile**	
					10th	**90th**
800,000	$ 95.94	$ 106.18	0.385	4.802	-$ 139.80	$ 364.46

6.6 Cash Flow Analysis and Net Present Value

In order to determine the profitability of the ship through its lifetime, a cash flow analysis is performed. Essentially, the cash flow analysis consists of the following parts: Yearly earnings, yearly OPEX, yearly CAPEX. The voyage related expenditures (VOYEX) are already included during the simulation of the earnings, as the earnings reflects the income after fuel costs are subtracted. However, the fuel price difference is needed to determine the expected value of fuel switching. Thus, the savings made from fuel switching must be added in the equation below. Naturally, there is no added value from fuel switching in the conventional case when there is only consumption of VLSFO the whole operational lifetime.

$$\text{Cash flow} = \text{Yearly earnings} - \text{Yearly CAPEX} - \text{Yearly OPEX} + \text{Fuel switch} \tag{6.1}$$

If a dual fuel engine is installed, a fuel switch is performed if the alternate fuel is cheaper than the current fuel, which affects the VOYEX. However, this can only be done before the new emission regulations are implemented. After the implementation, there can be no consumption of VLSFO. Further, the CAPEX is calculated under the assumption that equal annual payments are paid during the years in operation. If a retrofit is performed, the cost of the retrofit is added to the cash flow, and the retrofit cost has a payment period of five years. The time in drydock is also accounted for, and no earnings or fuel costs are associated with the drydock period. It can also be noted that the daily OPEX is applicable for both sailing and non-sailing days. Additionally, the shipowner receives a payment when the product tanker is sold for scrapping. Finally, in order to calculate the NPV of the different cases, all cash flows are discounted to their present value. All relevant cash flow calculations can be examined in detail in Appendix B.8 if desired by the reader.

6.7 Valuation of Fuel Flexibility

The expected value of fuel flexibility can now be estimated. First, the conventional case is compared against the flexible configuration. In other words, this is the case without any regulations demanding a shift away from VLSFO, evaluating either a conventional configuration with only VLSFO, or a configuration with a dual fuel engine capable of switching between LPG and VLSFO. The case findings is presented below in Table 6.11, while the empirical cumulative distribution functions of the NPV of the two cases are given in Figure 6.11.

Table 6.11: Comparing the expected NPV of the conventional case and the case with fuel flexibility.

Case	**Initial investment**	**ENPV**	**Percentile**	
			10th	**90th**
Conventional	\$ 35,000,000	\$ 4,500,000	-\$ 3,200,000	\$ 12,000,000
Fuel flexible	\$ 41,000,000	\$ 2,900,000	-\$ 5,500,000	\$ 11,900,000

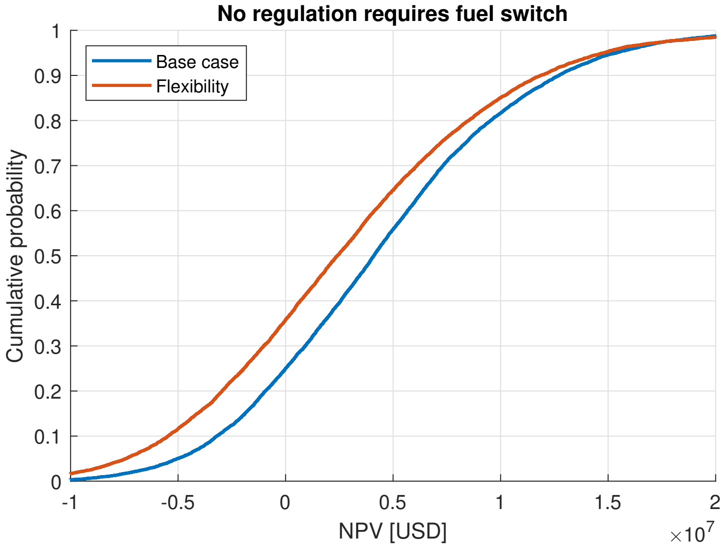


Figure 6.11: Cumulative distribution functions of the NPV for a conventional ship compared to a ship with fuel flexibility.

Under the given circumstances of the case study, implementation of fuel flexibility is expected to be less profitable than the conventional configuration if no future regulations demand a shift away from VLSFO. This is reflected by the difference between the expected NPV (ENPV) of the two case configurations. The conventional case has an ENPV of approximately \$ 4.5 million, while the fuel flexible case shows an ENPV of approximately \$ 2.9 million. Thus, the expected performance of a fuel flexible product tanker in terms of profitability is approximately \$ 1.6 million lower than a conventional product tanker. The 10 % Value at Risk (VaR) is measured as the 10th percentile of the calculated values, and there is a 10 % probability of loosing more than approximately \$ 3.2 million and \$ 5.5 million for the conventional and the fuel flexible configuration, respectively.

It should be recognized that the cumulative distribution function of the NPV is a result of 10,000 independent simulation paths. If the simulated earnings are high, both configurations have a high profitability. This is reflected by a 90th percentile of the NPV of approximately \$ 12 million. For the fuel flexible configuration, high NPV is reached during combinations of high earnings and cheap LPG fuel prices. Further, according to the cumulative distribution functions, the chance of a negative NPV is approximately 25 % and 35 % for the conventional and fuel flexible configuration, respectively.

If new emission regulations are implemented, there are two possible candidates of compliance in the case study. Either having a product tanker designed for fuel flexibility from the beginning or by performing a retrofit on a later occasion. The profitability of the two possibilities is dependent on when the emission regulations are implemented. The expected value of fuel flexibility for the different regulation scenarios are seen below in Table 6.12, and the cumulative distribution functions are seen in Figure 6.12.

Table 6.12: Expected value of fuel flexibility if implementation of new emission regulations.

Scenario	Regulation year	ENPV		Value of flexibility
		Retrofit	Flexible	
Strict	2025	-$ 10,400,000	-$ 5,800,000	$ 4,600,000
Moderate	2030	-$ 6,400,000	-$ 2,100,000	$ 4,300,000
Soft	2035	-$ 3,200,000	$ 700,000	$ 3,900,000

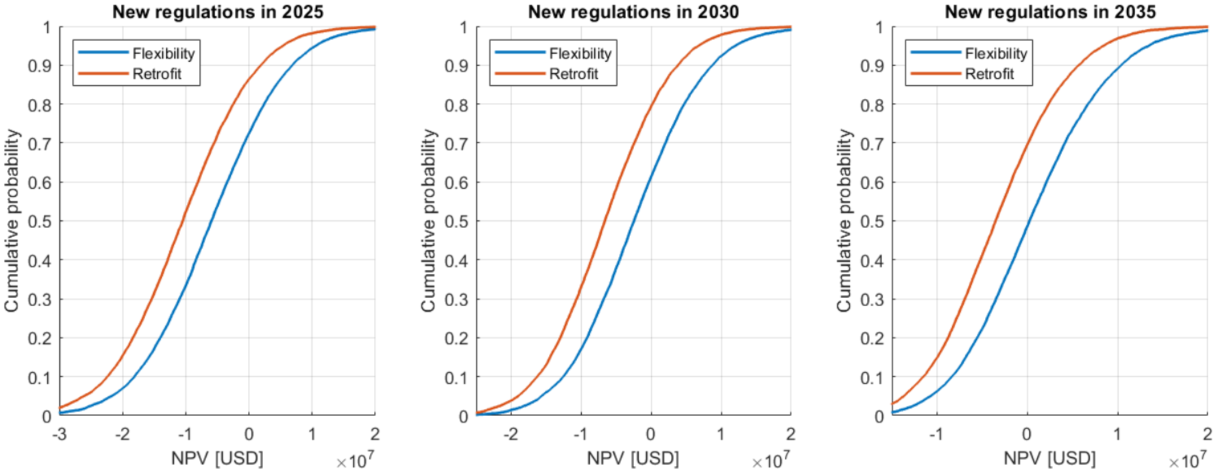


Figure 6.12: Cumulative distribution functions of the NPV for different regulation scenarios.

It can be seen that the profitability increases with the time to implementation of new regulations. However, the profitability is low compared to the conventional case without regulations. This is an expected outcome, due to that after the new regulations are implemented, it is not possible to choose the cheapest fuel out of LPG and VLSFO, as VLSFO is no longer allowed. In addition, if the ship is conventional, an LPG system must be retrofitted at a certain cost. Further, it can be seen that fuel flexibility outperforms the retrofit option. The ENPV is remarkably higher for the flexible product tanker compared to if a retrofit is done, and this accounts for all of the three regulation scenarios. However, the value of flexibility decreases if the time to regulation implementation increases.

6.8 Sensitivity Analysis

As seen in the cumulative distribution functions to all of the included cases, the uncertainty of the NPV is high. In the base case without any new emission regulations, the difference between the 10th and the 90th percentile is $ 15.2 million and $ 17.4 million for the conventional and fuel flexible product tanker respectively. This is a consequence of the wide variety of possible earnings, which was seen earlier in Figure 6.8. In order to better understand the uncertainty of the results, a sensitivity analysis is conducted to evaluate to what degree the results are affected by changes. This is done in terms of changing one variable at a time, to calculate how the ENPV correspondingly is affected. The tornado diagram in Figure 6.13 illustrates the results of the sensitivity analysis.

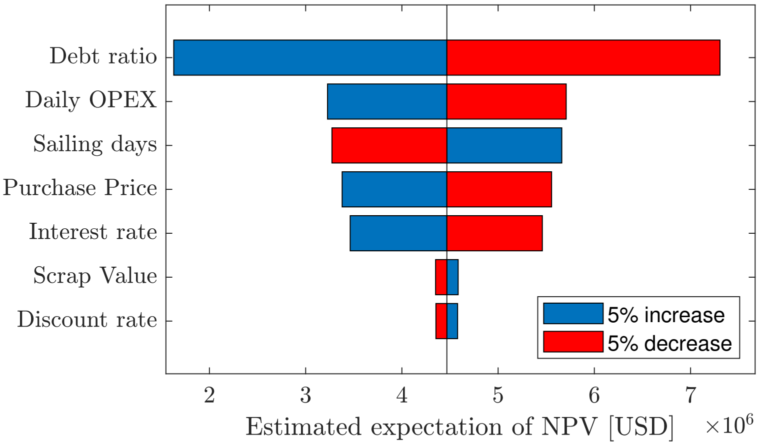


Figure 6.13: Tornado diagram illustrating how the ENPV is affected by changes.

The tornado diagram illustrates how the ENPV is changed in the conventional case. The blue bars represent the change in ENPV of a 5 % increase, while the red bars represent the change in ENPV by a 5 % decrease. The parameters are displayed in a decreasing order, in which the parameter most sensitive to change is displayed on the top of the diagram. It is seen that the debt ratio is an important parameter for the profitability of the project. This is expected, as shipping is known to be capital intensive, and thus, a high debt ratio comes at a cost. The acquiring of capital and the evaluation of annual payments is done through a simplified approach in the case study, due to that financial acrobatics is considered to be outside of the scope of this case study. However, it is interesting to observe the importance the debt ratio has on the expected profitability. Further, the OPEX is an important parameter for the case profitability. The OPEX can be estimated with low uncertainty by examining previously known OPEX for similar ships. Similar to the debt ratio, the interest rate have a substantial effect on the ENPV. Given the current economical status of the world economy, an interest rate of 8.5 % is considered to be high. Thus, a decrease of the interest rate is suggested, which naturally implies a higher ENPV. Additionally, the purchase price is seen to have a considerable effect on the project performance, and this highlights the importance of investment timing. The importance of timing is further supported by the high fluctuation in newbuilding cost, as earlier seen in Figure 6.1. The scrap value and discount rate are identified to have a low impact on the expected profitability of the project.

6.8.1 Sensitivity of Retrofit Cost

In the cases where emission regulations are implemented, the flexible configuration outperforms the retrofit one. However, it is interesting to evaluate how low the retrofit cost must be in order to be competitive under the given circumstances of the case study. Thus, an iteration process is conducted. As Table 6.13 displays, the retrofit cost must be reduced dramatically before it can be cost-competitive with a flexible design. Such low retrofit costs are argued to be unrealistic.

Table 6.13: Cost of retrofit in order to be competitive against the flexible configuration.

Year	New retrofit cost	Cost reduction	ENPV	
			Retrofit	Flexible
2025	$ 2,750,000	67 %	-$ 5,400,000	-$ 5,800,000
2030	$ 3,000,000	67 %	-$ 2,100,000	-$ 2,100,000
2035	$ 3,400,000	66 %	$ 600,000	$ 700,000

6.8.2 Fuel Price Sensitivity

The case results are sensitive to the simulated fuel price differences. Originally, the fuel prices of both LPG and VLSFO are modeled under the assumption that they revert to a long-term mean value. The long-term mean value is in the model set equal to the starting fuel price of the simulation, $ 400 and $ 300 for LPG and VLSFO respectively. Thus, with two fuel prices that both occasionally revert towards their respective starting value, the fuel price difference of highest frequency is expected to be close to the difference in starting price of the two fuel alternatives. This is illustrated in the histogram in Figure 6.14 which shows the distribution of fuel price differences that are used in the case study.

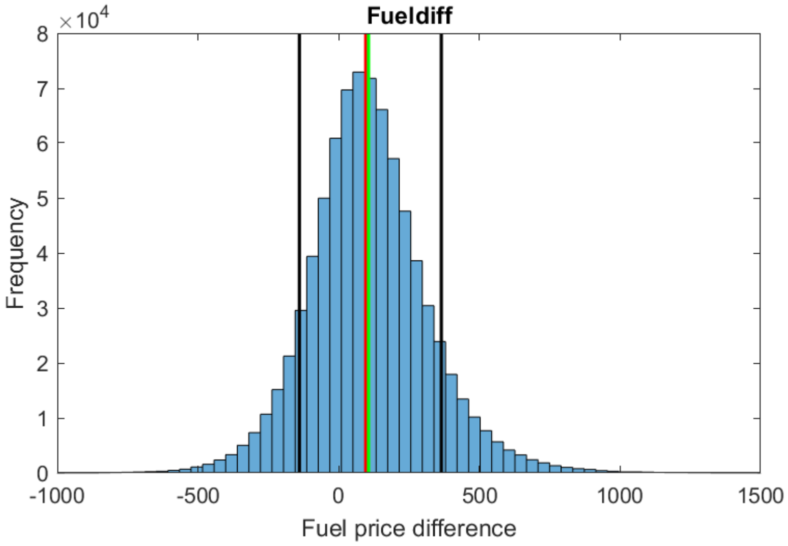


Figure 6.14: Histogram of simulated fuel price differences. Going left to right, the vertical lines represent the 10th percentile, median, mean and 90th percentile of the data set.

In order to determine how decisive the fuel price differences are for the ENPV, a fuel price sensitivity analysis is conducted. The analysis assumes a set deterministic fuel price difference during the whole operational lifetime and the results of the sensitivity analysis are shown below in Table 6.14.

Table 6.14: Sensitivity analysis of fuel price difference using deterministic fuel prices. A positive ΔFuel indicates VLSFO being cheaper than LPG.

ΔFuel	Scenario	Regulation year	ENPV		Value of flexibility
			Retrofit	Flexible	
-$ 100	Strict	2025	$ 1,900,000	$ 8,800,000	$ 6,900,000
	Moderate	2030	$ 700,000	$ 8,800,000	$ 8,100,000
	Soft	2035	-$ 40,000	$ 8,800,000	$ 8,840,000
-$ 50	Strict	2025	-$ 1,100,000	$ 4,300,000	$ 5,400,000
	Moderate	2030	-$ 1,000,000	$ 4,300,000	$ 5,300,000
	Soft	2035	-$ 800,000	$ 4,300,000	$ 5,100,000
$ 0	Strict	2025	-$ 4,100,000	-$ 200,000	$ 3,900,000
	Moderate	2030	-$ 2,700,000	-$ 200,000	$ 2,500,000
	Soft	2035	-$ 1,600,000	-$ 200,000	$ 1,400,000
$ 50	Strict	2025	-$ 7,000,000	-$ 3,200,000	$ 3,800,000
	Moderate	2030	-$ 4,400,000	-$ 2,000,000	$ 2,400,000
	Soft	2035	-$ 2,300,000	-$ 1,000,000	$ 1,300,000
$ 100	Strict	2025	-$ -10,000,000	-$ 6,200,000	$ 3,800,000
	Moderate	2030	-$ 6,200,000	-$ 3,700,000	$ 2,500,000
	Soft	2035	-$ 3,100,000	-$ 1,800,000	$ 1,300,000

If emission regulations are implemented, the flexible configuration outperforms the cases with retrofit for all evaluated fuel price differences. Naturally, the value of the fuel flexibility is higher if LPG is cheaper than VLSFO. However, for the cases in which VLSFO remains cheaper than LPG, the value of flexibility is decreasing when the time to regulation implementation increases.

Further, the conventional base case is compared against the flexible configuration. If no regulations are implemented, the flexible configuration is competitive from a fuel price of -$ 50.

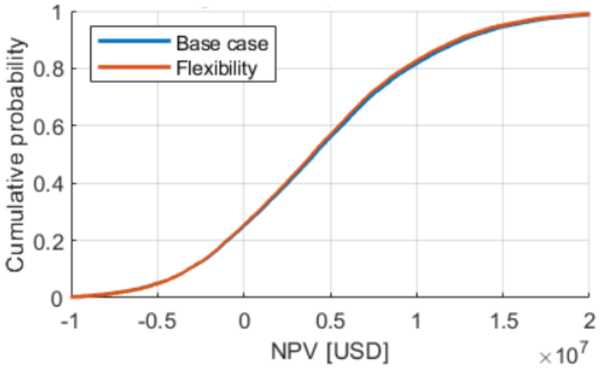


Figure 6.15: If no emission regulations are implemented, a deterministic fuel price difference of -$ 50 or lower makes the flexible engine attractive.

6.9 Concluding Remarks and Further Work for the Case Study

Through the creation of a case study, the value of adding fuel flexibility to a MR2 product tanker is estimated. Fuel flexibility as a provider of the option to perform fuel switching between VLSFO and LPG is compared against a reactive approach to future environmental regulations in terms of retrofitting to obtain compliance. The alternative providing flexibility outperforms the reactive approach of retrofitting when facing different future environmental regulations. As discussed, the results are sensitive to future earnings and fuel price differences, which both are considered to be highly uncertain. Anyhow, if emission regulations are implemented, the flexible design is seen as the better alternative unless the cost of retrofitting is drastically reduced. In case no emission regulations are implemented, the study suggests that a conventional product tanker has a higher expected value than a flexible configuration. However, through evaluating the sensitivity analysis it is stated that the flexible configuration may outperform the conventional configuration if LPG consistently is cheaper than VLSFO.

The future earnings of the case study are predicted by examining historical data. This is done through the use of a stochastic mean-reverting process. An issue with the mean-reverting process when modeling future earnings, is the lack of persistent high or low levels. When substantial high or low values are reached, the values often revert back to the long-term mean value quickly. Thus, the fat tail properties that often are seen in earnings distributions are somewhat lacking. The implementation of jump-diffusion in the model is therefore a possible measure for further work. Anyhow, it is argued that the simulations forms a more accurate picture of future earnings than what a set deterministic rate would do, and given the similarities to the historical data set, the simulated earnings are considered to be sufficient. However, it is important to consider the variety of possible outcomes for the NPV in the various simulations, as the difference between the 10th and 90th percentile are substantial.

Similar to the simulated earnings, the fuel prices are modeled as a mean-reverting process. Likely, the fuel prices will be strongly affected by implementation of new regulations. If a regulation requires a shift away from VLSFO, a sudden rise in the demand of a lower-carbon fuel is likely to affect the price of the given fuel. However, in the case study, the value gained from fuel switching is obtained before regulation implementation, and therefore, the simulated fuel price difference is considered to be sufficient.

The real option of the case study is whether to have a higher initial investment to include a dual fuel engine, which again leads to the option to perform a fuel switch. The retrofit is not considered as an option, it is a reactive change to new regulation, and the option to retrofit years in advance of a possible regulation is not considered. A possible inclusion in the model could be to allow for an early retrofit given a beneficial fuel price development. Additionally, being able to time the retrofit, drydocking in times of high earnings are potentially also avoided. Such model implementations are expected to increase the ENPV of the inflexible configurations. However, a retrofit timing dependent on the fuel price does not make sense in the current model, due to that the fuel prices are reverting back to a long-term mean. Again, this argues for inclusion of jump-diffusion in the model. The effect of optimal timing of the retrofit is suggested as a potential aspect for further work.

The possibility of even stricter regulations than what are presented in the case is a possibility. If so, the value of flexibility is expected to have an even bigger edge compared to a reactive approach to regulations. When the IMO reduction goals are concretized, possible timelines for future fuel transitions are easier identified. If a further transition is needed after already having left VLSFO, fuel bridging technology may add substantial value to flexible configurations.

7 Discussion

The operational lifetime of a ship is over several decades. Thus, it is challenging to take all future uncertainties into consideration during the ship design, but nevertheless, the uncertainties should be accounted for in the best way possible. The implementation of flexibility in ship design is considered to be a possible measure to cope with future contextual uncertainties. The purpose of such an implementation is to have a design that is capable of adapting to a changing context in a cost-efficient manner. However, the implementation of a flexible design is worthless if the flexibility is never exercised. In addition, the inclusion of flexibility in ship design naturally increases the total investment cost, and thus, the possibility of facing opposition from the stakeholders is increased accordingly. Shipping is already capital intensive. Consequently, stakeholders may doubt whether it is worth to invest more for a flexible alternative, especially when there is a possibility that the flexibility is left unused. This highlights the importance of being able to determine the expected value of flexibility, but also the importance of being able to clearly communicate how the flexibility valuation is estimated. Simply, if the stakeholders doubt the credibility of the flexibility valuation, a conventional configuration is more likely to be chosen.

Earlier in the thesis, real options were introduced as providers of flexibility, and a separation was made between real options *in* and *on* systems. Real options *on* systems typically evaluates investment decisions on a fleet level, including the option to expand or reduce a fleet, or the option to put a ship in lay-up. *On* options treat technology as a black box and therefore tend to have a lower degree of complexity than what it the case for *in* options. The case study evaluated a possible implementation of a dual fuel engine. This is considered to be a real option *in* a system. This option is further the provider of the option to perform a fuel switch, which is also considered to be an *in* option. In general, assumptions that require technical understanding are needed in order to estimate the value of *in* options. Further, the assumptions that are made must be justified properly in order to gain a credible valuation of the flexibility introduced by *in* options. Again, if there is a lack of credibility in the results, there will likely be no flexibility implementation.

Considerations for when flexibility is good engineering practice, and when it is not, is an important aspect. In general, if the expected return for a flexible configuration is higher than the expected return of a conventional configuration, the flexible alternative can be considered. Though, given an uncertain future context, it is argued that this is not sufficient. The profitability of a project can be drastically changed between different scenarios. Thus, the flexible configuration should be measured against the conventional configuration for all scenario developments that are considered to be likely. If the conventional configuration is consistently outperformed, implementation of flexibility is likely to be profitable.

A distinction between two types of design flexibility was made by separating versatility and retrofittability. Versatility and retrofittability are defined as the ability of a system to satisfy diverse needs *without* or *with* change of the form respectively. Thus, the flexible configuration in the case study increases the versatility. For given future scenarios, the flexible configuration in the case study is expected to increase the value. In turn, retrofittability is not evaluated as a provider of flexibility during the case study. It is not known whether the pathway from VLSFO to LPG will be necessary, or if future fuel price differences make a transition to LPG beneficial. In ten years, LNG might stand out as a better alternative than LPG. Thus, if a ship is made retrofittable for several fuel alternatives, the retrofittability may provide a substantial value. A comparison between implementation of retrofittability and the dual fuel configuration would therefore also be interesting. According to DNV GL (2020), retrofittability is gaining popularity as the numbers of LNG ready ships are increasing. Hence, it is reason to believe that also retrofittability is a possible candidate to face an uncertain future.

8 Conclusion

Implementation of flexibility in ship design is a strong candidate to increase the profitability in shipping. Seen from a shipowners perspective, a reactive approach to changes may seem like a more comfortable approach than a proactive approach, due to that it feels less uncertain. However, as seen in the case study, the implementation of flexibility is likely to outperform a reactive approach to future emission regulations. Thus, the use of fuel flexibility as an approach to handle future uncertainty is therefore concluded to be suitable. The methods used to estimate the value of the flexibility are also transferable to other candidates of flexibility.

When evaluating candidates of flexibility, the degree of future uncertainty is an important factor. A distinction is made between flexibility that increases either the versatility or the retrofittability. During times of high uncertainty, it is argued that retrofittability may be favorable compared to versatility. The economical downside is lower than compared to a versatile design in cases when the predicted changes becomes unnecessary. By designing for retrofittability, decisions can be delayed until the circumstances of the future are less uncertain. When considering fuel flexibility, a comparison of versatility and retrofittability would therefore be an interesting topic for further work.

References

Aatola, H., Larmi, M. & Sarjovaara, T. (2008) Hydrotreated Vegetable Oil (HVO) as a Renewable Diesel Fuel: Trade-off between NOx, Particulate Emission, and Fuel Consumption of a Heavy Duty Engine. *SAE International Journal of Engines,* 1. DOI: 10.4271/2008-01-2500.

Alizadeh, A. H. & Nomikos, N. (2009) *Shipping derivatives and risk management.* Basingstoke: Palgrave Macmillan.

Balcombe, P., Brierley, J., Lewis, C., Skatvedt, L., Speirs, J., Hawkes, A. & Staffell, I. (Feb. 15, 2019) How to decarbonise international shipping: Options for fuels, technologies and policies. *Energy Conversion and Management,* 182, pp. 72–88. DOI: 10.1016/j.enconman.2018.12.080.

Bendall, H. B. & Stent, A. F. (2005) Ship Investment under Uncertainty: Valuing a Real Option on the Maximum of Several Strategies. *Maritime Economics & Logistics,* 7(1), pp. 19–35. DOI: 10.1057/palgrave.mel.9100122.

Bjerksund, P. & Ekern, S. (1995) Contingent claims evaluation for mean-reverting cash flows in shipping. *Real Options in Capital Investment.* London: Praeger, pp. 207–221.

Black, F. & Scholes, M. (1973) The Pricing of Options and Corporate Liabilities. *Journal of Political Economy,* 81(3). Publisher: The University of Chicago Press, pp. 637–654. DOI: 10.1086/260062.

Boyle, P. P. (1977) Options: A Monte Carlo approach. *Journal of Financial Economics,* 4(3), pp. 323–338. DOI: 10.1016/0304-405X(77)90005-8.

Brynolf, S., Andersson, K. & Fridell, E. (2011) A comparative life cycle assessment of marine fuels. *Proceedings of the Institution of Mechanical Engineers Part M-Journal of Engineering for the Maritime Environment,* 225, pp. 97–110. DOI: 10.1177/1475090211402136.

Cardin, M.-A., Ranjbar-Bourani, M. & Neufville, R. de (2015) Improving the Lifecycle Performance of Engineering Projects with Flexible Strategies: Example of On-Shore LNG Production Design. *Systems Engineering,* 18, pp. 253–268. DOI: 10.1002/sys.21301.

Carriere, J. F. (1996) Valuation of the early-exercise price for options using simulations and nonparametric regression. *Insurance: Mathematics and Economics,* 19(1), pp. 19–30. DOI: 10.1016/S0167-6687(96)00004-2.

Clarksons Research (2019a) *Dry Bulk Trade Outlook.* Volume 25.

Clarksons Research (2019b) *Seaborne Trade Monitor.* Volume 6.

Clarksons Research (2020) *Shipping Intelligence Network.* Available at: https://sin.clarksons.net/ (accessed: 04/20/2020).

Cox, J. C., Ross, S. A. & Rubinstein, M. (1979) Option pricing: A simplified approach. *Journal of Financial Economics,* 7(3), pp. 229–263. DOI: 10.1016/0304-405X(79)90015-1.

Crawley, E. F., Cameron, B. G. & Selva, D. (2016) *System architecture: Strategy and product development for complex systems.* Boston: Pearson.

Cuthbertson, K. & Nitzsche (2001) *Financial Engineering: Derivatives and Risk Management.* New York: Wiley.

Danish Ship Finance (2019) *Shipping Market Review: Devember.* Available at: https://www.shipfinance.dk/media/2000/shipping-market-review-december-2019.pdf (accessed: 04/16/2020).

Dixit, A. (1989) Entry and Exit Decisions under Uncertainty. *Journal of Political Economy,* 97(3). Publisher: The University of Chicago Press, pp. 620–638. DOI: 10.1086/261619.

Dixit, A. & Pindyck, R. S. (1994) *Investment under Uncertainty.* Princeton, New Jersey: Princeton University Press.

DNV GL (2016) *Costs and benefits of alternative fuels.* Available at: https://www.dnvgl.com/maritime/publications/alternative-fuels-study.html (accessed: 04/04/2020).

DNV GL (2019a) *Assessment of Selected Alternative Fuels and Technologies.* Available at: https://www.dnvgl.com/maritime/publications/alternative-fuel-assessment-download.html (accessed: 09/15/2019).

DNV GL (2019b) *Low carbon shipping towards 2050.* Available at: https://www.dnvgl.com/publications/low-carbon-shipping-towards-2050-93579 (accessed: 02/15/2020).

DNV GL (2019c) Maritime Forecast to 2050, Energy Transition Outlook 2019.

DNV GL (2020) *Alternative Fuel Insight.* Available at: https://afi.dnvgl.com/Statistics?repId=0 (accessed: 05/30/2020).

Erikstad, S. O. (2017) Design decisions facing uncertainty [Powerpoint presentation].

Erikstad, S. O. & Rehn, C. F. (2015) Handling Uncertainty in Marine Systems Design – State-of -the-Art and Need for Research. *12th International Marine Design Conference 2015 Proceedings,* 2:324–342.

Evans, J. H. (1959) Basic Design Concepts. *Journal of the American Society for Naval Engineers,* 71(4). _eprint: https://onlinelibrary.wiley.com/doi/pdf/10.1111/j.1559-3584.1959.tb01836.x, pp. 671–678. DOI: 10.1111/j.1559-3584.1959.tb01836.x.

Gao, L., Porter, A. L., Wang, J., Fang, S., Zhang, X., Ma, T., Wang, W. & Huang, L. (2013) Technology life cycle analysis method based on patent documents. *Technological Forecasting and Social Change,* Future-Oriented Technology Analysis 80(3), pp. 398–407. DOI: 10.1016/j.techfore.2012.10.003.

Gaspar, H. M. (2013) Handling aspects of complexity in conceptual ship design. PhD thesis. Trondheim: NTNU.

Gaspar, H. M., Rhodes, D., Ross, A. & Erikstad, S. (2012) Addressing Complexity Aspects in Conceptual Ship Design: A Systems Engineering Approach. *Journal of Ship Production and Design,* 28, pp. 145–159. DOI: 10.5957/JSPD.28.4.120015.

Hagen, A. & Grimstad, A. (2010) The extension of system boundaries in ship design. *The International Journal of Maritime Engineering,* 152, A17–A28. DOI: 10.3940/rina.ijme.2010.a1.167.

Harrington, S. E. & Niehaus, G. R. (2003) *Risk management and insurance.* Vol. 2. New York: McGraw Hill.

Hassan, R., Neufville, R. de & McKinnon, D. (2005) Value-at-risk analysis for real options in complex engineered systems. *2005 IEEE International Conference on Systems, Man and Cybernetics.* 2005 IEEE International Conference on Systems, Man and Cybernetics. Vol. 4. ISSN: 1062-922X, 3697–3704 Vol. 4. DOI: 10.1109/ICSMC.2005.1571721.

Haug, E. (2007) *The complete guide to option pricing formulas.* 2nd ed. New York: McGraw-Hill.

Hoegh, M. W. (1998) *Options on Shipbuilding Contracts.* MSc. MIT.

IMF (2020) *World Economic Outlook, April 2020.* Available at: https://www.imf.org/en/Publications/WEO/Issues/2020/04/14/weo-april-2020 (accessed: 04/22/2020).

IMO (2014) *Third IMO Greenhouse Gas Study.* Available at: http://www.imo.org/en/OurWork/Environment/PollutionPrevention/AirPollution/Pages/Greenhouse-Gas-Studies-2014.aspx (accessed: 02/01/2019).

IMO (2016) Module 2 - Ship Energy Efficiency Regulations and Related Guidelines.

IMO (2019) *Special Areas Under MARPOL.* Available at: http://www.imo.org/en/OurWork/Environment/SpecialAreasUnderMARPOL/Pages/Default.aspx (accessed: 10/22/2019).

Kavussanos, M. G. & Alizadeh-M, A. H. (2002) Seasonality patterns in tanker spot freight rate markets. *Economic Modelling,* 19(5), pp. 747–782. DOI: 10.1016/S0264-9993(01)00078-5.

Kolmogorov, A. N. (1983) Combinatorial foundations of information theory and the calculus of probabilities. *Russian Mathematical Surveys,* 38(4), pp. 29–40.

Kulatilaka, N. (1993) The Value of Flexibility: The Case of a Dual-Fuel Industrial Steam Boiler. *Financial Management,* 22(3). Publisher: [Financial Management Association International, Wiley], pp. 271–280. DOI: 10.2307/3665944.

Liang, Z. X., Yan, L. & Shang, J. Z. (2009) Collaborative multidisciplinary decision making based on game theory in ship preliminary design. *Journal of Marine Science and Technology,* 14(3), pp. 334–344. DOI: 10.1007/s00773-009-0048-3.

Lin, J., Weck, O. de, Neufville, R. de & Yue, H. K. (2013) Enhancing the value of offshore developments with flexible subsea tiebacks. *Journal of Petroleum Science and Engineering,* 102, pp. 73–83. DOI: 10.1016/j.petrol.2013.01.003.

Malkiel, B. G. (2007) *A random walk down Wall Street : the time-tested strategy for successful investing.* 9th ed. New York: W.W. Norton & Company.

McManus, H. & Hastings, D. (2007) A Framework for Understanding Uncertainty and Its Mitigation and Exploitation in Complex Systems. *Engineering Management Review, IEEE,* 34, pp. 81–81. DOI: 10.1109/EMR.2006.261384.

Meade, N. (2010) Oil prices — Brownian motion or mean reversion? A study using a one year ahead density forecast criterion. *Energy Economics,* 32(6), pp. 1485–1498. DOI: 10.1016/j.eneco.2010.07.010.

Merton, R. C. (1976) Option pricing when underlying stock returns are discontinuous. *Journal of Financial Economics,* 3(1), pp. 125–144. DOI: 10.1016/0304-405X(76)90022-2.

Myers, S. C. (1977) Determinants of corporate borrowing. *Journal of Financial Economics,* 5(2), pp. 147–175. DOI: https://doi.org/10.1016/0304-405X(77)90015-0.

Neufville, R. de, Hodota, K., Sussman, J. & Scholtes, S. (2008) Real Options to Increase the Value of Intelligent Transportation Systems. *Transportation Research Record,* 2086(1). Publisher: SAGE Publications Inc, pp. 40–47. DOI: 10.3141/2086-05.

Neufville, R. de & Scholtes, S. (2011) *Flexibility in Engineering Design.* Massachusetts: The MIT Press.

Norsepower (2019) *Norsepower rotor sails confirmed savings of 8.2% fuel and associated CO2 in Maersk Pelican project.* Available at: https://www.norsepower.com/post/norsepower-rotor-sails-confirmed-savings-of-8-2-fuel-and-associated-co2-in-maersk-pelican-project (accessed: 11/13/2019).

Nyhus, E. (2019) 6th Intersessional Working Group on the Reduction of GHG Emissions (ISWG - GHG 6) [Powerpoint presentation].

Portin, K. (2019) Future fuels for environmental friendly engines [Powerpoint presentation], Wärtsila.

Rader, A. A., Ross, A. M. & Rhodes, D. H. (2010) A methodological comparison of Monte Carlo Simulation and Epoch-Era Analysis for tradespace exploration in an uncertain environment. *2010 IEEE International Systems Conference.* 2010 4th Annual IEEE Systems Conference. IEEE, pp. 409–414. DOI: 10.1109/SYSTEMS.2010.5482433.

Rehn, C. F. (2018) Ship Design under Uncertainty. PhD thesis. Trondheim: NTNU.

Rehn, C. F. & Garcia Agis, J. J. (2018) Flexibility in marine systems design - A collection of cases from the industry.

Rehn, C. F., Garcia Agis, J. J., Erikstad, S. O. & Neufville, R. de (Nov. 1, 2018) Versatility vs. retrofittability tradeoff in design of non-transport vessels. *Ocean Engineering,* 167, pp. 229–238. DOI: 10.1016/j.oceaneng.2018.08.057.

Rhodes, D. H. & Ross, A. M. (Apr. 2010a) Five aspects of engineering complex systems: Emerging constructs and methods. *2010 IEEE International Systems Conference*, pp. 190–195. DOI: 10.1109/SYSTEMS.2010.5482431.

Rhodes, D. H. & Ross, A. M. (2010b) Shaping socio-technical system innovation strategies using a five aspects taxonomy. *EuSEC.*

Ross, A. M., Rhodes, D. H. & Hastings, D. E. (2008) Defining changeability: Reconciling flexibility, adaptability, scalability, modifiability, and robustness for maintaining system lifecycle value. *Systems Engineering,* 11(3), pp. 246–262. DOI: 10.1002/sys.20098.

Rudi, S. (2019) Reduction of GHG Emissions for a Deep-Sea Shipping Fleet.

Simon, H. A. (1991) The Architecture of Complexity. *Facets of Systems Science.* International Federation for Systems Research International Series on Systems Science and Engineering. Boston, MA: Springer US, pp. 457–476. DOI: 10.1007/978-1-4899-0718-9_31.

Singer, D. J., Doerry, N. & Buckley, M. E. (2009) What Is Set-Based Design? *Naval Engineers Journal,* 121(4), pp. 31–43. DOI: doi:10.1111/j.1559-3584.2009.00226.x.

Smit, H. T. (2004) *Strategic investment : real options and games.* Princeton, N.J: Princeton University Press.

Sødal, S., Koekebakker, S. & Aadland, R. (2008) Market switching in shipping — A real option model applied to the valuation of combination carriers. *Review of Financial Economics,* 17(3), pp. 183–203. DOI: 10.1016/j.rfe.2007.04.001.

Stopford, M. (2009) *Maritime Economics.* 3rd ed. London: Routledge.

Trading Economics (2020a) *Brent Crude Oil.* Available at: https://tradingeconomics.com/commodity/brent-crude-oil (accessed: 03/24/2020).

Trading Economics (2020b) *CBOE Volatility Index.* Available at: https://tradingeconomics.com/vix:ind (accessed: 04/26/2020).

Traut, M., Gilbert, P., Walsh, C., Bows, A., Filippone, A., Stansby, P. & Wood, R. (2014) Propulsive power contribution of a kite and a Flettner rotor on selected shipping routes. *Applied Energy,* 113, pp. 362–372. DOI: 10.1016/j.apenergy.2013.07.026.

Trigeorgis, L. (1993) Real Options and Interactions with Financial Flexibility. *Financial Management,* 22(3), pp. 202–224.

Trigeorgis, L. (1995) *Real options in capital investment: Models, strategies, and applications.* Westport, Conn: Praeger.

Tvedt, J. (1997) Valuation of VLCCs under income uncertainty. *Maritime Policy & Management,* 24(2), pp. 159–174. DOI: 10.1080/03088839700000067.

UNCTAD (2019) *Review of Maritime Transport 2019.* UNCTAD. Available at: https://unctad.org/en/PublicationsLibrary/rmt2019_en.pdf (accessed: 04/15/2019).

Wang, T. (2005) Real Options "In" Projects and Systems Design : Identification of Options and Solutions for Path Dependency. Accepted: 2006-02-02T18:54:45Z. Thesis. Massachusetts Institute of Technology.

Wang, T. & de Neufville, R. (2005) Building Real Options into Physical Systems with Stochastic Mixed-Integer Programming. Massachusetts Institute of Technology. Engineering Systems Division.

Wijst, D. v. d. (2013) *Finance: A Quantitative Introduction.* Cambridge: Cambridge University Press.

Appendix

A Binomial Option Pricing Model

```
% 1: CALL OPTION ON SISTERSHIP
% 2: PUT OPTION TO ABANDON PROJECT/SCRAP SHIP

function OptionValue = BOPM(option) % Option: 1/2

% Get option parameters
switch(option)
    % CALL OPTION ON SISTERSHIP
    case 1
        OptionType = 1; % Due to call
        InitialCost = 50;
        sigma = 0.15;
        r = 0.05;
        time2maturity = 1;
        nBOPM = 6;
        ∆_t= time2maturity/nBOPM;
        X = 50;

    %  PUT OPTION TO ABANDON PROJECT/SCRAP SHIP
    case 2
        OptionType = 0; %put
        InitialCost = 10;
        sigma = 0.30;
        r = 0.05;
        time2maturity = 6;
        nBOPM = 6;
        ∆_t= time2maturity/nBOPM;
        X = 4;
end

% Parameters of binomial process
u = exp(sigma*(sqrt(∆_t)));      % upward movement factor
d = 1/u;                             % downward movement factor
p = (exp(r*∆_t)- d)/(u - d);      % risk neutral probability of an upward movement

%Price Lattice
st=nBOPM+1; % + 1 due to origin is at step 0
PriceLattice = zeros(st,st);
PriceLattice(1,1) = InitialCost;
for i=2:st
    PriceLattice(1,i) = InitialCost*u^(i-1);
    i=i+1;
end

for i=2:st
    for j=i:nBOPM+1
        PriceLattice(i,j) = PriceLattice(i-1,j-1)*d;
    end
end


% Option valuation Lattice
EarlyExercise = 0;

if OptionType == 1; % if call option
    for i=1:st
        OptionLattice(i,st) = max(PriceLattice(i,st)-X,0);
```

```
        if OptionLattice(i,st) < 1e-5
            OptionLattice(i,st) = 0; % Avoid e-0X etc...
        end
    end


    for j=nBOPM:-1:1
        for i=2:j+1
            alive = (p*OptionLattice(i-1,j+1) +...
                (1-p)*OptionLattice(i,j+1))*exp(-r*Δ_t);
            dead = PriceLattice(i-1,j)- X; % dead = execution
            OptionLattice(i-1,j) = max(dead,alive);
            if dead > alive
                EarlyExercise = EarlyExercise + 1;
            end
        end
    end
    OptionValue = OptionLattice(1,1);

elseif OptionType == 0; % if put option
    for i=1:st
        OptionLattice(i,st) = max(X-PriceLattice(i,st),0);
        if OptionLattice(i,st) < 1e-5
            OptionLattice(i,st) = 0; % Avoid 0.0005
        end
    end

    for j=nBOPM:-1:1
        for i=2:j+1
            alive = (p*OptionLattice(i-1,j+1) +...
                (1-p)*OptionLattice(i,j+1))*exp(-r*Δ_t);
            dead = X - PriceLattice(i-1,j);
            OptionLattice(i-1,j) = max(dead,alive);
            if dead > alive
                EarlyExercise = EarlyExercise + 1;
            end
        end
    end
    OptionValue = OptionLattice(1,1);
end
end
```

B Case Study

B.1 Main Script

```
% ------------------------------------------------------------------------
%    Script for option to switch fuels, various cases.
%-------------------------------------------------------------------------
clear all
clc
%_______________________________________________________________________
% Case 0: Base case. Ship runs on VLSFO only all lifetime, with no
%         possibility to switch fuels.
%________________________________________________________________________
% Case 1: Ship is able to switch between LPG and VLSFO. Higher machinery
%         cost. VLSFO not compliant at certain point

% Case 2: Originally no fuel flexibility as in case 0. Must retrofit to be
%         compliant. (VLSFO not compliant at certain point)
% ________________________________________________________________________
% Case 3: Fuel Flexibility LGP/VLSFO, no future regulations stopping VLSFO

%________________________________________________________________________
Case =2;
nSim = 10000;
rng('default'); % Setting simulation seed for reproducibility

%% Get relevant Case Characteristics

[dr, ir, Vessel_age, T_vessel, PurchasePrice, Vessel_Value,...
    NH3_start, LPG_start, OPEX_nonfuel,...
    VLSFO_start, Consumption, Loan,Drydock_days,Retrofit_cost,...
    Retrofit_year,Equity,Regulation_year,Sailing_days,LPG_lossfactor,...
    Debt_ratio,Steel_price,MachineryAddedCost] = GetCaseCharacteristics(Case);

%% Get Historical Earnings for MR Product Tanker from 1990- April 2020
Plots = 0;
[MR_earnings,year_earnings_MR,year_avg_mr,mr_avg_earnings] = MR_Earnings(Plots);

%% Future Earnings for MR Product Tanker
Plots = 0;

[Sim_Earnings,MeanEarningsRate] = SimulateEarnings(T_vessel,nSim,...
    MR_earnings,year_earnings_MR,year_avg_mr,mr_avg_earnings,Plots);

%% Fuel Statistics
Plots =0;
[FuelDiff,VLSFO,LPG] = SimulateFuelPriceDifference(T_vessel,nSim,...
    LPG_start,VLSFO_start,Plots);

%% VOYEX
VOYEX_diff = VOYEX2(Case,Consumption,VLSFO,LPG,T_vessel,Retrofit_year,...
    FuelDiff,Regulation_year,Sailing_days,MachineryAddedCost);

%% CAPEX
CAPEX = GetCAPEX(Case,Retrofit_year,Retrofit_cost,Loan,T_vessel,ir);

%% Evaluate cash flows for NPV calculations, base case, no fuel switch
CF = CashFlow(T_vessel,VOYEX_diff,...
   OPEX_nonfuel,MeanEarningsRate,Loan,Case,Retrofit_year,Drydock_days,...
   CAPEX,Sailing_days,LPG_lossfactor);

%% Discount the calculated cash flows and getting NPV
```

```matlab
Plots = 0;
NPV = GetNPV(CF,dr,nSim,T_vessel,Vessel_Value,Equity,Plots);
avg = mean(NPV);
prc10 = prctile(NPV,10);
prc90 = prctile(NPV,90);
if Case == 0
    figure(10)
    hold on
    a = cdfplot(NPV);
    xlabel('NPV [USD]')
    ylabel('Cumulative probability')
    title('')
    legend('Base case','Fuel Flexibility')
    set(a,'Linewidth',1.6);
    avg = mean(NPV);
    prc10 = prctile(NPV,10);
    prc90 = prctile(NPV,90);

elseif Case == 3 % Run case 3 after case 0
    figure(10)
    b = cdfplot(NPV);
    xlabel('NPV [USD]')
    ylabel('Cumulative probability')
    xlim([-1e7 2e7])
    title('No regulation requires fuel switch')
    legend('Base case','Flexibility','Location','northwest')
    set(b,'Linewidth',1.6)
end
```

B.2 Case Characteristics

```matlab
function [dr, ir, Vessel_age, T_vessel, PurchasePrice, Vessel_Value,...
    NH3_start, LPG_start, OPEX_nonfuel,...
    VLSFO_start, Consumption, Loan,Drydock_days,Retrofit_cost,Retrofit_year,...
    Equity,Regulation_year,Sailing_days,LPG_lossfactor,Debt_ratio,...
    Steel_price,Scrap_value,MachineryAddedCost] = GetCaseCharacteristics(Case)

% Rates
dr = 0.05; % Discount rate
ir = 0.085; % Ship loan interest rate

% Time parameters
Vessel_age = 0;
T_vessel = 20; % Ship is sold for scrapping after 20 years
Sailing_days = 52/73; % 260/365, ratio sailing days per year

% Ship Purchase Price
PurchasePrice = 35e6;
Debt_ratio = 0.70;
Equity = 1 - Debt_ratio;
MachineryAddedCost = 6e6;
if Case == 1 || Case == 3
    PurchasePrice = PurchasePrice + MachineryAddedCost;
end



% OPEX
OPEX_nonfuel = 6500; % Daily OPEX [USD]

%VOYEX related
```

```
VLSFO_start = 200;
LPG_start = 400;
NH3_start = 800;
Consumption = 28; % [mt/day]

% Vessel value loss through years (linearly)
Lws = 10375;
Steel_price = 600; % [USD/tonne]
Scrap_value = Lws * Steel_price;
loss_factor = nthroot(Scrap_value/PurchasePrice,T_vessel);
Vessel_Value  = zeros(1,T_vessel);
Vessel_Value(1) = PurchasePrice;
Loan = PurchasePrice*Debt_ratio;
for i=2:T_vessel
    Vessel_Value(i) = PurchasePrice * loss_factor.^i;
end

%Environmental regulation
Regulation_year = 10; % 1st Jan 2030

%  less space for cargo if LPG system
LPG_lossfactor = 0.98;

%Below relevant for case 2
Drydock_days = 30;
Retrofit_cost = 6e6*1.25;
Retrofit_year = 9; % During 20xx (2020 + Retrofit_year)



if Retrofit_year+1 > Regulation_year
    error('Retrofit must be within regulation implementation')
end


end
```

B.3 Historical Earnings

```
% Function reads .xlsx data and plots value for earnings
% from "Shipping Intelligence Network Timeseries" (Clarksons)

function [MR_earnings,year_earnings_MR,year_avg_mr,mr_avg_earnings] =...
    MR_Earnings(Plots)

fid = 'earnings.xlsx';
MR_earnings = xlsread(fid,'F7:F1587');
mr_avg_earnings = xlsread('earnings.xlsx','avg','C3:C64');
year_avg_mr = xlsread('earnings.xlsx','avg','B3:B64');

n_data_MR = length(MR_earnings);
year_start_MR = 1990+4/365; % 5 jan 1990
year_end_MR = 2020 + 106/366; % 17 april 2020
st = (year_end_MR - year_start_MR)/n_data_MR;
year_earnings_MR = year_start_MR:st:year_end_MR;
year_earnings_MR(:,n_data_MR) = [];



% Time Series Characteristics
kurt = kurtosis(MR_earnings);
```

```
skew = skewness(MR_earnings);
mdn = median(MR_earnings);
avg = mean(MR_earnings);
prc10 = prctile(MR_earnings,10);
prc90 = prctile(MR_earnings,90);

if Plots

    hold on
    plot(year_earnings_MR,MR_earnings,'color','black','LineWidth',0.1);
    plot(year_avg_mr,mr_avg_earnings,'-.','color','red','LineWidth',2);
    xlabel('Year')
    ylabel('Earnings [USD/day]')
    xlim([1989.99 2020.5]);
    legend('MR earnings','Annual average MR earnings');
    hold off

    R = price2ret(MR_earnings);
    figure
    histfit(R)
    xlabel('Weekly returns')
    ylabel('Frequency')
%     x0=10;
%     y0=10;
%     width=400;
%     height=300;
%     set(gcf,'position',[x0,y0,width,height]);
    figure
    qqplot(R)
    ylabel('Quantiles of weekly returns')
    title('')

    figure
    histogram(MR_earnings,50);
    xlabel('Earnings [USD/day]')
    ylabel('Frequency')
    line([mdn, mdn], ylim, 'LineWidth', 1.5, 'Color', 'r')
    line([avg, avg], ylim,'Color', 'g','LineWidth', 1.5)
    line([prc10, prc10], ylim, 'LineWidth', 1.5, 'Color', 'black')
    line([prc90, prc90], ylim, 'LineWidth', 1.5, 'Color', 'black')
end
end
```

B.4 Simulation of Future Earnings

```
% Estimating the parameters of the mean-reversion process
% in order to simulate earnings

function [Sim_Earnings,MeanEarningsRate] = SimulateEarnings(T_vessel,nSim,...
    MR_earnings,year_earnings_MR,year_avg_mr,mr_avg_earnings,Plots)

St = log(MR_earnings);
dSt = diff(St);
dt = 1/52.177457; % one week/weeks per year
dStdt = dSt/dt;
St(end) = []; % to ensure vector of same length

% Polynomial curve fitting to estimate parameters
p = polyfit(St, dStdt, 1);
res = dStdt - polyval(p,St);  % evaluates the polynomial p at each point in St

```

```
kappa = -p(1);
meanReverting = p(2)/kappa;
sigma = std(res) * sqrt(dt);

%https://se.mathworks.com/help/finance/hwv.html
% hwv with constant volatility equals Ornstein-Uhlenbeck
OUmodel = hwv(kappa, meanReverting, sigma,  'StartState', St(end));

% Simulation
n_years_sim = T_vessel;% 20 years of weekly simulation
n_Steps = round((1/dt)*n_years_sim);
[Sim_Earnings, Time] = simulate(OUmodel,n_Steps,'nTrials',nSim, 'DeltaTime',dt);
Sim_Earnings = exp(Sim_Earnings); % Earnings again, not log earnings
Sim_Earnings = squeeze(Sim_Earnings);% Removal of redundant dimension
Sim_Earnings = Sim_Earnings';
Time = Time';

% Visualize Simulation Paths

[r,c] = size(Sim_Earnings);
Time_0 = 2020 + 107/366; % when earnings.xlsx data end (17 april 2020)
Time = Time_0 + Time;

if Plots == 2
    for i=1:r
        hold on
        plot(Time,Sim_Earnings(i,:));
    end
end

MeanInSim = zeros(1,length(nSim));
MedianInSim = zeros(1,length(nSim));
skew = zeros(1,length(nSim));
for i=1:nSim
    MeanInSim(i) = mean(Sim_Earnings(i,:));
    MedianInSim(i) = median(Sim_Earnings(i,:));
    skew(i) = skewness(Sim_Earnings(i,:));
end

% Find when year change and takes mean earnings of each year
YearChanging = zeros(1, T_vessel);
for i= 1:T_vessel
    j=1;
    yearcheck = 2020+i;
    while Time(j) < yearcheck && j < length(Time)
        j = j + 1;
    end
    YearChanging(i) = (j-1);
end

SimsPerYear = zeros(1,(length(YearChanging)+1)); % +1 to incl until mid april
SimsPerYear(1) = YearChanging(1);

for i=2:length(YearChanging)
    SimsPerYear(i) = YearChanging(i) - YearChanging(i-1);
end
% further to include from 2020+T_vessel until mid april
mid_april = c - sum(SimsPerYear);
SimsPerYear(end) = mid_april;

MeanEarningsRate = zeros(r,length(SimsPerYear));
AccumulatedSimEarnings = zeros(r,length(SimsPerYear));
yearly = zeros(r,length(SimsPerYear));
```

```
for q=1:r
    for n = 1:length(YearChanging)
        j = 1;
        accumSimEarnings = 0;
        while j ≤ YearChanging(n) && j ≤ length(Sim_Earnings)
            accumSimEarnings = Sim_Earnings(q,j) + accumSimEarnings;
            j = j + 1;
        end
        AccumulatedSimEarnings(q,n) = accumSimEarnings;
    end
    yearly(q,1) = AccumulatedSimEarnings(q,1);
    for i=2:length(SimsPerYear)
        yearly(q,i) = AccumulatedSimEarnings(q,i) - AccumulatedSimEarnings(q,i-1);
    end
    % and again adding for mid april (Last column of yearly)
    midapril = sum(Sim_Earnings(q,:)) - AccumulatedSimEarnings(q,T_vessel);
    yearly(q,end) = midapril;
    for i=1:length(SimsPerYear)
        MeanEarningsRate(q,i) = yearly(q,i)/SimsPerYear(i);
    end
end %q

%preparing for plot
if Plots

%     figure
%     histfit(MeanInSim,50,'Lognormal')
%     pHat = lognfit(MeanInSim);
%     title('Average earnings for each simulation')
%     skewness_future_earnings = skewness(MeanInSim);
%     kurtosis_future_earnings = kurtosis(MeanInSim);

    x = 2020:(2020 + T_vessel);
    x_val = zeros(1,2*length(x));
    x_val(1:2:end) = x(1:1:end);
    x_val(2:2:end) = x(1:1:end);
    x_val(2) = Time_0;
    x_val(1) = [];
    x_val(end+1) = T_vessel + Time_0;
    y_val = zeros(1,2*length(MeanEarningsRate));
    year_sim_end = year_earnings_MR(end) + (n_Steps*dt);
    year_sim = year_earnings_MR(end):dt:year_sim_end;

    figure
    histogram(Sim_Earnings,100)
    xlim([0 6e4])
    xlabel('Simulated earnings [USD/day]')
    ylabel('Frequency')
    onedim = Sim_Earnings(:);
    kurt = kurtosis(onedim);
    skew = skewness(onedim);
    prc10 = prctile(onedim,10);
    prc90 = prctile(onedim,90);
    mdn = median(onedim);
    avg = mean(onedim);
    line([mdn, mdn], ylim, 'LineWidth', 1.5, 'Color', 'r');
    line([avg, avg], ylim,'Color', 'g','LineWidth', 1.5);
    line([prc10, prc10], ylim,'Color', 'black','LineWidth', 1.5);
    line([prc90, prc90], ylim,'Color', 'black','LineWidth', 1.5);

    figure(99)
    histogram(Sim_Earnings(1,:),50)
    x=Sim_Earnings(1,:);
```

```matlab
    prc10 = prctile(x,10);
    prc90 = prctile(x,90);
    mdn = median(x);
    avg = mean(x);
    line([mdn, mdn], ylim, 'LineWidth', 1.5, 'Color', 'r');
    line([avg, avg], ylim,'Color', 'g','LineWidth', 1.5);
    line([prc10, prc10], ylim,'Color', 'black','LineWidth', 1.5);
    line([prc90, prc90], ylim,'Color', 'black','LineWidth', 1.5);
    xlim([0 35e3])
    ylim([0 80])
    xlabel('Earnings [USD/day]')
    ylabel('Frequency')
    x0=10;
    y0=10;
    width=400;
    height=300;
    set(gcf,'position',[x0,y0,width,height]);
    figure(100)
    histogram(Sim_Earnings(2,:),50)
    x=Sim_Earnings(2,:);
    prc10 = prctile(x,10);
    prc90 = prctile(x,90);
    mdn = median(x);
    avg = mean(x);
    line([mdn, mdn], ylim, 'LineWidth', 1.5, 'Color', 'r');
    line([avg, avg], ylim,'Color', 'g','LineWidth', 1.5);
    line([prc10, prc10], ylim,'Color', 'black','LineWidth', 1.5);
    line([prc90, prc90], ylim,'Color', 'black','LineWidth', 1.5);
    xlim([0 35e3])
    ylim([0 80])
    xlabel('Earnings [USD/day]')
    ylabel('Frequency')
    x0=10;
    y0=10;
    width=400;
    height=300;
    set(gcf,'position',[x0,y0,width,height]);



    if nSim < 10
    for i=1:r
        y_val(1:2:end) = MeanEarningsRate(i,1:1:end);
        y_val(2:2:end) = MeanEarningsRate(i,1:1:end);
        figure(i+1)
        hold on
        plot(year_earnings_MR,MR_earnings,'color','cyan','LineWidth',1);
        plot(year_avg_mr,mr_avg_earnings,'-.','color','black','LineWidth',2);
        plot(year_sim,Sim_Earnings(i,:),'r','LineWidth',1);
        plot(x_val,y_val,'-.','color','black','LineWidth',2);
        legend('Historical earnings','Annual average','Simulated earnings');
        xlabel('Year')
        ylabel('Earnings [USD/day]')
        xlim([1989.99 2040.2])
        ylim([0 55000])
            if i > 1
                break
            end
        hold off
    end

end
end
```

B.5 Simulation of Fuel Price Difference

```
% Simulation of LPG and VLSFO price, as a mean-reverting stochastic process


function [FuelDiff,VLSFO,LPG] = SimulateFuelPriceDifference(T_vessel,nSim,...
    LPG_start,VLSFO_start,Plots)

dt = 0.25;
sigma = 0;
kappa = 0.3;

%-------------------------
% LPG PRICE SIMUALATION
%-------------------------

St = log(LPG_start);
meanReverting = St;
OUmodel = hwv(kappa, meanReverting, sigma,  'StartState', St);
n_years_sim = T_vessel;
n_Steps = (1/dt)*n_years_sim;
[LPG, Time] = simulate(OUmodel,n_Steps,'nTrials',nSim, 'DeltaTime',dt);
LPG = exp(LPG);
LPG = squeeze(LPG);
LPG = LPG';

%----------------------------
%     VLSFO PRICE SIMULATION
%----------------------------

St = log(VLSFO_start);
meanReverting = St;
OUmodel = hwv(kappa, meanReverting, sigma,  'StartState', St);

n_years_sim = T_vessel;
n_Steps = (1/dt)*n_years_sim;
[VLSFO, Time] = simulate(OUmodel,n_Steps,'nTrials',nSim, 'DeltaTime',dt);
VLSFO = exp(VLSFO);
VLSFO = squeeze(VLSFO);
VLSFO = VLSFO';
Time = Time';
[r,c] = size(VLSFO);

%----------------------------------
% FUEL PRICE DIFFERENCE LPG vs VLSFO
%---------------------------------
FuelDiff = zeros(r,c);
for i=1:r
    for j=1:c
        FuelDiff(i,j) = LPG(i,j) - VLSFO(i,j);
    end
end

Time_0 = 2020;
Time = Time_0 + Time;


if Plots
    for i=1:3
        figure(i)
        hold on
        plot(Time,VLSFO(i,:),'LineWidth',1.5)
```

```
        plot(Time,LPG(i,:),'LineWidth',1.5)
        plot(Time,FuelDiff(i,:),'LineWidth',1.5)
        legend('VLSFO','LPG','Price difference','Location','northwest')
        xlabel('Year')
        ylabel('Fuel Price [USD/tonne MGO eq.]')
    end
    histFuel = FuelDiff;
    histFuel(:,1) = [];
    histFuel = histFuel(:);
    maks = max(histFuel);
    minimum = min(histFuel);
    avg = mean(histFuel);
    mdn = median(histFuel);
    skew = skewness(histFuel);
    kurt = kurtosis(histFuel);
    prc10 = prctile(histFuel,10);
    prc90 = prctile(histFuel,90);

    figure
    histogram(histFuel,100)
    title('Fueldiff')
    xlim([-1000 1500])
    xlabel('Fuel price difference');
    ylabel('Frequency')
    line([mdn, mdn], ylim, 'LineWidth', 1.5, 'Color', 'r')
    line([avg, avg], ylim,'Color', 'g','LineWidth', 1.5)
    line([prc10, prc10], ylim, 'LineWidth', 1.5, 'Color', 'black')
    line([prc90, prc90], ylim, 'LineWidth', 1.5, 'Color', 'black')
end
```

B.6 VOYEX Calculations

```
function VOYEX_diff = VOYEX2(Case,Consumption,VLSFO,LPG,T_vessel,...
    Retrofit_year,FuelDiff,Regulation_year,Sailing_days,MachineryAddedCost)
[r,c] = size(VLSFO);
VOYEX = zeros(r,c-1);

% Case 0: Base case
for i=1:r
    for j = 1:c %
        VOYEX(i,j) = Consumption * VLSFO(i,j) * Sailing_days*365.25;
    end
end

AnnualMeanVOYEX = zeros(r,c);
YearlyAvgVOYEX = zeros(r,T_vessel);
for i=1:r
    s = 1;
    for j=1:4:c
        AnnualMeanVOYEX(i,j) = (VOYEX(i,j) + VOYEX(i,j+1) + VOYEX(i,j+2)...
            + VOYEX(i,j+3))/4;
        YearlyAvgVOYEX(i,s) = AnnualMeanVOYEX(i,j);
        s=s+1;
        if j ≥ c-4
            break
        end
    end
end
Basecase_YearlyAvgVOYEX = YearlyAvgVOYEX;

if Case == 1
```

```
for i=1:r
    for j = 1:c
        if j ≤ (Regulation_year)*4
            if VLSFO(i,j) ≥ LPG(i,j)
            VOYEX(i,j) = Consumption * LPG(i,j) * Sailing_days*365.25;
            elseif LPG(i,j) > VLSFO(i,j)
            VOYEX(i,j) = Consumption * VLSFO(i,j) * Sailing_days*365.25;
            end
        elseif j > (Regulation_year)*4
            VOYEX(i,j) = Consumption * LPG(i,j) * Sailing_days*365.25;
        end
    end
end

%Retrofit is done in Retrorfit_year, LPG consumption ready from
%Retrorfit_year + 1
elseif Case == 2
 for i=1:r
    for j = 1:c % *4 due to quarterly prices
        if j ≤ (Retrofit_year+1)*4
            VOYEX(i,j) = Consumption * VLSFO(i,j) * Sailing_days*365.25;
        elseif j > (Retrofit_year+1)*4 && VLSFO(i,j) ≥ LPG(i,j)
            VOYEX(i,j) = Consumption * LPG(i,j) * Sailing_days*365.25;
        elseif j > (Retrofit_year+1)*4 && LPG(i,j) > VLSFO(i,j)...
                && j ≤ (Regulation_year)*4
            VOYEX(i,j) = Consumption * VLSFO(i,j) * Sailing_days*365.25;
        else
            VOYEX(i,j) = Consumption * LPG(i,j) * Sailing_days*365.25;
        end
    end
 end
elseif Case == 3
 for i=1:r
    for j = 1:c % *4 due to quarterly prices
        if VLSFO(i,j) > LPG(i,j)
            VOYEX(i,j) = Consumption * LPG(i,j) * Sailing_days*365.25;
        else
            VOYEX(i,j) = Consumption * VLSFO(i,j) * Sailing_days*365.25;
        end
    end
 end
end

%The average yearly VOYEX is the average of each quarterly price
AnnualMeanVOYEX = zeros(r,c);
YearlyAvgVOYEX = zeros(r,T_vessel);
for i=1:r
    s = 1;
    for j=1:4:c
        AnnualMeanVOYEX(i,j) = (VOYEX(i,j) + VOYEX(i,j+1) + VOYEX(i,j+2)...
            + VOYEX(i,j+3))/4;
        YearlyAvgVOYEX(i,s) = AnnualMeanVOYEX(i,j);
        s=s+1;
        if j ≥ c-4
            break
        end
    end
end

VOYEX_diff = zeros(r,T_vessel);
% Change in VOYEX due to fuel flexibility/environmentalr regulations:
if Case ≠ 0
    for i=1:r
```

```
        for j=1:T_vessel
            VOYEX_diff(i,j) = Basecase_YearlyAvgVOYEX(i,j) - YearlyAvgVOYEX(i,j);
        end
%         tot_diff(i) = sum(VOYEX_diff(i,:));
%         tot_diff_snitt = mean(tot_diff);
    end
%     if Case == 3
%     figure
%     histogram(tot_diff,50)
%     line([MachineryAddedCost, MachineryAddedCost], ylim, 'LineWidth', 1.5, 'Color', 'r')
%     title('Value of fuel switch each simulation')
%     end
end
end
```

B.7 CAPEX Calculations

```
% Function to calculate the CAPEX

function CAPEX = GetCAPEX(Case,Retrofit_year,Retrofit_cost,Loan,T_vessel,ir)

r = ir;

%Loan*(1+r) = A + A/(1+r) + A/(1+r)^2 + A/(1+r)^3
%  = A (1-(1/1+r)^N)/(1-(1/(1+r))

AnnualPayment = Loan*(1+r)/((1-(1/(1+r))^T_vessel)/(1-1/(1+r)));

Interest = zeros(1,T_vessel+1);
Principal = zeros(1,T_vessel+1);
Loan_size = zeros(1,T_vessel+1);
CAPEX = zeros(1,T_vessel);

Loan_size(1)=Loan;
Interest(1)=0;
Principal(1)=0;
for i=2:T_vessel+1
    Interest(i) = Loan_size(i-1)*r;
    Principal(i) = AnnualPayment-Interest(i);
    Loan_size(i) = Loan_size(i-1)-Principal(i);
end
Principal = Principal(2:end);
Interest = Interest(2:end);
for i=1:T_vessel
    CAPEX(i) = Interest(i) + Principal(i); % To check AnnualPayment calc in
                                           % line 10 and get vector format
end

if Case == 2 % Added CAPEX of LPG retrofit, pay-down time of 5 years
    Payments = 5;
    AddedAnnualPayment = Retrofit_cost*(1+r)/((1-(1/(1+r))^Payments)/(1-1/(1+r)));
    Payment_start = Retrofit_year+1;
    Last_Payment = Payment_start+Payments-1;
    for i=Payment_start:Last_Payment
        CAPEX(i) = CAPEX(i) + AddedAnnualPayment;
    end
end
end
```

B.8 Cash Flow

```
function CF = CashFlow(T_vessel,VOYEX_diff,...
    OPEX_nonfuel,MeanEarningsRate,Loan,Case,Retrofit_year,Drydock_days,...
    CAPEX,Sailing_days,LPG_lossfactor)

OPEX_year = OPEX_nonfuel*Sailing_days*365.25;
OPEX_yearly = zeros(1,T_vessel);
OPEX_yearly(1) = OPEX_year;
for i=2:T_vessel
OPEX_yearly(i) = OPEX_year*1.02^(i-1);
end



%-----------------------------
%      Yearly Avg Earnings
%-----------------------------
[r,c] = size(MeanEarningsRate);
x=zeros(r,T_vessel);

for i=1:r
    for j=2:c
        x(i,j-1) = MeanEarningsRate(i,j);
    end
end
MeanEarningsRate = x;
EarningsYearly = MeanEarningsRate*Sailing_days*365.25;

if Case == 2 % if retrofit
    for i=1:r
        EarningsYearly(i,Retrofit_year) = MeanEarningsRate(i,Retrofit_year)*...
            ((Sailing_days*365.25) - Drydock_days);
    end
end

%------------------------------
%    YEARLY CASH FLOW
%------------------------------
CF = zeros(r,T_vessel);
for i=1:r
    for j=1:T_vessel
        if Case == 0
            CF(i,j) = EarningsYearly(i,j) - OPEX_yearly(j) - CAPEX(j);
        elseif Case == 1
            CF(i,j) = EarningsYearly(i,j)*LPG_lossfactor + VOYEX_diff(i,j)...
                - OPEX_yearly(j) - CAPEX(j);
        elseif Case == 2 && j ≤ Retrofit_year
            CF(i,j) = EarningsYearly(i,j) + VOYEX_diff(i,j) - OPEX_yearly(j)...
                - CAPEX(j);
        elseif Case == 2 && j > Retrofit_year
            CF(i,j) = EarningsYearly(i,j)*LPG_lossfactor + VOYEX_diff(i,j)...
                - OPEX_yearly(j) - CAPEX(j);
        elseif Case == 3
            CF(i,j) = EarningsYearly(i,j)*LPG_lossfactor + VOYEX_diff(i,j)...
                - OPEX_yearly(j) - CAPEX(j);
        end
    end
end
end % function
```

B.9 Net Present Value

```
% PRESENT VALUE OF CASH FLOWS & NET PRESENT VALUE

function NPV = GetNPV(CF, dr, nSim, T_vessel,Vessel_Value,Equity,Plots)

r=nSim;
c=T_vessel;
PV = zeros(r,c);
NPV = zeros(1,r);

InitialPayment = -Vessel_Value(1)*Equity;

for i=1:r
    for j=1:c
        PV(i,j) = CF(i,j)/((1+dr)^(j));
    end
    NPV(i) = sum(PV(i,:)) + Vessel_Value(end)/((1+dr)^(T_vessel))-InitialPayment;
end

mdn = median(NPV);
if Plots
figure
histogram(NPV,75);
title('ENPV for each simulation');
hold on
line([mdn, mdn], ylim, 'LineWidth', 1.5, 'Color', 'r')
% figure
% cdfplot(NPV);
% title('Cumulative density function of the NPV');
end
```

C Sensitivity Analysis

C.1 Base Case Sensitivity

```
% SENSITIVITY ANALYSIS
run NPV_ShipConventional % Case = 0
ENPV_BaseValue = mean(NPV);

% Sensitivity parameters
names = {'Discount rate';'Interest rate';'Daily OPEX';'Sailing days';...
    'Debt ratio';'Purchase Price';'Scrap Value'};
n_param = length(names)*2; % times two bc higher and lower value for each
factor = 0.05;
up = 1+factor;
down = 1-factor;

% Preallocating
ENPV=zeros(1,n_param);
ENPV_up = zeros(1,n_param/2);
ENPV_down = zeros(1,n_param/2);

for i=1:n_param
[dr, ir, Vessel_age, T_vessel, PurchasePrice, Vessel_Value,NH3_start,...
    LPG_start, OPEX_nonfuel,VLSFO_start, Consumption, Loan,Drydock_days,...
    Retrofit_cost,Retrofit_year,Equity,Regulation_year,Sailing_days,...
    LPG_lossfactor,Debt_ratio,Steel_price,Scrap_value,...
    MachineryAddedCost] = GetCaseCharacteristics(Case);
if i == 1
    dr = dr*down;
elseif i==2
    dr = dr*up;
elseif i == 3
    ir = ir*down;
elseif i == 4
    ir = ir*up;
elseif i == 5
    OPEX_nonfuel = OPEX_nonfuel*down;
elseif i == 6
    OPEX_nonfuel = OPEX_nonfuel*up;
elseif i == 7
    Sailing_days = Sailing_days*down;
elseif i == 8
    Sailing_days = Sailing_days*up;
elseif i == 9
    Debt_ratio = Debt_ratio*down;
elseif i == 10
    Debt_ratio = Debt_ratio*up;
elseif i == 11
    PurchasePrice = PurchasePrice*down;
elseif i == 12
    PurchasePrice = PurchasePrice*up;
elseif i == 13
    Scrap_value = Scrap_value*down;
elseif i == 14
    Scrap_value = Scrap_value*up;
end
if i == 9 || i == 10
    Equity = 1 - Debt_ratio;
    Loan = PurchasePrice*Debt_ratio;
elseif i == 11 || i == 12
    Lws = 10375;
    Steel_price = 600;
```

```
    Scrap_value = Lws * Steel_price;
    loss_factor = nthroot(Scrap_value/PurchasePrice,T_vessel);
    Vessel_Value  = zeros(1,T_vessel);
    Vessel_Value(1) = PurchasePrice;
    Loan = PurchasePrice*Debt_ratio;
    for j=2:T_vessel
        Vessel_Value(j) = PurchasePrice * loss_factor.^j;
    end
elseif i == 13 || i == 14
    Lws = 10375;
    loss_factor = nthroot(Scrap_value/PurchasePrice,T_vessel);
    Vessel_Value  = zeros(1,T_vessel);
    Vessel_Value(1) = PurchasePrice;
    for j=2:T_vessel
        Vessel_Value(j) = PurchasePrice * loss_factor.^j;
    end
end

VOYEX_diff = VOYEX2(Case,Consumption,VLSFO,LPG,T_vessel,Retrofit_year,...
    FuelDiff,Regulation_year,Sailing_days,MachineryAddedCost);
CAPEX = GetCAPEX(Case,Retrofit_year,Retrofit_cost,Loan,T_vessel,ir);
CF = CashFlow(T_vessel,VOYEX_diff,...
   OPEX_nonfuel,MeanEarningsRate,Loan,Case,Retrofit_year,Drydock_days,...
   CAPEX,Sailing_days,LPG_lossfactor);
NPV = GetNPV(CF,dr,nSim,T_vessel,Vessel_Value,Equity,Plots);

ENPV(i) = mean(NPV);
end

s=1;
for i=1:2:n_param
    ENPV_down(s) = ENPV(i);
    s=s+1;
    if s > n_param/2
        break
    end
end
s=1;
for i=2:2:n_param
    ENPV_up(s) = ENPV(i);
    s=s+1;
    if s > n_param/2
        break
    end
end

ENPV_up_diff = abs(ENPV_up - ENPV_BaseValue) ;
[ENPV_up_diff,index] = sort(ENPV_up_diff,'ascend');
ENPV_up = ENPV_up(index);
ENPV_down = ENPV_down(index);
names = names(index);

figure
h = barh(ENPV_up);
bh = get(h,'BaseLine');
set(bh,'BaseValue',ENPV_BaseValue);
hold on
x_min = min(ENPV);
x_max = max(ENPV);
xlim([0.95*x_min 1.05*x_max])
barh(ENPV_down,'r')
set(gca,'yticklabel',names)
set(gca,'Ytick',[1:length(names)],'YTickLabel',[1:length(names)])
```

```
set(gca,'yticklabel',names)
legend('5% increase','5% decrease','Location','southeast')
xlabel('Estimated expectation of NPV [USD]')
set(groot,'defaultAxesTickLabelInterpreter','latex');
set(groot,'defaultTextInterpreter','latex') %latex axis labels
set(groot,'defaultLegendInterpreter','latex');
set(gca,'FontSize',12)
```

C.2 Comparison of Flexibility and Retrofit Option

```

run NPV_ShipConventional % Make sure Case = 1
BasecaseNPV = NPV;

years = [5 10 15];
l = length(years);
Retrofit = [(6e6*(1+.02)^5)*1.25 (6e6*(1+.02)^10)*1.25 (6e6*(1+.02)^15)*1.25];
% Compunded to get future value of retrofit, + 30% due to retrofit itself

EstimatedNPV1 = zeros(l,nSim);
EstimatedNPV2 = zeros(l,nSim);

% Fuel flexible
for i=1:l
    Regulation_year = years(i);
    Retrofit_year = Regulation_year - 1;

    VOYEX_diff = VOYEX2(Case,Consumption,VLSFO,LPG,T_vessel,Retrofit_year,...
        FuelDiff,Regulation_year,Sailing_days);
    CAPEX = GetCAPEX(Case,Retrofit_year,Retrofit_cost,Loan,T_vessel,ir);
    CF = CashFlow(T_vessel,VOYEX_diff,...
        OPEX_nonfuel,MeanEarningsRate,Loan,Case,Retrofit_year,Drydock_days,...
        CAPEX,Sailing_days,LPG_lossfactor);
    NPV = GetNPV(CF,dr,nSim,T_vessel,Vessel_Value,Equity,Plots);

    EstimatedNPV1(i,:) = NPV;
end


% Retrofit case
for i=1:l
    Case = 2; % Now retrofitting...

    [dr, ir, Vessel_age, T_vessel, PurchasePrice, Vessel_Value,...
    NH3_start, LPG_start, OPEX_nonfuel,...
    VLSFO_start, Consumption, Loan,Drydock_days,Retrofit_cost,...
    Retrofit_year,Equity,Regulation_year,Sailing_days,LPG_lossfactor,...
    Debt_ratio,Steel_price,Scrap_value] = GetCaseCharacteristics(Case);

    Regulation_year = years(i);
    Retrofit_year = Regulation_year - 1;
    Retrofit_cost = Retrofit(i);

    VOYEX_diff = VOYEX2(Case,Consumption,VLSFO,LPG,T_vessel,Retrofit_year,...
        FuelDiff,Regulation_year,Sailing_days);
    CAPEX = GetCAPEX(Case,Retrofit_year,Retrofit_cost,Loan,T_vessel,ir);
    CF = CashFlow(T_vessel,VOYEX_diff,...
        OPEX_nonfuel,MeanEarningsRate,Loan,Case,Retrofit_year,Drydock_days,...
        CAPEX,Sailing_days,LPG_lossfactor);
    NPV = GetNPV(CF,dr,nSim,T_vessel,Vessel_Value,Equity,Plots);

```

```
    EstimatedNPV2(i,:) = NPV;
end
figure(1337)
subplot(1,3,1)
hold on
a = cdfplot(EstimatedNPV1(1,:));
b = cdfplot(EstimatedNPV2(1,:));
title('New regulations in 2025')
legend('Flexibility','Retrofit','Location','northwest')
xlabel('NPV [USD]')
ylabel('Cumulative probability')
xlim([-3e7 2e7])
subplot(1,3,2)
hold on
c=cdfplot(EstimatedNPV1(2,:));
d=cdfplot(EstimatedNPV2(2,:));
title('New regulations in 2030')
legend('Flexibility','Retrofit','Location','northwest')
xlabel('NPV [USD]')
ylabel('Cumulative probability')
xlim([-2.5e7 2e7])
subplot(1,3,3)
hold on
e=cdfplot(EstimatedNPV1(3,:));
f=cdfplot(EstimatedNPV2(3,:));
title('New regulations in 2035')
legend('Flexibility','Retrofit','Location','northwest')
xlabel('NPV [USD]')
ylabel('Cumulative probability')
xlim([-1.5e7 2e7])

set(a, 'LineWidth',1.6);set(b, 'LineWidth',1.6);set(c, 'LineWidth',1.6);
set(d, 'LineWidth',1.6);set(e, 'LineWidth',1.6);set(f, 'LineWidth',1.6);
avg1 = mean(EstimatedNPV1(1,:));avg2 = mean(EstimatedNPV1(2,:));
avg3 = mean(EstimatedNPV1(3,:));avg4 = mean(EstimatedNPV2(1,:));
avg5 = mean(EstimatedNPV2(2,:));avg6 = mean(EstimatedNPV2(3,:));
```

NTNU
Norwegian University of
Science and Technology