

# Carbon Risk and Mitigating Strategies in the Maritime Industry

An investigation into the financial risk of the energy and climate transition, and its main drivers

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Marine Technology / SDPO / Shipping Management

Delft University of Technology  
SDPO.18.043.m

 **TU Delft**

Public Version



# Carbon Risk and Mitigating Strategies in the Maritime Industry

An investigation into the financial risk of the energy and climate  
transition, and its main drivers

By

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In partial fulfilment of the requirements for the degree of Master of Science  
at the Delft University of Technology.

Education: Marine Technology – SDPO – Shipping Management

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Delft, October 3, 2018



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# Abstract

The shipping industry accounts for a significant share in global GHG emissions<sup>1</sup>. Especially since Business as Usual (BaU) scenario studies project that the emissions due to shipping could increase by 50 [%] to 250 [%] in the period to 2050 (IMO, 2015), shipowners face a potential regulatory threat. Major climate regulations for shipping already entered into force, and a range of possible instruments may be applied going forward. Besides the risk of direct regulation, there is also a risk of being indirectly impacted by energy and/or climate regulation in other sectors. The direct and indirect regulations can adversely impact the operations, cashflow, and economic value of enterprises of existing shipowners and charterers of ships. Shipowners and financiers that are unaware of these developments, or that do not take timely mitigating actions, may potentially face considerable financial losses.

This study aims to provide further insight in the potential of financial losses and mitigating actions that shipowners can take. Typical core drivers, factors, and dependencies have been studied from literature in order to come up with an effective approach to capture the threat of Carbon Risk. As a result, a Carbon Risk framework is been developed, showing (inter)dependencies between all Carbon Risk factors. We found that Carbon Risk factors can be divided in two categories, namely: 1) Structural Risk, and 2) Event Driven Risk. Structural Risk targets all GHG intensive firms and/or value chains whereas Event Driven Risk can occur very sudden and/or can target specific firms. In addition to the framework, typical Carbon Risks have been identified for the shipping industry.

Carbon Risk is a complex risk due to the many different risk factors and interdependencies. This research focuses on Structural Risk. A Carbon Tax is used as a proxy for Regulatory Risk and demand substitution (i.e. a 20 [%] reduction of cargo) is used as proxy for Substitution Risk. By distinguishing vessels by type and size, we account for different technical, operational, and market characteristics. We focus on crude oil tankers, container ships, and bulk carriers because they are the three most significant sectors from a CO<sub>2</sub> perspective (IMO, 2015). To cover the key drivers of Carbon Risk, as identified in the framework, the method is divided into four steps, with each step providing further information on the impact and mitigating actions available to a ship owner. In the first step, the first order impact of a Carbon Tax (Regulatory Risk) across 9 sub sectors is assessed. Then, in the second step, the effect of economies of scale on the competitive position within a sub segment is been determined. Subsequently, in step 3, technical adjustments to the ship are accounted for by estimating the added cash flow due to an improvement in fuel efficiency. The outcome of step 3 can be used to determine to what extent energy efficient investments can mitigate the impact of a Carbon Tax and to which extent such investments would be economically feasible. At last, in step 4, the impact of 20 [%] demand substitution is investigated.

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<sup>1</sup> “For the period 2007–2012, on average, shipping accounted for approximately 3.1% of annual global CO<sub>2</sub> and approximately 2.8% of annual GHGs on a CO<sub>2</sub>e basis using 100-year global warming potential conversions from the IPCC Fifth Assessment Report (AR 5).” (IMO, 2015)

The first order financial impact<sup>2</sup> of a Carbon Tax of 50 [\$/Tonne CO<sub>2</sub>] is significant. Note that other levels of the tax have also been tested, for which results are shown in the results section. However, assuming a Carbon Tax of 50 [\$/Tonne CO<sub>2</sub>], the minimum cost assessment shows that transport costs rise with an average of at least 13.5 [%]. In addition, the economical speed decreases due to a Carbon Tax. The maximum profit assessment shows that the first order impact on profit can range between the -27.9 [%] and -124.7 [%] (impacts lower than -100 [%] indicate ships no longer generate profit). The results indicate that the containerships, large tankers, and large bulk carriers are the most susceptible to a Carbon Tax. The main reason is that these vessels have a high share of fuel costs on total costs/revenue. This is driven by 3 factors, namely: travelling speed, additional fuel consumption, and relatively longer voyage distances. The higher the typical share of fuel costs (read: fuel consumption) of a particular sub segment/voyage the larger the impact on the modelled transport costs and profit. Mitigating the impact of a Carbon Tax by lowering the ship's speed will go at the expense of the ship's productivity.

However, for ships operating within a competitive sub segment (step 2 of the analysis), larger ships have an advantage over smaller ships. The main reason is that the larger ship has lower transport prices compared to its smaller competitors due to a smaller increase in OPEX, CAPEX, and voyage costs compared to the increase of cargo capacity.

In addition, within the sub segment, the financial impact of a Carbon Tax is the highest for the least fuel-efficient vessels (step 3 of the analysis). In general, fuel efficiency related investments have a significant positive impact, and the financial benefits of such adjustments increase substantially after the introduction of a Carbon Tax (e.g. for ship/case 1.9 (Neo Panamax containership), given the scenario variables, a 10-year investment horizon, a 10 [%] discount rate, and a Carbon Tax of 50 [\$/Tonne CO<sub>2</sub>], the DCF becomes 14.9 [M\$] which is 39.1 [%] higher than without a Carbon Tax). Even before regulatory certainty, it is advised that shipowners and financiers (as part of their Carbon Risk mitigation strategy) research fuel efficient mitigation options (technological investments) under different Carbon Tax levels. When there is certainty about future market-based measures, early adaptors/investors of viable fuel-efficient measures (under future regulatory conditions) will benefit most of the investment and improve their competitive position.

The financial impact of Demand Substitution is significant (for all cases). Containerships have the highest first order impact on maximum profit due to 20 [%] demand substitution. The sensitivity analysis showed that the impact is higher for containerships compared to bulk carriers and oil tankers due to the differences in nature of demand substitution. The impact of the containership cases is significantly lower if the same modelling method as for the bulk carriers and oil tankers is used to simulate demand substitution. The implication of the above is that it matters for ship owners how they (can) respond to Demand Substitution. However, the likelihood of substitution demand is not included in the analysis and can differ between sectors. The scale of future demand substitution remains uncertain (see section 3.2.4). Therefore, it is possible that the risk (impact and likelihood) can be higher for (coal) dry bulk carriers and/or oil tankers if the demand of fossil fuels will drop quickly due to e.g. climate change regulation.

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<sup>2</sup> Cargo price readjustments are not included in the model. Therefore, we classify the impact as: 'first order impact'. However, the model allows for speed adjustments and determines the maximum profit (best combination between revenue and costs) for each Carbon Tax level and/or demand substitution level.

# Acknowledgements

First of all, I want to thank my supervisor Arnold Mulder for the patient guidance throughout the project. I am deeply grateful for the support, coaching, remarks, and discussions which have led to many valuable insights. I would also like to thank Koos Frouws and Eddy van de Voorde for the useful critiques and suggestions. Last, but not least, I want to thank my parents, brothers, and friends for all the support during my graduation.

*M.W.M. Koopman  
Delft, September 2018*

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# 1. Introduction

The background behind this research can be found in paragraph 1.1, the objective of this research in paragraph 1.2, and the structure of this report in paragraph 1.3.

## 1.1. Background

The shipping industry accounts for a significant share in global GHG emissions<sup>3</sup>. Especially since Business as Usual (BaU) scenario studies project that the emissions due to shipping could increase by 50 [%] to 250 [%] in the period to 2050 (IMO, 2015), shipowners face a potential regulatory threat. The sector's growth path, in combination with its strong reliance on fossil fuels are likely to be at odds with the Paris Agreement (Rahim, Islam, & Kuruppu, 2016). The agreement was signed in 2016 and aims to limit global warming well below 2 [°C] above pre-industrial levels (UNFCCC, 2015). The agreement was ratified by 158 nations, implying that many nations around the world may opt to apply stringent emissions regulations to reach this goal, including regulations onto the maritime sector. Shipowners and financiers that are unaware of these developments, or that do not take timely mitigating actions, may potentially face considerable financial losses. So far, however, limited research has been performed to assess this potential financial impact. Therefore, this study aims to provide further insight in the potential of financial losses and mitigating actions that shipowners can take.

A significant number of scientists believe that global warming is accelerating and that it is extremely likely to have been caused by, among other things, emission of greenhouse gases (GHGs) due to human activity (Doran & Zimmerman, 2009) (Anderegg, Prall, Harold, & Schneider, 2010). GHGs are those gases in the atmosphere that absorb and emit radiation within the thermal infrared range which causes the greenhouse effect. The greenhouse effect is believed to be the cause of global warming, leading to e.g. warming of the atmosphere, acidification of oceans, more severe drought of land and intensified weather events. In addition, the physical impacts on the planet can have serious knock-on economic and social effects (IPCC, 2014).

The potential harmful effects of GHG emissions are used to drive adoption of climate treaties, policies, regulation, and other mitigation measures. In 1992, the United Nations Framework Convention on Climate Change (UNFCCC) was adopted and entered into force on 21 March 1994. At the time of writing, 196 states have ratified the UNFCCC. The ultimate objective is to achieve: "stabilization of greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system" (UNFCCC, 1992). The convention provides a framework for further international climate treaties but has no binding limits nor enforcement mechanisms of itself. In 2016, the Paris Agreement entered into force which builds upon the UNFCCC from 1992. The agreement aims to limit global warming well below 2 [°C] above pre-industrial levels and to pursue efforts to limit the temperature increase to 1.5 [°C] above pre-

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<sup>3</sup> "For the period 2007–2012, on average, shipping accounted for approximately 3.1% of annual global CO<sub>2</sub> and approximately 2.8% of annual GHGs on a CO<sub>2</sub>e basis using 100-year global warming potential conversions from the IPCC Fifth Assessment Report (AR 5)." (IMO, 2015)

industrial levels (UNFCCC, 2015). To illustrate the level of support, by the time of writing, 158 of the 197 parties of the UNFCCC have ratified the Paris Agreement. To meet the aim of the Paris Agreement, studies show that the level of GHG emissions have to decrease significantly. According to the IPCC, the GHG emissions have to be lowered by approximately 40 to 70 percent compared with 2010 by 2050, and to near-zero by 2100 only to have a likely change to limit global warming to two degrees Celsius (IPCC, 2014).

Major climate regulations for shipping already entered into force, and a range of possible instruments may be applied going forward. First, examples of instruments that have already been introduced are: the Energy Efficiency Design Index (EEDI) (IMO, 2012), and Emission Control Areas (ECAs) (IMO, 2017). Also, at the beginning of 2018 large ships using EU ports are required to monitor, report, and verify their CO<sub>2</sub> emissions. This is the first step as part of their strategy for integrating maritime emissions into the EU's policy for reducing its domestic greenhouse gas emissions (European Commission, 2017). Second, looking forward, the demand for more severe regulation is rising. For instance, the European Union (EU) is calling for further regulation of climate pollution in international waters by the IMO. In addition, the EU already outlined plans to include ship related pollution mitigation policy if substantial regulation not exist by 2023 (Macalister, 2017). A range of possible regulations and instruments can be deployed. Future direct regulation can consist of, among other things, emission limitation and taxation of emissions instruments.

Besides the risk of direct regulation, there is also a risk of being indirectly impacted by energy and/or climate regulation in other sectors. Especially if shipowners rely on GHG intensive value chains. Energy and/or climate regulation can cause demand shifts of products and between products. For example, a switch from coal to gas in power generation can potentially lower the demand for bulk carriers and increase the demand for gas carriers. At the same time, the total demand in both markets can decline due to a more efficient use of resources.

The direct and indirect regulations can adversely impact the operations, cashflow, and economic value of enterprises of existing shipowners and charterers of ships. For instance, the main engines (propulsion) are the dominant fuel consumers onboard of most ships. Fuel costs can represent as much as 50 to 60 [%] of the total ship operating costs (WSC, 2008)<sup>4</sup>. Because of the significant share of fuel consumption in operational costs, taxation of emissions can increase operational costs significantly. Also, besides emission taxation, emission limitations can result in changes of the operational profile of ships and can drive other expensive mitigation measures as well. Given these examples, it is possible that the value and/or earnings of shipowners are impacted because they rely on greenhouse gas (GHG) intensive activities and/or value chains. If the impact is large and shipowners do not take timely mitigating action, Carbon Risk could even result in bankruptcy.

However, GHG emission regulation could also result in potential positive effects on shipping businesses and it can create opportunities in the shipping industry as well. For example, Corbett, Wang, & Winebrake (2009) showed that speed reduction can be applied to reduce the total amount of CO<sub>2</sub> emissions in shipping on the majority of the analyzed routes. According to their study, the total amount of CO<sub>2</sub> emissions decreased even when additional ships are added to maintain

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<sup>4</sup>Corresponding marine bunker fuel prices of \$552 per ton (year: 2008)



scheduled frequency (Corbett, Wang, & Winebrake, 2009). If additional ships are needed to maintain scheduled frequency, it is possible that this can absorb excess fleet capacity which can have positive effects on ship value and/or earnings. Also, as earlier mentioned, in some cases, fuel costs can represent as much as 50 - 60 [%] of total ship operating costs (WSC, 2008). Therefore, speed reduction, in order to reduce CO<sub>2</sub> emissions, can lead to a significant reduction of operational cost as well. As a result, if ships are directly or indirectly forced to reduce their operational speed due to regulation it could have a possible positive financial effect for shipowners.

Considering the potential Carbon Risk factors and drivers, Raucci, et al. (2017) states that there is a need to better understand which shipping assets will remain competitive, which will not, and what this will mean for the financiers of billions worth of assets in the maritime industry. For example, many banks engage in maritime related financing and are therefore also susceptible to Carbon Risk. By gaining further insight into Carbon Risk, banks can preserve and/or strengthen their financial health, determine and assess risk mitigation measures, and take advantage of the new opportunities decarbonization will create.

## **1.2. Research objective**

The objective of the upcoming thesis work is to define, measure, and reveal the level of Carbon Risk for shipowners and to assess mitigating strategies as part of the assessment of the bank's exposure to Carbon Risk. Carbon Risk for shipowners covers: the risk (impact and likelihood) that the value and/or earnings of shipowners decline because they rely on greenhouse gas (GHG) intensive activities and/or value chains<sup>5</sup>.

## **1.3. Structure of the report**

This paper is structured as follows. First a literature review will be conducted, in chapter 2. In the literature review, Carbon Risk definitions and frameworks along with the potential risks and opportunities will be studied from current literature. Also, the financial impact of Carbon Risk on sectors and operators inside and outside the maritime industry will be reviewed. Subsequently, the level of information of the current literature about the financial impact of Carbon Risk for shipowners will be assessed. The literature gap between the literature and the thesis objective will be exposed/addressed and the contribution of this study will be given.

Chapter 3 concerns the methodology. First, the Carbon Risk framework will be outlined which is used in this thesis. Subsequently, the scope of the project will be established. The scope of the project includes among other things: relevant ship types and sizes, cargo types, market segments, risks, regulation, and side effects. Thereafter, the method to assess the financial impact of Carbon Risk will be determined along with relevant parameters which will be used in the assessment. Subsequently, the results will be shown in chapter 4. The conclusion and discussion corresponds respectively with chapter 5 and chapter 6.

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<sup>5</sup> In other words, Carbon Risk for shipowners covers: the risk (impact and likelihood) of being financially impacted (company's value, revenue, profit, margin) because of the reliance on greenhouse gas (GHG) intensive activities and/or value chains.



## 2. Literature review

This chapter is structured as follows. First in paragraph 2.1, several Carbon Risk frameworks from literature will be presented along with characteristics and indicators of firms to assess their exposure to Carbon Risk. In paragraph 2.2, methods to assess the financial impact of Carbon Risk are addressed and results of some financial impact studies will be presented. In paragraph 2.3, shipping related GHG regulation will be discussed. In paragraph 2.4, the synthesis/conclusion of the literature study can be found. Subsequently, in paragraph 2.5, the literature gap and the contribution of this study will be given.

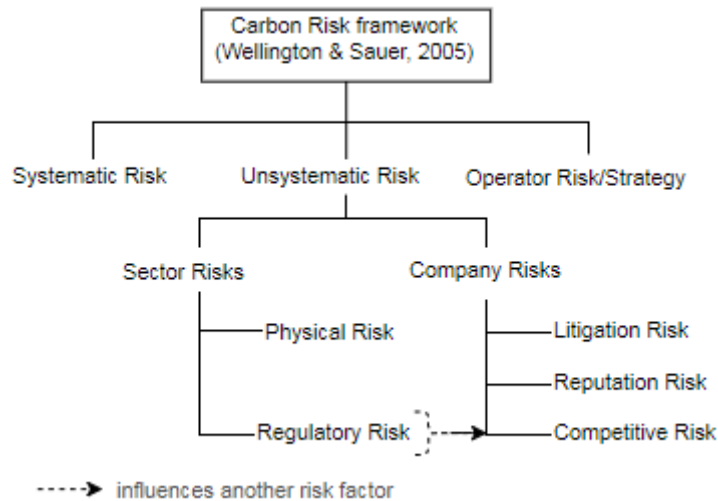
### 2.1. How is Carbon Risk defined in literature?

First, in paragraph 2.1.1 we shed light on theoretical climate risk frameworks. Subsequently, in paragraph 2.1.2 we provide an overview of risk exposure characteristics/indicators that are used in literature to assess a firm's exposure to Carbon Risk. Together, the frameworks and indicators expose possible drivers of Carbon Risk.

#### 2.1.1. Carbon Risk framework

In this paragraph, several Carbon Risk frameworks are discussed. The frameworks differ in structure but typically share core drivers, factors, and dependencies.

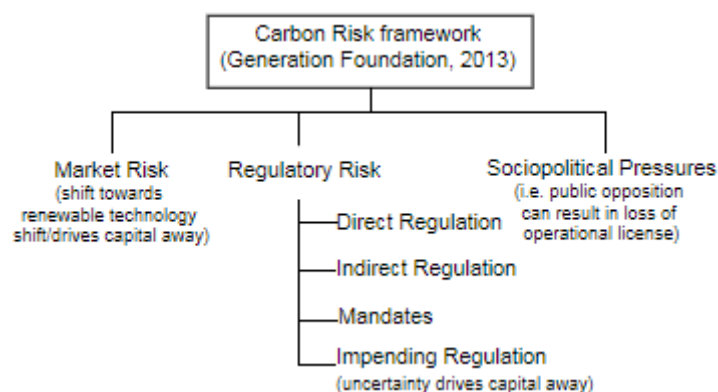
In 2005, Wellington and Sauer provided a framework intended to help investors identify and evaluate the impact of climate risk on their investment portfolios, see Figure 2.1 for a graphical overview. They differentiate between systematic and unsystematic risk. Systematic risk is associated with macro-economic and market risk (i.e. policies that affects: energy prices, national income, health, and agriculture). Unsystematic risk is related to a specific sector or security (i.e. a company's earnings, profitability, and return on invested capital). In their paper, they focus on unsystematic risk which they divide into sector specific risks and company specific risks. The sector specific risks are: Physical Risk and Regulatory Risk (will create a cost for CO<sub>2</sub>). Company specific risks are subdivided in: Litigation Risk, Reputation Risk, and Competitive Risk (Wellington & Sauer, 2005). Competitive Risk is driven by (impending) regulation because the applied regulatory framework causes competitive challenges between companies.



**Figure 2. 1 - Interpretation of the Carbon Risk framework of Wellington & Sauer (2005) (own composition)**

Coburn, Donahue, and Jayanti (2011) stated that (institutional) investors have paid close attention to risks and opportunities related to climate change the last 10 years. They refer to climate risks factors such as: regulations, indirect consequences<sup>6</sup> and business trends (driven by legal, economic, or technological developments), competitiveness, litigation, and Physical Risk (Coburn, Donahue, & Jayanti, 2011).

Generation Foundation (2013) highlighted regulation, market forces, and sociopolitical pressures as risks associated with GHG intensive assets. They divide Regulatory Risk into: direct regulation, indirect regulation, mandates, and impending regulation, see Figure 2.2 for a graphical overview. According to Generation Foundation (2013), impending regulation can cause uncertainty about the stringency and impact on assets which can drive capital away from those assets. Market Risk is associated with positive characteristics of renewable technology which can cause a shift of capital allocation away from GHG intensive assets. And Sociopolitical Pressures, such as public opposition, can cause a loss of the operational license of GHG intensive companies in extreme cases (Generation Foundation, 2013).



**Figure 2. 2 - Interpretation of the Carbon Risk framework of Generation Foundation (2013) (own composition)**

<sup>6</sup> "...for example, decreasing demand for goods or energy sources associated with high greenhouse gas emissions or increasing demand for "cleaner" products or energy sources, or by increasing competition to develop new products" (Coburn, Donahue, & Jayanti, 2011).

In 2015, the World Resource Institute (WRI) and the United Nations Environment Programme Finance Initiative (UNEP-FI) provided a discussion framework to assess the risk that a loan is not repaid or an investment does not perform as expected due to a GHG constrained global economy (Carbon Asset Risk). Their framework focusses on risks associated with climate mitigation for energy related CO2 emissions. WRI and UNEP-FI (2015) discusses three core Carbon Risk factors, namely: Policy and Legal, Technology, and Market and Economic factors, see Figure 2.3 for a graphical overview. Reputational Risk (i.e. damage to brand value or reputation) is discussed, but no specific evaluation approaches are provided.

Policy and legal risk factors are: climate related policies, regulation, and (environmental) litigation. These risk factors could change the way an asset is operated and could have a financial impact on the asset as well. Besides the impact on asset level, it could also change the overall demand for energy. Technological breakthroughs of alternative and low carbon technologies are considered as risks as well. It could lead to greater energy efficiency and could have an impact on the competitiveness of assets and businesses. Market and economic changes can occur due to climate related policy and regulations, technological breakthroughs, and changing consumer demand.

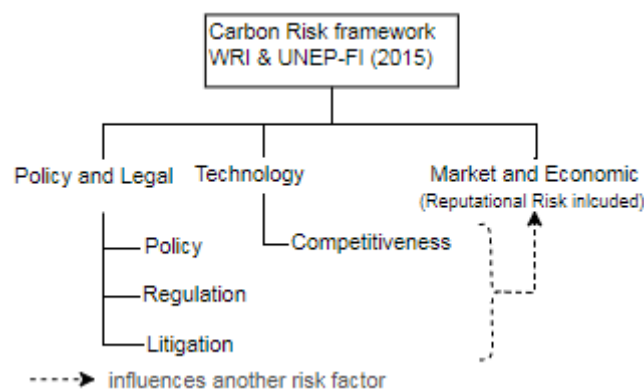


Figure 2. 3 - Interpretation of the Carbon Risk framework of WRI & UNEP-FI (2015) (own composition)

### Comparison and own framework

Comparing the frameworks, one can notice that different categories and structures are used with similarities in core drivers, factors, and dependencies. WRI and UNEP-FI (2015) noted the difficulty breaking down components of Carbon Risk because many factors are closely intertwined and not always easy to isolate. As example they argue that policy changes can lead to new economic incentives and also drive technological innovation and deployment (WRI & UNEP-FI, 2015). Subsequently, technological breakthroughs could impact the competitiveness of assets and businesses resulting in financial and operational impact on company level. In 2005, Wellington and Sauer noted similar relations between risk factors. They point out that regulation could have a direct financial impact on the sector, and thus on each specific company. Subsequently, the financial and operational impact of regulation could lead to changes in competitiveness between companies as well. Together or apart from each other, these changes can result in serious company specific financial consequences.

It is important to take the value chain into account for the assessment of Carbon Risk because demand (output of sector/company of interest), supply (input of sector/company of interest) and

price are driving forces for the financial health of a company. Value chains are concatenations of companies within a variety of sectors adding value to products and services ending by the (end) customers, see Figure 2.4. Wellington and Sauer (2005) emphasize that policies can affect (for example) energy prices, national income, and agriculture on a macroeconomic level. Macroeconomic changes can affect the price of raw materials and/or energy among others, needed for the production process of firms. Therefore, with respect to the whole supply chain, policy and regulation can be subdivided in direct and indirect regulation. Direct regulation targets the sector and companies of interest whereas indirect regulation targets successor and/or predecessor sectors and companies. As already discussed, WRI and UNEP-FI (2015) note that not only policy and regulation can affect market and economic circumstances but technological breakthroughs and changing consumer demand as well. Subsequently, changes in economic circumstances can change the competitive positioning between companies within a sector.

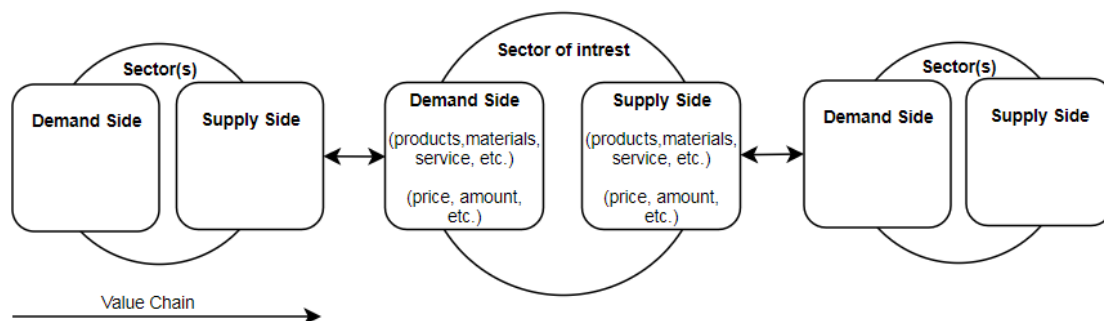


Figure 2.4 – Representation of a value chain (own composition)

Wellington and Sauer (2005) classify Regulatory Risk and Physical Risk as sector risks and Competitive Risk, Reputation Risk, and Litigation Risk as company risks. Regulatory Risk (direct regulation) is seen as the main driver for competitive challenges between companies. Market and Economic risk, as defined by WRI and UNEP-FI (2015), corresponds partly with Substitution Risk in this paper. Market and Economic Risk concern all market and economic changes due to Carbon Risk according to WRI and UNEP-FI (2015), in this paper, market and economic changes due to direct regulation are accounted as the effect of direct regulation, technological breakthroughs, and competitiveness; and not directly included into our framework. Generation Foundation (2013) includes direct regulation, indirect regulation, impending regulation, and mandates in Regulatory Risk whereas indirect regulation is incorporated into Substitution Risk in this paper. Generation Foundation (2013) also point out that market forces can shift capital away from fossil fuels due to increased attractiveness of low carbon alternatives. Therefore, technological breakthroughs can play a role in the shift of capital. Also, (existing) low Carbon alternatives can be made more attractive due to changes in the regulatory environment.

We divide Carbon Risk factors in two categories, namely: 1) Structural Risk and 2) Event Driven Risk. Structural Risk targets all GHG intensive firms and/or value chains and is divided into Regulatory Risk, Substitution Risk, Technological Risk, Structural Physical Risk, Operational Risk, and Competitive Risk. Whereas Event Driven Risk can occur very sudden and/or can target specific firms. This category is divided into Reputational Risk, Litigation Risk and Event Driven Physical Risk. The definitions of the Risk factors along with some examples can be found in Table 2.1.

**Table 2. 1 - Carbon Risk factors and framework**

<b>Carbon Risk<sup>1</sup> factors</b>		
<b>Risk</b>	<b>General definition</b> The risk of being financially impacted ...	<b>Description and examples</b>
<b>Regulatory</b>	... by regulation and/or regulatory uncertainty.	Various instruments can be applied to execute GHG emission reducing climate policy, such as: GHG emission taxes, GHG emission trading programs, process or product standards, technology tax incentives, emissions intensity targets, market subsidies (feed-in tariffs) and penalties (Wellington & Sauer, 2005) (Kim, An, & Kim, 2015) (Standard & Poor's, 2013). All these instruments can result in a financial impact on the company of interest. Also, regulatory uncertainty can drive capital away for investments or refinancing.
<b>Substitution</b>	... due to changes in demand (output of sector/company of interest) and/or supply (input of company of interest) in the value chain.	Among others, demand and/or supply in the value chain can be impacted by regulation applied to entities in the value chain, consumer demand changes (behavioural changes), and physical environmental changes. Substitution Risk applies to two different market dynamics, namely: Market Based and Contract Based. Market Based refers to normal market dynamics with a large number of suppliers, homogeneous goods, and an open market. Contract Based refers to a high dependency on one supplier/customer either due to few suppliers/customers, a contract, or geographical location and/or infrastructure.
<b>Structural Physical</b>	... due to structural environmental changes.	For example: shipping could be affected due to structural changes in ocean circulation, changing the route specific environmental/physical circumstances (current can affect fuel consumption positively or negatively).
<b>Competitive</b>	... due to a shift in competitiveness between the company of interest and the competitors.	The risk of changes in the competitive position with respect to the competitors resulting in financial impact. Competitive changes are among others the production price (efficiency, emission intensity) and production speed.
<b>Technological</b>	... due to technological breakthroughs and/or positive changes to the economic viability of current technology.	Technological breakthroughs can threaten the status quo by being more favorable (financial or operational) compared to current technology. This can lead to changes in competitiveness and demand of the company's product/services.
<b>Event Driven Physical</b>	... by sudden (short-term/event driven) environmental phenomes and weather circumstances.	For example, local rough weather such as high sea states (waves) and/or wind can cause damage and delay resulting in financial impact.
<b>Reputational</b>	... due to a negative view with respect to climate change by entities in the value chain which can result in a boycott, lower sales, or higher production costs.	Targets specific companies within a sector due to the way they achieve/produce those products and services with respect to climate change. If Reputational Risk applies/impacts the whole group/industry/sector in the same way it is classified under Substitution Risk.
<b>Litigation</b>	... by lawsuits/prosecution.	Litigation can result in direct costs related to the lawsuit (i.e. manpower), can drive capital away, and can result in reputational damage.

<sup>1</sup> Carbon Risk: the risk (impact and likelihood) of being financially impacted (company's value, revenue, profit, margin) because of the reliance on greenhouse gas (GHG) intensive activities and/or value chains.

As earlier mentioned, all risk factors and impacts are interdependent, resulting in higher order effects making Carbon Risk difficult to assess. The Carbon Risk factors and (inter)dependencies are mapped in order to have a simplified graphical overview which resulted in a framework, see Figure 2.5. Higher order effects of risk factors should be accounted for when assessing the impact of Carbon Risk on the company of interest. To illustrate this necessity, two examples will be given.

Example 1, regulation on the sector of interest can have several first order and higher order effects; together responsible/accountable for the impact on the sector/industry and individual companies. The first order effect refers to the operational and financial impact given Business As Usual (BAU) and ceteris paribus conditions. Higher order effects are assumed to be negligible if the

first order impact is small. Higher order effects should be accounted for if the first order impact is large. The first order impact can result in a change in the way operating the targeted asset. These operational changes can result in a different financial impact compared to BAU and ceteris paribus conditions. Consequently, changing supply characteristics of products/services (i.e. prices, amount, speed) can cause a shift in equilibrium between supply and demand. All these changing variables, together and/or independently of each other, can cause competitive changes and challenges between assets (and operators); resulting in winners and losers. At the same time, technological development (i.e. incentivized by the financial impact of regulation) can give a competitive advantage to asset owners adopting/investing in the fuel efficient techniques/measures.

Example 2, regulation applied to entities in the value chain can lead to changes in demand (output of sector of company of interest) and/or supply (input of company of interest) of successor and predecessor entities within the value chain; resulting in volume and price changes of products and services. These changes can lead to an interplay between operational, financial and competitive changes/impacts for firms.

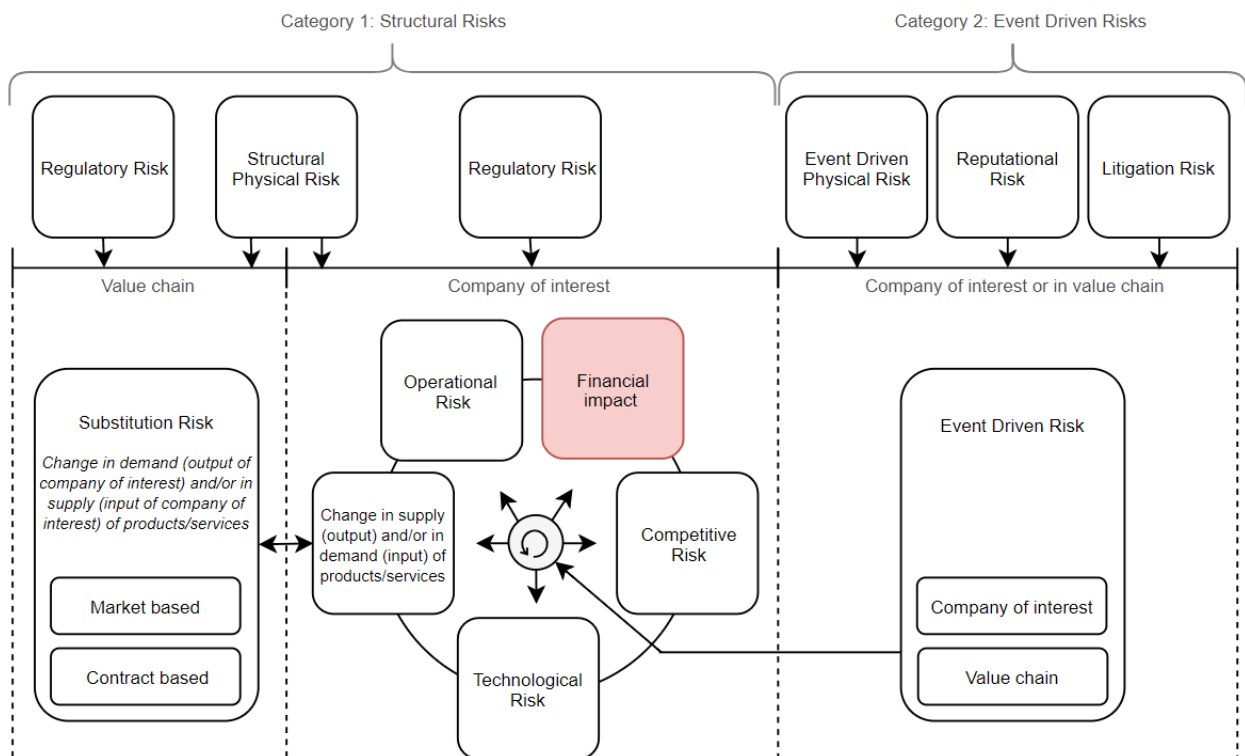


Figure 2. 5 - Carbon Risk factors and (inter)dependencies (own composition)



### **2.1.2. Exposure to Carbon Risk**

This paragraph addresses several characteristics and indicators which are used in literature to infer the exposure to Carbon Risk of a firm, thereby explicitly or implicitly trying to capture the potential impact of drivers identified in the previously discussed Carbon Risk frameworks (see paragraph 2.1.1).

The screening of a firm can include several exposure factors such as: fuel type, location, operational lifetime, cost of production, and emission intensity. Indicators of how the operator is managing Carbon Risk, the operator earnings margin, and whether it faces low Carbon competitors can be included as well (WRI & UNEP-FI, 2015). Caldecott, Dericks, and Mitchell (2015) also consider age and the technical lifetime<sup>7</sup> of assets as important factors in regulatory vulnerability. Efficiency is considered to be an important factor because regulation could be designed to financially disadvantage less efficient plants. Also, the age of the asset is considered to be an important factor because of the feasibility of investments for mitigating measures (Caldecott, Dericks, & Mitchell, 2015). Besides the company itself, the value chain must also be taken into account during the screening of firms.

Castelo Branco, et al. (2012) used a multi criteria approach for quantifying the vulnerability of oil companies to climate policies. Five criteria are used for assessing the exposure on company level, namely: market share, carbon emissions, energy efficiency, corporate aspects, and financial leverage. Indicators and ratios, such as market location, total emissions, emission intensity, and financial leverage are used in order to evaluate the criteria's. An Analytic Hierarchy process (AHP) is used in order to assign weights to all the different factors. "Indicators that consider location aspects (i.e. consumer market, reserve location, E&P facilities and refining units) were divided into country groups, considering the existence or nonexistence of targets and pressures for GHG emission reduction." Companies were divided into five groups in accordance to the severity and characteristics of regulations in place. Although numerical numbers are used in order to quantify the result, the indicator scores are determined on a predetermined scale or relative to each other. On a scale of 1 (low) to 5 (high), the final score of the vulnerability to climate policies of RepsolYPF, Shell, BP, Exxon, Chevron, and Petrobras was respectively 2.3, 2.7, 3.1, 3.2, 3.7, and 3.9 (Castelo Branco, et al., 2012).

## **2.2. Financial and operational impact of Carbon Risk**

As already stated in the background section, there is a need to better understand the financial impact of Carbon Risk for companies and financiers. This chapter covers different methods to assess the financial impact of Carbon Risk and several insights/results will be given as well.

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<sup>7</sup> Note: newer assets are longer exposed to future regulation, assuming the same duration of the technical lifetime between newer and older assets. Costs of investments of GHG mitigating technologies are difficult to recover for vessels with short technical and operational lifetimes left. That being said, newer vessels are exposed also on the long-term (regulation can become more severe over time) because they have longer technical and operational lifetime left. In general, years can go by between the adoption of regulation and the effective date. Therefore, the oldest vessels may already be out of service before new regulatory instruments are in force.

### **2.2.1. Methods to assess the financial impact of Carbon Risk**

Carbon Risk can be assessed for several aggregated levels, namely: asset level, operator/company level, and financial portfolio level (Wellington & Sauer, 2005). In literature, different methods and tools to assess the level of Carbon Risk are suggested. The quality of the analysis depends on the method and on the many different assumptions and simplifications made in order to model the impact.

#### **Discounting cash flows**

Wellington and Sauer (2005), argue that two primary concepts/tools can be used to discount Climate Risk in valuing securities. The first option is to incorporate the added potential risk from climate regulation by changing the required rate of return upward (risk premium). They argue that this option might be more appropriate to reflect climate risk across a diversified portfolio in a period of policy uncertainty. However, they note that climate risk is not distributed evenly across time because competitiveness, and therefore financial impact, is not static (Wellington & Sauer, 2005). Option two consist of adjusting cash flow estimates according to an assessment of competitive positioning around climate policies. They state that this option is (in general) better suited if there is more certainty around future policies. Several measures are noted that can be used in order to assess the impact on the cash flow and revenue, such as: Net Present Value (NPV), Internal Rate of Return (IRR), and break-even prices (WRI & UNEP-FI, 2015).

#### **Deterministic versus Stochastic modelling**

To determine the impact of Carbon Risk, deterministic models (e.g. (Raucci, et al., 2017)) and stochastic models (e.g. (Abadie, Goicoechea, & Galarraga, 2016)) appear in Carbon Risk literature. Stochastic risk models are based on estimated deviations from an average value whereas there is no room for random variation in deterministic models. Specific tools/techniques for stochastic risk modelling are among others MonteCarlo (MC) simulation and the concepts of Value at Risk (VaR) and Expected Shortfall (ES). Value at Risk (VaR) and Expected Shortfall (ES) can be used to specify the risk of (financial) loss over time. Whereas MonteCarlo (MC) simulation can be used, among others, to calculate the Value at Risk (VaR) and Expected Shortfall (ES) for a great number of trajectories. Also, Real Option Analysis can be applied to include uncertainty into the decision-making process, for example for investment decisions in retrofits (Abadie, Goicoechea, & Galarraga, 2016).

#### **Dynamic versus Static models**

Models can be time dependent (dynamic) (Taylor, 1976) (Luo, Fan, & Liu, 2009) or time independent (static/point in time). Static models can be used to show impact over time by comparing the results between points with changed circumstances, variables, and equilibrium states. But static models do not show what happens between those intervals<sup>8</sup>. Dynamic models do take time dependent variables and interactions/feedback effects into account, in a way making it possible to show the whole movie instead of only some snapshots. This enables to see how the impact shifts gradually over time, usually being more representative with respect to reality. The downturn of dynamic

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<sup>8</sup> "The comparative statics approach is roughly analogous to using snapshots from a camera to record developments during a dynamic event. With each snapshot a static but informative picture is presented. Imagine, for example, taking a picture at the beginning of a horse race, ten shots throughout the race, and one at the finish. The developed film would constitute a "comparative statics" record of a very dynamic race. As such it would have very useful information about the race, but probably not as much as a video record. In a comparative statics economic model, each equilibrium solution is like a snapshot of the economy at one point in time" (Evans, 1997).

models is that they can be very hard to solve, and that time depended relationships are difficult to obtain in some cases.

### **Carbon Pricing**

Carbon regulation can be modelled by including Carbon pricing (Raucci, et al., 2017). Multiple scenarios with different Carbon emission prices, technology investments, market barriers, and macro scenarios can be assessed over time in order to get a comprehensive view of the impact of this type of Carbon Risk. The Carbon Pricing Leadership Coalition (CPLC) urges financial institutions to apply internal Carbon pricing on their portfolio using shadow prices for Carbon emissions in order to evaluate the sensitivity of investments to future potential regulatory scenarios (CPLC, 2017). Barradale (2014) states that Expected Carbon Payment<sup>9</sup> is a better proxy for the cost of Carbon than the expected Carbon price.

### **Bottom-up or top-down**

WRI and UNEP-FI (2015) discusses two approaches to assess Carbon Risk for portfolios; 1) assessing Carbon Risk for physical assets and rolling up to the portfolio, and 2) starting from the portfolio, taking into account the mix of investments (diversification) and expected risk correlations. "Following the initial screening assessment, the key focus of the operator level approach is on stress testing and scenario analysis, using general economic frameworks to forecast potential future outcomes under a range of different assumptions (for example, a future world where governments take action to avoid global average temperatures rising by more than 2 [°C] above pre-industrial levels) (WRI & UNEP-FI, 2015)."

### **Scenarios Analysis**

Also, each model can be used for one or more scenarios (scenario analysis) (Bokenkamp, LaFlash, Singh, & Wang, 2005) (WRI & UNEP-FI, 2015). Standard & Poor's (2013) underlines the benefits of stress testing underlying assumptions made for one particular scenario. By stress testing underlying assumptions of the scenario, insight is given to the range of other potential outcomes instead of just the effect of one scenario. Standard & Poor's (2013) assessed the impact of low demand scenarios for oil companies and finds that: "the financial models that use past performance and creditworthiness may be insufficient to guide investors looking to understand the possible effects of future carbon constraints on the oil sector".

### **Non-financial assessment**

Besides methods to assess the financial impact directly, an important relative non-financial proxy for the level of Carbon Risk is the company's strategy and competitive positioning around Carbon Risk factors (i.e. regulation). Investors can use this Carbon Risk proxy to separate climate winners from climate losers (Wellington & Sauer, 2005).

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<sup>9</sup> Expected Carbon Payment is the product of the expected price and the probability that this price would actually be faced in the case of a particular investment (Barradale, 2014).

## 2.2.2. Financial and operational impact of Carbon Risk

Carbon Risk can have potential disruptive consequences for companies and financiers which rely on greenhouse gas (GHG) intensive activities and/or value chains because it can have possible financial and operational impacts. Therefore, there is a need to know the scale of the financial and operational impact to take timely mitigating action.

Among others, carbon policy and regulation are considered to be a large risk factor which can have financial and operational impacts. Wellington and Sauer (2005) give the following examples how policy and regulation could affect profitability. Revenues, cost of goods sold, operating cost, and capital expenditures can be impacted by among others: pricing structures, changing supply and demand patterns, and new products and market opportunities. In addition, WRI and UNEP-FI (2015) note that the impact of regulation depends on the type of regulation, the instruments, the timeframe of compliance, and the likelihood of enactment of implementation.

### Impacts in non-shipping sectors

Kim, An, and Kim (2015) determined the effect of Carbon Risk on the cost of equity. They defined Carbon Risk as climate change related risks which can cause future potential losses or current debts due to increasingly severe regulations on GHG emissions. The research was focused on the top 10 highest emitting industries, like: energy, oil, cement, steel, and chemical companies. By using a regression method on a sample of 379 firms for the period 2007 to 2011, they found that companies with high carbon intensity will face a higher cost of equity<sup>10</sup>.

Caldecott, Dericks, and Mitchell (2015) assess the impact of climate related policy to the least efficient and most polluting coal fired power stations, called: subcritical<sup>11</sup>. Due to the nature of these subcritical power stations, they are more vulnerable to policy and regulation than cleaner and more efficient power stations. The research concluded that there may be a significant number of stranded SCPS assets through forced closure and impairment of profitability<sup>12</sup>. Generation Foundation (2013) notes that tightened emission standards can lead to a negative impact on assets and therefore on the company's valuation.

A study of Standard & Poor's (2013) to the creditworthiness of oil companies resulted in a potential negative outlook revision resulting in downgrades over 2014 - 2017 for smaller companies whereas the impact on the larger companies is seemed to be less severe.

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<sup>10</sup> "Applying the coefficient of CARBON, a 10% improvement in carbon intensity, or equivalently, the reduction of carbon intensity from 543.4 to 489.1 kg of CO<sub>2</sub>, will lead to 0.08% savings in cost of equity capital. Stated differently, a 10% improvement in carbon productivity, a reciprocal of carbon intensity, will result in a 0.08% point decrease in the cost of equity capital" (Kim, An, & Kim, 2015).

<sup>11</sup> "Subcritical is the least efficient and most polluting form of coal fired generation - it requires more fuel and water to generate the same amount of power, and creates more pollution as a result. The average subcritical coal-fired power station (SCPS) emits 75% more carbon pollution than an average advanced ultra-supercritical - the most up-to-date form of coal-fired power station - and uses 67% more water" (Caldecott, Dericks, & Mitchell, 2015).

<sup>12</sup> China: "In addition to regulatory risk, physical water scarcity is a serious risk to a significant portion of the SCPS fleet, with nearly 37% of the fleet located in watersheds with high water stress and 33% of the fleet in watersheds with both high water stress and mean 100km Radius PM 2.5 pollution above WHO levels."

USA: "proposed state-based GHG emission reductions promise to put further pressure on existing SCPSs. Early analysis of this proposed regulation suggests that \$28 billion in industry value will eventually be stranded, though immediate plant closures are expected to be minimal."

EU: "Europe's non-GHG emission policies have and will continue to close significant amounts of coal-fired generation.", India: "The Indian SCPS fleet faces serious water-related risks that are threatened to worsen, with currently 33% of generators located in areas of extremely high water stress" (Caldecott, Dericks, & Mitchell, 2015).

Abadie, Goicoechea, and Galarraga (2016) analyzed the risk of EU ETS allowances on the cement industry by using MonteCarlo (MC) simulations, the concepts of Value at Risk (VaR) and Expected Shortfall (ES), and Real Option Analysis. By calculating the trigger price of the investment cost of optimal retrofitting a wet cement plant to a dry one; they find that the trigger price of the cost of the investment is notable lower than an NPV of zero. The Real Option Analysis explains that investments are not made in some cases while the NPV is zero or even positive. In these cases, a higher NPV is needed to overrule the value of the wait option. In other words, the company would require a higher return once regulatory uncertainty, and the company's option to wait for regulatory clarity, is taken into account.

National governments can shut down GHG intensive operations by law. Recently, the new formed Dutch government announced to shut down all coal power plants by 2030 (Sterling, 2017). The concerning power plants are recently completed, having a technical lifetime beyond 2030. However, the plants can switch fuels, i.e. from coal to relative expansive biomass.

## **Impacts in the maritime sector**

### **Emissions Trading**

According to Faber, Markowska, Eyring, Cionni, and Selstad (2010), shipowners, operators, managers, and crew may be directly impacted by a Maritime Emissions Trading System (METS) because the operating costs would be affected<sup>13</sup>. Also, they note that the administrative burden would increase due to the obligation to report the emissions and to surrender allowances. Shipper, charter, cargo owner, cargo buyer, cargo seller could be indirectly impacted by the increase of the transportation costs. Policy and regulation can result in demand for more efficient technology and ship design which could impact the ship builder and engine manufactures. Eventually, in the end, consumers will pay a share of the cost increase (Faber, Markowska, Eyring, Cionni, & Selstad, 2010). If the cost of transportation increases; the demand and supply equilibrium will change which can result in changing freight rates.

Faber, Markowska, Eyring, Cionni, and Selstad (2010) argue that smaller and older ships may be put in a disadvantageous position due to Carbon pricing via ETS because the emissions of CO<sub>2</sub> per [kg] of cargo are much higher for such ships than for modern and bigger vessels. "They will become less competitive because in order to recover the costs of operating the ships, they will have to charge higher prices for the same service."

The International Chamber of Shipping (2017) states that by incorporating shipping in unilateral Carbon schemes, using the example of including shipping in EU ETS, the level playing field would be destroyed and it would damage the authority of IMO. Also, they mention that "any measures adopted by IMO must apply to all ships equally regardless of the flag state, in order to maintain a level playing and to avoid 'carbon leakage'".

In a study regarding performance drivers of the EU ETS, Mulder (2015) found that there is considerable investment uncertainty under EU ETS. Devanney (2011) notes that: "investors tend to invest less money when they are uncertain about future prices than when they are confident about the prices they are facing". Compared to the ETS, a fuel tax would diminish the uncertainty.

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<sup>13</sup> "Conversely, higher fuel prices lower the share in total costs" (Faber, Markowska, Eyring, Cionni, & Selstad, A Global Maritime Emissions Trading System: Design and Impacts on the Shipping Sector, Countries and Regions, 2010).

## Fuel Tax

Corbett, Wang, and Winebrake (2009) find that a fuel tax of about 150 [\$/Tonne] fuel will lead to an average speed reduction of 20 to 30 [%]. They find this result by “applying a profit maximizing equation to estimate route specific economically efficient speeds for ships calling on US ports”. Within certain engine power ranges, speed reduction will reduce the resistance significantly resulting in fuel consumption savings. Devanney (2010) find a similar trend, he argues that VLCC vessels will decrease their speeds due to a fuel tax. Subsequently, he mentions that the average speed of the operational fleet decreases, potentially resulting in the absorption of excess fleet capacity.

CPLC (2017) notes that a Carbon emission price can cause a shift in the vessels day rate (charter rate), value and liquidity due to increased operational costs benefiting the more Carbon efficient vessels. Subsequently, they mention that Carbon pricing can possibly impact the creditworthiness of less efficient vessels/owners.

Raucci et al. (2017) performed a case study on shipping risks associated with climate change mitigation policy for newbuild drybulk ships in the size range 60000-99999 [dwt]. The level of risk related to climate risk is included via Carbon pricing. Four scenarios are analyzed; a carbon price of 50 [\$/tonne] and 200 [\$/tonne] is used both in combination with low and high freight rates. Four situations are considered within these four scenario constraints, namely: new build vessels in the year 2020 and 2030 both under long and short-term investment perspectives. The time horizon to recoup the energy efficiency technology improvements for the long-term perspective is 7 years whereas it is 3 years for the short-term perspective. Market barriers to adopt energy efficiency technologies are included through a percentage of fuel saving which are passed through from the charterer to the shipowner. These market barriers are high in the short-term perspective and low in the long-term perspective.

The case study shows that vessels build under the short-term perspective have lower technical specifications than vessels build under the long-term perspective. According to Raucci et al. (2017) this difference can be associated with the recoup time of the investment costs of technical efficiency measures/technology. Lower technical specifications resulted in relatively constant operating speeds of 9 to 11 [kn] over time whereas the operating speed of vessels with higher technical specifications increase in speed over time from 10 to 14 [kn].

For the given scenarios there is no significant change in fuel and machinery choices. Also, low Carbon fuels were considered as not economically viable given the current technology costs and the set Carbon prices. Ships that do not anticipate to possible future regulation in the form of a Carbon price have to lower their speed (and therefore revenue) or have to undertake retrofitting to be competitive (Raucci, et al., 2017).

Raucci et al. (2017) points out that the operating costs of the more efficient ships are lower compared to the other ships and that charter rates can be higher due to a higher economical speed. Their analysis shows that the more efficient ships (long term scenario) generate higher profits except in the scenario of low freight rates combined with a low Carbon price. In addition, they note that there is no one-size-fits-all approach to mitigate or diminish the impact of Carbon pricing but that different market conditions require different approaches and responses.

Devaney (2011) argues that a bunker tax will slow the fleet down due to increased costs of burning fuel. He also mentions that more cargo carrying capacity is needed if the operating speed of the fleet decreases which can increase the spot rates and new build capacity as well. For new build ships, a Carbon tax can result in the adoption of energy efficient measures on the hull design, auxiliary engines and machinery, and the main engine. Also, changes in cargo carrying capacity by increasing the main dimensions or by lowering the lightship can be a result of increased fuel costs as well.

### **Supply and demand**

Faber, Markowska, Eyring, Cionni, and Selstad (2010) assume that a price increase of 10 [%] will decrease trade about 2 to 3 [%]<sup>14</sup>. But that does not mean that overall trade is going to decline because world trade is projected to grow with more than 2 to 3 [%] in future years. They state that the Maritime Emissions Trading System (METS) may only slow down world trade instead of decreasing the total absolute volume of world trade. In some cases, the cost of Carbon Risk can possibly be allocated to the customer, depending on the type of good and the price elasticity of demand<sup>15</sup>.

### **Substitution**

Sharmina, McGlade, Gilbert, and Larkin (2017) analyzed regional and global demand scenarios for coal, oil, and natural gas. They state that a shift in energy usage from coal and oil can have a significant impact on related shipping segments because about half of the world's oil supply, a fifth of coal supply and a tenth of natural gas supply are traded by. Two temperature pathways are used in the analysis, the first accounts for a global temperature rise above the 3 [°C] (>3 [°C]) and the second pathway accounts for an increase of temperature below the 2 [°C] (<2 [°C]). The <2 [°C] pathway shows a global decrease in the demand for oil (starting +/- after 2030) and coal (starting +/- after 2020) and an increase in the demand for gas (starting from today). However, keep in mind that the demand/use of fossil fuels can vary between regions. In some regions, an increase in use/demand of fossil fuel is expected. Therefore, local depended entities (i.e. with location bounded infrastructure) can be impacted differently depending on the region/location they are in. Also, even though demand is expected to rise in certain regions, it does not necessary mean that the shipping sector will benefit from increased demand<sup>16</sup>.

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<sup>14</sup> "In reality, improvements in fuel efficiency will result in lower price increases, and only in bad markets will prices be passed on" (Faber, Markowska, Eyring, Cionni, & Selstad, A Global Maritime Emissions Trading System: Design and Impacts on the Shipping Sector, Countries and Regions, 2010).

<sup>15</sup> "From these numbers we can draw a conclusion that the expected increase in consumer prices due to CO2 policy in maritime shipping ranges from 0.4 to 3%. The highest increase in prices (2-3%) is expected for raw materials, ores and coal (because a relatively high share of the value of these goods can be attributed to maritime transport costs), and the lowest, 0.4%, for crude oil. As raw materials are not consumed by the end user, the cost increase in consumer prices is probably towards the low values of the range presented here" (Faber, Markowska, Eyring, Cionni, & Selstad, A Global Maritime Emissions Trading System: Design and Impacts on the Shipping Sector, Countries and Regions, 2010).

<sup>16</sup> There are other forms of transportation, such as pipelines and railways.

## **2.3. Maritime GHG emission regulation and incentives**

In this chapter, active regulation (paragraph 2.3.1), incentives (paragraph 2.3.2), and future regulation (paragraph 2.3.3) related to Carbon mitigation will be presented. As already stated in paragraph 2.2.2, carbon policy and regulation can result in a large financial and operational impact. Therefore, it is key to understand the structure of active and impending regulation.

### **2.3.1. Active regulation**

In this paragraph, active regulation related to Carbon mitigation will be discussed.

#### **Ship Energy Efficiency Management Plan (SEEMP)**

The Ship Energy Efficiency Management Plan (SEEMP) is a mandatory mechanism for existing ship owners with the aim to optimize/improve the energy efficiency cost-effectively (i.e. speed, propeller optimization, hull maintenance, etc.). The SEEMP requirement is included in MARPOL Annex VI and is in force since 2011 for all new and existing ships. Verification of the mandatory requirement will be after January 1, 2013 (MEPC, 2011). The SEEMP provides insight in fuel consumption and cost-effective measures to improve fuel consumption. Monitoring of the fuel consumption can be done by means of the Energy Efficiency Operational Indicator (EEOI) which is included in the SEEMP. Monitoring, awareness, high carbon prices, and high fuel prices are expected to incentivize the uptake of cost-effective energy efficient measures established via the SEEMP (Bazari & Longva, 2011).

#### **Energy Efficiency Design Index (EEDI)**

The Energy Efficiency Design Index (EEDI) is a mandatory minimum energy efficiency level for new build ships, tightened every five years. Phase 0 starts from 1 January 2013, requiring new build ships to meet the reference line/level related to their ship type. Phase 1 to 3 runs respectively from 2015 - 2020, 2020 - 2025, and 2025 - 2030, requiring a 10 [%], 20 [%], and 30 [%] reduction in EEDI score (IMO, 2016)<sup>17</sup>. The EEDI applies to the following vessel types: oil tankers, bulk carriers, gas carriers, general cargo, container ships, refrigerated cargo and combination carriers.

The EEDI formula consists of the summation of the CO<sub>2</sub> emissions from the main engine, auxiliary engine, shaft generators/motors, minus energy efficient technology emission savings, divided by a measure related to transport work (ICCT, 2011). The EEDI baseline is based on vessels build between 1999 and 2009. Literature mentions that the design efficiency of the vessels built in that period were driven by the economic cycle (Faber, 't Hoen, Vergeer, & Calleya, 2016)<sup>18</sup> and relatively poor compared to vessels build before and after this date (Clean Shipping Coalition, 2016). Based on statistical analysis of IMO's EEDI database, Transport & Environment (2017) found that the majority of the vessels built between 2013 and 2017 already comply with the 2025 EEDI requirements, respectively: 71 [%] of the container vessels, 69 [%] of the general cargo ships, 26 [%] of the oil

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<sup>17</sup> Note: A relatively low EEDI score does not mean that the ship is more fuel efficient than ships with a higher EEDI score because the way operating the ship (operational profile) is very dominant factor as well.

<sup>18</sup> "The literature mentions two drivers for fuel-efficiency changes: changes of the fuel price (Smit & Pijcke, 1985) and changes in freight rates (Mortensen, 2009). In addition, steel and labour costs, yard availability, dimensions of locks and quays and other factors may play a role" (Faber, 't Hoen, Vergeer, & Calleya, 2016).



tankers, 13 [%] gas carriers, and 1 [%] of the bulk carriers<sup>19</sup>. The EEDI performance of the best performing 10 [%] of the analyzed vessels are on average 58 [%] for container vessels, 57 [%] for general cargo ships, 42 [%] for gas carriers, 35 [%] for oil tankers, and 27 [%] for bulk carriers, whereas the 2025 EEDI level requires only 30 [%] (Transport & Environment, 2017).

The main engine(s), auxiliary engines, shaft generators/motors, and efficiency technologies are all included in the EEDI formula. However, the EEDI score is based on sea trials, at 75 [%] MCR of the main engines, and does not represent the way the vessel is operated. Installing more power to reach higher maximum speeds will worsen the EEDI score significantly. This is due to the structure of the formula which determines the EEDI score. As a rule of thumb, ship power is roughly proportional to the cube of the speed. In the formula, the main engine power at 75 [%] of Maximum Continuous rating is included in the numerator and the corresponding ship speed at maximum design load condition stands in the denominator. Devanney (2010) says that, roughly speaking, 30 [%] reduction in power results in approximately 10 [%] reduction in speed and a 20 [%] reduction of the EEDI score. Reducing installed power can lead to the use of a smaller bore of the propeller and to engines with higher RPM. However, in general, higher powered vessels can use more efficient low speed engines in combination with relatively large propellers which can be operated at lower rounds per minute (rpm), resulting in a higher propeller efficiency. Devanney (2010) continues to explain that a non-EEDI ship uses only all his power when the market is in a high. If a non-EEDI vessel reduces his speed, little or no more power is used compared with an EEDI compliant ship.

### **Monitoring and verification**

As part of a three-step strategy to reduce emissions in the maritime sector; the IMO and EU both have mandatory data collection systems for fuel consumption of ships.

Starting in 2019, the Marine Environment Protection Committee (MEPC) of the International Maritime Organization (IMO) has approved mandatory requirements for all vessels of 5000 gross tonnage (GT) and above to collect fuel consumption data, emission data, and additional data such as proxies for transport work (i.e. distance traveled). The data has to be reported to the flag state at the end of each year after which the data has to be submitted to the IMO Ship Fuel Consumption Database (IMO, 2016). The database will be anonymized and only accessible to parties to MARPOL Annex VI (Helavuori, 2017).

The EU MRV (Monitoring, Reporting, Verification) entered into force in 2015 and requires to monitor, report, and verify CO<sub>2</sub> emissions on an annually basis starting in 2018. The MRV is mandatory for vessels larger than 5000 gross tonnage [GT] calling at EU and EFTA (Norway and Iceland) ports. Annual CO<sub>2</sub> emission data along with additional parameters (i.e. cargo carried on voyage basis) will be verified by certified parties and managed by the European Maritime Safety Agency (EMSA). Specific data on vessel basis will be made publicly available after each year of data collection (EU, 2015).

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<sup>19</sup> "Given that no bulk carrier has reported the use innovative electrical and/or mechanical energy saving technologies, there is considerable scope for further improvement in this category of ships. This also applies to all major ship types, of which only 9% of containerships have reported the use of innovative technologies" (Transport & Environment, 2017).  
"... in order to incentivise development and deployment of further energy saving technologies and innovative ship designs, the revision of existing and setting of future design standards should be based on the performance of the 10% best ships in the market" (Transport & Environment, 2017).

### 2.3.2. Active incentives

Industry incentives related to Carbon emission and climate change can come in a variety of forms, such as port discounts, flag state discounts, fuel efficiency discounts, and increased charter prices for efficient ships.

#### Port discounts

Port authorities can provide discounts based on, among others, a Green Award certificate or on a Environment Ship Index (ESI) score<sup>20</sup>. For example, the port of Rotterdam provides discounts to vessels with a Green Award (Port of Rotterdam Authority, n.d.). In addition, they reward ocean going vessels with a 10 percent reduction on the gross tonnage port fees if they have a ESI score of 31 or higher (Port of Rotterdam Authority, 2015). Among the Port of Rotterdam, other ports are also providing discounts for energy efficient vessels as well (Green Award, n.d.). Major world ports are also united in the World Ports Climate Initiative (WPCI), an initiative to reduce their greenhouse gas emissions from the sector (WPCI, n.d.).

#### Registry/flag state discounts

Flag states can apply schemes to incentivize the reduction of CO<sub>2</sub> emissions and other emissions such as sulphur oxides (SO<sub>x</sub>) by providing discounts. The Singapore Registry of Ships provides discounts on registration fees and on the annual tonnage tax for ships with efficient designs exceeding the EEDI standards. The discount can be as much as a 75 [%] reduction of initial registration fees and a 50 [%] rebate on annual tonnage tax (MPA, 2017). Another example comes from the Liberian Registry, they provide discounts<sup>21</sup> to vessels retrofitting energy efficient technologies according to their green initiative (Liberian Registry, n.d.).

#### Other industry incentives and awareness

Nowadays, tools<sup>22</sup> are used by some charterers to shift away from the most inefficient ships; in a sense rewarding more efficient ships for their performance (Hardcastle, 2016). However, it is hard to assess the actual fuel efficiency of a vessel. Agnolucci, Smith, & Rehmatulla (2014) analyzed how financial savings arising from energy efficient ships are allocated between owners and those hiring the ships. Based on their method and dataset, they found that only in 40 [%] of the cases 50 - 25 [%] of the financial savings based on design efficiency flowed back to the shipowners. Prakash, Smith, Rehmatulla, Mitchell, & Adland (2016) find little to no evidence in time charter rates showing a preference for ships with better GHG ratings. This could be due to a lack of (verified) accurate information about the efficiency of ships. Due to this non-preference, there is a very marginal incentive for shipowners to invest in the energy efficiency of their ships. Transparency on operational performance along with accurate efficiency ratings can help reward the shipowner and charterers by chartering and investing in energy efficient ships.

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<sup>20</sup> However, note that the ESI or EEDI score is not an optimal proxy for efficiency because an efficient vessel can be operated inefficiently.

<sup>21</sup> "Under the agreement between The Liberian Registry, ESF and CWR, each ship retrofitted by ESF under the innovative Self- Financing Fuel- Saving Mechanism will be entitled to a 50% discount on annual tonnage tax in the first year and up to 25% discount in the second and third years- a discount of up to \$13,800 for a ship of 100,000 gross tons" (Green4sea, 2015).

<sup>22</sup> Tools which are used are among others the GHG rating tool from the Carbon War Room and RightShip (Carbon War Room & Partners, n.d.).

There are already some initiatives to reward efficiency. For example, one initiative to reduce CO<sub>2</sub> comes from a network of large corporates that have joined the Clean Cargo Working Group (CCWG) from the Business for Social Responsibility (BSR). BSR (n.d.) state that they are “helping ocean freight carriers track and benchmark their performance and easily report to customers in a standard format and allowing shipping customers to review and compare carriers’ environmental performance when reporting and making informed buying decisions”. Another example of an initiative to reward efficiency comes from The Boosting Initiatives for Collaborative Emission-reduction with the Power of Shippers (BICEPS). BICEPS is an initiative from large corporates, such as AkzoNobel and DSM, and tries to reward clean shipping. Their rating system can be used by procurements and rates ships by five criteria’s according to their sustainable and effective shipping operations (BICEPS Network, n.d.).

Besides rewarding the most efficient vessels, there is a change that the cost of financial loans will increasing and/or will be more difficult to obtain for less efficient vessels. It is likely that the more efficient ships will be rewarded by higher rates or vessel employment<sup>23 24</sup>. Therefore, it becomes increasingly relevant for financial institutions to account the efficiency of the vessel in their investment risk pricing structure. Especially with stringent regulation in mind, such as Carbon taxes, investment risk and the efficiency of the vessel can become more and more correlated.

### **2.3.3. Likely future regulation**

Technical and operational measures can reduce GHG emission significantly. Regulation can enforce such measures or can incentivize the use of it. As already stated in Table 2.1, various instruments can be applied to execute GHG emission reducing climate policy; such as GHG emission taxes, GHG emission trading programs, process or product standards, technology tax incentives, emissions intensity targets, market subsidies (feed-in tariffs) and penalties (Wellington & Sauer, 2005) (Kim, An, & Kim, 2015) (Standard & Poor's, 2013).

#### **Background**

The EU and IMO are key players in reducing GHG emissions in shipping. Both have a three-way step strategy to reduce emissions in the maritime sector. The first step is emission data collection of ships (see also paragraph 2.3.1); followed by an analysis phase; ending with policy decisions. A global approach is needed due to: 1) the global character of the shipping industry in order to minimize Carbon leakage, and 2) the to avoid distortion of the level playing field. Therefore, according to the EU, IMO is the most preferred option to adopt sector wide emission mitigation policy (EU, 2017). The initial strategy from IMO to reduce GHG emissions is likely to be adopted in 2018 and will contain a list of activities with relevant timelines and provides for alignment of those new activities with the ongoing work by the MEPC (IMO, 2016). Five years later in 2023, IMO foresees to adopt a revised strategy to include short-, mid-, and long-term further measures (IMO, 2016).

Fossil fuel consumption is highly correlated with CO<sub>2</sub> emission. Carbon pricing in shipping can potentially be an effective measure to reduce GHG emissions in shipping. Because it can result in

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<sup>23</sup> “An energy efficient vessel has lower fuel costs and better chartering potential, which may lead to a higher initial asset value and a longer period of economic depreciation. With more indexed orientated freight rates, inefficient vessels will have smaller margins and a reduced budget for maintenance, crew, conditions, systems and loss control measures.” (Rightship, n.d.)

<sup>24</sup> Note: do consider the extra cost of these fuel-efficient ships, maybe they save a lot but do have a lot higher CAPEX.

negative marginal abatement cost for technical and operational measures to reduce fuel consumption/Carbon emissions. As already stated in paragraph 2.2.2, Carbon pricing can increase operational costs significantly which can result in speed reduction, and therefore fuel savings, to maximize profit. It can incentivize other technical and operational energy efficient reduction measures as well, such as weather routing, engine and propeller optimization, hull cleaning, changes in design. The revenue from such a Carbon emission pricing scheme can be used to finance future low carbon research, reward efficiency, contribute to low carbon investment, or to compensate third world economies/developing countries (IMO, n.d.).

Although the shipping industry accounts for a significant share in global GHG emissions, the fact that ships move about 90 [%] of global world trade can potentially influence the severity of the impending regulation for the maritime industry. Different reduction rates among industries can be imposed. For example, the Korean government imposed a 61.7% reduction of GHG emissions for the electric and electronics industry by 2020 compared to 6.5% for the steel industry. Kim, An, & Kim (2015) suggests that a possible reason lies within the government's consideration of possible loss of international competitiveness.

#### **Fuel levy/Carbon levy/Carbon tax**

Emissions can be taxed via a fuel levy (fuel consumption is highly correlated with CO<sub>2</sub> emission) or by means of emission data. Compared to ETS, a fuel levy is administrative relatively simple and provides certainty about the price per unit of emissions/fuel. The International Monetary Fund (IMF) is calling for a carbon levy including international coordination (Darby, 2016) (Grey, 2016). The International Chamber of Shipping (ICS) states that: "if IMO Member States should decide to adopt a shipping MBM, the industry's clear preference is for a global fuel levy, rather than emissions trading or complex alternatives using arbitrary and theoretical metrics" (ICS, 2015).

#### **Carbon Emission Trading System**

Emissions can be priced via an Emission Trading System (ETS). Members of the European Parliament (MEP's) increase the pressure on the IMO to agree on reduction measures before 2021. They voted in favor to include ships calling on EU ports in a reformed ETS by 2023 if the IMO does not have corresponding (comparable) measures in place (EU, 2017). According to Raucci, et al (2017), the earliest entry date for a carbon price mechanism by IMO would be 2025 because the revised strategy has to be adopted by 2023 and administrative infrastructure have to be setup.

Besides the EU, recently, China has created several emission trading schemes but did not included shipping, yet. However, a pilot is carried out in Shanghai where ports and local shipping were included in the scheme (Merk, 2016) (ICAP, 2017). Rising pressure, leading economy's, potential positive effects and opportunities that come with de-carbonization can lead to future decisions to include shipping in emission trading schemes (in my opinion).

#### **Forced speed limit/reduction**

Forced speed limitations can reduce GHG emissions. However, this option comes with a lot of legal, safety, technical, monitoring and compliance, and administrative issues (Maggs, 2011). Therefore, this option is mentioned but not further investigated.

## **2.4. Synthesis/conclusion**

In chapter 2.1, this study finds that Carbon Risk is a diverse and complex risk type. The literature study reveals that Carbon Risk can be split into two categories, namely: Structural Risk and Event Driven Risk. Because of the differences in nature between Structural Risk and Event Driven Risk, different methods are needed in order to assess the impact of each. Both Structural Risk and Event Driven Risk factors can hit the company directly or via the value chain. Also, inter(dependencies) between risk factors should be taken into account when assessing Carbon Risk.

The literature study finds that the shipping industry accounts for a significant share in global GHG emissions and it is projected to grow even larger. In addition, the sector has a strong reliance on fossil fuels. Major climate regulations for shipping already entered into force and a range of possible instruments may be applied going forward, see chapter 2.3. Possible instruments are among others, tightened EEDI limits, port discounts, ETS, or a Carbon Tax. In addition, recent events such as the Paris Agreement, the initial GHG strategy of IMO, and non-governmental initiatives increased the level of Carbon Risk.

Most impact assessments are focused on the impact of Regulatory Risk. Studies on other (non-shipping) sectors revealed that the impact of Carbon Risk could be severe, see chapter 2.2. Among others, researchers found that Carbon Risk could lead to: 1) a higher cost of equity, 2) a negative effect on the creditworthiness of the company, 3) a negative impact on assets and therefore on the company's valuation, and 4) stranded assets through forced closure and impairment of profitability.

Carbon Risk can be assessed for several aggregated levels, namely: asset level, operator/company level, and financial portfolio level. In literature, different methods and tools to assess the level of Carbon Risk are suggested. The quality of the analysis depends on the method and on the many different assumptions and simplifications made in order to model the impact, see chapter 2.2. Among others, cash flows can be discounted by changing the required rate of return upward (risk premium) or cash flow estimates could be adjusted according to an assessment of competitive positioning around climate policies. In addition, Carbon Risk assessments/models can be deterministic or stochastic. Additionally, assessment models can be either dynamic or static (point in time).

## **2.5. Literature gap and contribution of this study**

As already stated in the background section, there is a need to better understand the financial impact of Carbon Risk for companies and financiers in order to take timely mitigating action. Currently, a lot of research is done on the potential of market-based measures with respect to global GHG emission reduction in shipping. There are quite extensive assessments of the impact of Carbon pricing on the economical speed of some ship types and sizes. However, the impact on the shipowners cash flow or competitive position has remained limited. In addition, there is limited data available about the impact of a Carbon Tax between sub segments, the main drivers behind it, and a clarification on why the impact differs between segments.

To get a better understanding of Carbon Risk, its main drivers, and to rank sub sectors accordingly, a cross sectoral scenario assessment should be conducted. Therefore, our research focuses on the

financial and operational impact of a Carbon Tax and demand substitution across different sub segment (ship size and type). In addition, the effect on the competitive position within the sub sector and the room to actually invest in efficiency related investments will be assessed. The results should give a complete overview of the risk and the mitigation actions available to the shipowner.



# 3. Methodology

This chapter describes the method to determine the impact of Carbon Risk. This chapter is structured as follows. First in chapter 3.1, our focus with respect to the Carbon Risk framework will be presented. In chapter 3.2, the method to assess Carbon Risk will be explained. Subsequently, the modelling method will be discussed in chapter 3.3.

## 3.1. Carbon Risk framework

Our framework divides Carbon Risk into two categories, namely: 1) Structural Risk, and 2) Event Driven Risk, see chapter 2.1.1. Structural Risk could have a financial impact on the whole sector simultaneously; changing the dynamics in the shipping industry. Whereas Event Driven Risk can occur very sudden, can target specific firms within a sector, and is hard to predict. As a result of the differences in nature between Structural Risk and Event Driven Risk, different methods are needed in order to assess the impact of each. Event Driven Risk will be out of scope in this assessment. That does not mean Event Driven Risk is less important or carries less financial risk than Structural Risk, yet it is best analyzed in a separate analysis. This research will thus focus on Structural Risk. Structural Risk can be divided into Regulatory Risk and Substitution Risk, and both will be covered in this research. As discussed in chapter 2.3, major Carbon Risks for the shipping industry are: 1) Carbon pricing (Regulatory Risk), and 2) increased efficiency awareness (Substitution Risk), and 3) demand substitution (Substitution Risk)<sup>25</sup>.

## 3.2. Method overview

In this study, we address several aspects of Carbon Risk, and the impacts it may have on the sector. Therefore, the method covers four steps, with each step providing further information on the impact and mitigating actions available to a ship owner. See Figure 3.1 for the included/accounted dependencies per step. In the first part of this paper (step 1), we will assess the financial and operational impact of a Carbon Tax across nine market segments. In step 1 we aim to address which market segments are most exposed to Carbon Risk. For a full description of step 1, see section 3.2.1.

In the second part of our analysis (step 2), we zoom in into the competitive position of a shipowner within the sub segment that is most exposed to Carbon Risk (following the outcome in step 1) and verify whether the Carbon Risk is materially different for ships that are 15 [%] larger or smaller. Hence, we aim to analyze if there are winners and losers within a sub-segment. For a full description of step 2, see section 3.2.2.

In the third part of our analysis (step 3), we assume a 10 [%] more fuel efficient ship, and compare the outcome with the Carbon Risk found in step 1. Lower Carbon Risk (lower financial losses) could provide a rationale for capital investments in a ship to improve the technical specification (i.e. fuel economy) of the ship. Step 3 would therefore reveal to what extent such investments would be economically feasible. The approach used for the third part will be explained in section 3.2.3.

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<sup>25</sup> Carbon Risk and/or mitigation actions can change the competitiveness of a company. Therefore, the impact of Carbon Risk (i.e. Carbon pricing or increased efficiency awareness) could also be positive/an opportunity.



And in the fourth part of our analysis (step 4), we assess the potential impact of Substitution Risk. For a further explanation of step 4, see section 3.2.4. An overview of the method for each step can be found in Figure 3.2. First, the approach of the first part is further detailed below.

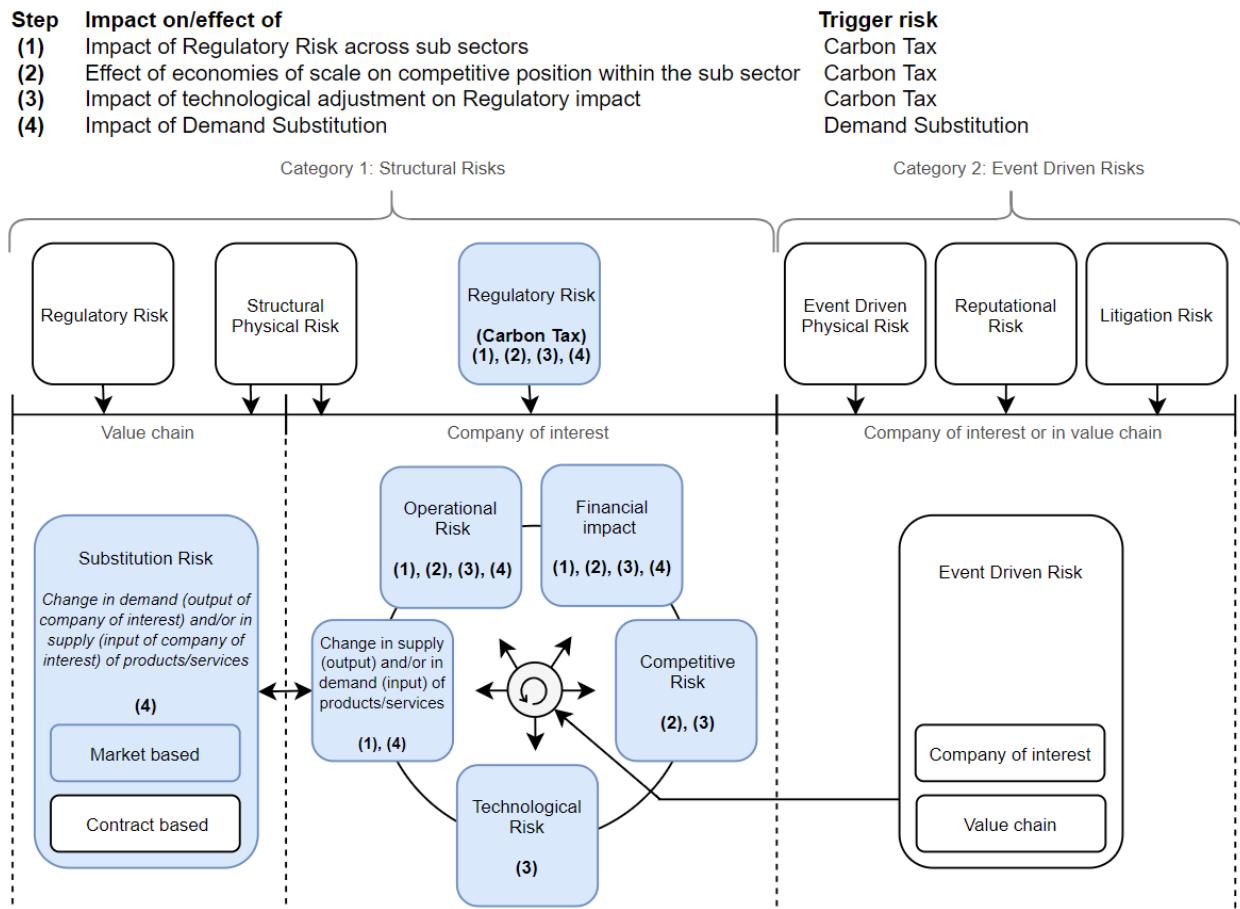


Figure 3. 1 - Selection of Carbon Risk factors (blue) for each step (own composition)

### 3.2.1. Step 1 – Impact of Regulatory Risk across sub sectors

In the first part of this thesis (step 1) we will assess the impact of Carbon regulation on the profit before interest and taxes of ships in three sectors: crude oil tankers, container ships, and bulk carriers. Within each sector, the impact assessment will be done for a small, medium, and large vessel. Hence, the assessment will be done for nine vessels in total. The choice for these sectors and size ranges will be explained in the next section. The annual profit for these nine vessels will be calculated under four scenarios, as shown in Figure 3.2. The scenarios assume average economic conditions, a recession, and also differentiate between the BAU regulatory environment and an assumed Carbon Tax. How these scenarios will be defined specifically, will also be explained below. Based on the above analysis, four profit levels will be calculated for each vessel (A1, A2, B1, B2). As a result, the impact of introducing a Carbon tax can be assessed both under average economic conditions and in case of an economic recession.

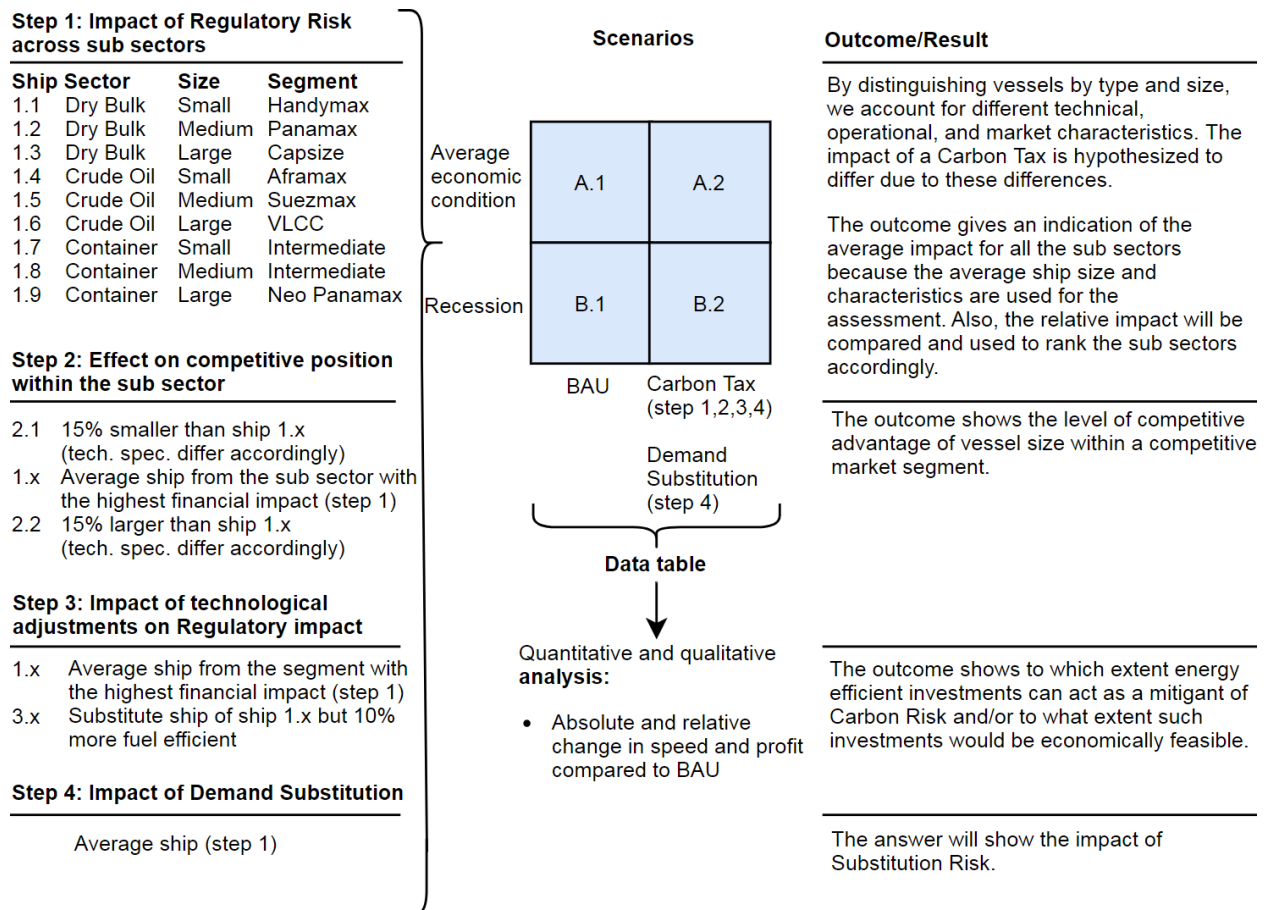


Figure 3. 2 - Simplified overview of the research method (own composition)

Note that shipowners, when faced with the introduction of a Carbon Tax or economic recession (or both) can mitigate the financial impact through operational adjustments. Because fuel consumption is related to the cube of the speed, it is highly likely that speed adjustments will be partially used as operational mitigation measure to lower Carbon costs. We take this operational flexibility into account when calculating profit levels. Hence, given the scenario, the vessel's speed is optimized to maximize profits. In the end, lower operating speeds may increase the demand for vessels and provide upward pressure on the spot price.

### Sector, size, and technical specifications

By distinguishing vessels by type and size, we account for different technical, operational, and market characteristics. We focus on crude oil tankers, container ships, and bulk carriers because they are the three most significant sectors from a CO<sub>2</sub> perspective (IMO, 2015). Vessels are most often classified by size range separated by maximum (whether or not historical) size limits for certain routes. We select a typical small, medium, and large vessel from size ranges which differ substantially in size between each other, see Figure 3.2. Were the typical size corresponds to the average size of the particular sub segment (based on [Removed due to copyright issues], see Table 3.1 for the average size of each vessel. We assume that by using the average ship specifications for each sub segment, the financial and operational impact (impact on travelling speed) are good indicators for the average impact on the whole fleet. Therefore, we assume that the impact on travelling speed of the average vessel reflects the average impact on travelling speed of the entire sub segment. This assumption allows us to assess the total change of cargo carrying capacity for the

entire sub segment. For the size setting, we use the average size from each ship type/size range from [Removed due to copyright issues]. All vessels within the size range are used as input to determine the average size.

For each sub segment, the typical main dimensions are based on peer group analysis of vessels which are close to the average capacity within the sub segment, see Table 3.1. In addition, the peer group consists of relative new vessels to account for the latest design considerations. The method which is used to determine the typical dimensions and corresponding fuel consumption characteristics will be discussed in paragraph 3.3.1.

**Table 3. 1 - Specified vessel specifications for each sub segment for step 1**

Segment	Dry Bulk			Crude			Container		
Sub segment	Handymax	Panamax	Capesize	Aframax	Suezmax	VLCC	Intermediate Containership	Intermediate Containership	Neo-Panamax
Ref. no.	1.1	1.2	1.3	1.4	1.5	1.6	1.7	1.8	1.9
<b>Average vessel capacity</b>									
Size range (min; max) 1.1-1.6: [DWT], 1.7-1.9: [TEU]	Data removed due to copyright								
Database size [no. vessels]									
Avg. capacity 1.1-1.6: [DWT], 1.7-1.9: [TEU]									
<b>Peer group analysis (based on the calculated average vessel capacity, see above)</b>									
Peer group size [ no. vessels]	Data removed due to copyright								
Avg. Capacity 1.1-1.6 [DWT], 1.7-1.9: [TEU]									
Avg. LOA [m]									
Avg. Draft [m]									
Avg. Breadth [m]									
Avg. Age [y]									
Avg. Design speed [kn]									
<b>Vessel dimensions and capacity</b>									
LOA [m]	197.3	228.6	295.5	245.6	274.7	333.4	256.3	281.0	366.8
Draft [m]	12.9	14.4	18.3	14.9	17.0	21.6	12.7	14.4	15.3
Breadth [m]	32.3	32.7	47.1	43.6	48	60	36.1	41.7	49.6
Capacity 1.1-1.6 [DWT], 1.7-1.9: [TEU]	60147	81556	192141	111904	156851	308925	4651	6651	13530
Source: [Removed due to copyright issues]									

### 3.2.2. Step 2 – Effect on competitive position within the sub sector

In theory, given that the cargo capacity of the ship is fully utilized, more cargo carrying capacity (economies of scale/larger ships) lowers the transport costs per unit of cargo. Partly due to a relatively small increase of operational costs and building costs with respect to the increase in DWT (Chen, Frouws, & Voorde, 2010). As discussed in the introduction of paragraph 3.2, we will zoom in into the competitive position of a shipowner within the sub segment (direct competitors) that is most exposed to a Carbon Tax (following the outcome in step 1). In this step, we verify whether the impact is significantly different for ships 15 [%] larger and smaller in terms of DWT. Hence, we aim to analyze if there are winners and losers within a sub-segment.

### **3.2.3. Step 3 – Impact of technological adjustments on financial impact**

In this step, technical mitigation strategies are reviewed for the sub segment that was tested to face the most Carbon Risk in step 1. By changing the operational efficiency upward, but keeping capital costs unchanged, we will calculate the annual profit under the four predefined scenarios (A1, A2, B1, B2), as shown in Figure 3.2. The outcome will be compared with the original ship without the adjusted fuel efficiency (from step 1). As a result, we determine the yearly change in profit and the financial viability (room to actually invest in the technological adjustment) of fuel-efficient related investments both under average economic conditions and in case of an economic recession.

This step provides an indication of the financial viability of technical mitigation measures regarding a Carbon Tax. When the actual investment costs to effectuate a 10 [%] efficiency improvement are known (which is case specific), shipowners can determine the financial advantage of such an investment by taking the extra yearly profit due to the extra fuel efficiency (determined in this step) and the vessels age, among others, into account.

### **3.2.4. Step 4 – Impact of Substitution Risk**

As is discussed in section 2.2.2, Sharmina, McGlade, Gilbert, and Larkin (2017) analyzed regional and global demand scenarios for coal and oil. The <2 [°C] pathway shows a global decrease in the demand for oil (starting +/- after 2030) and coal (starting +/- after 2020). Looking forward, the demand for more severe regulation to shift away from fossil fuels is rising. “If changes in the supply of any energy commodities are as rapid as the Paris Agreement's goals (i.e. 2 [°C] and especially 1.5 [°C]) imply, the shipping industry could be faced with a fast pace of change, including likely lower demand for energy-related shipments” (Sharmina, McGlade, Gilbert, & Larkin, 2017). However, the scale of demand substitution remains uncertain<sup>26</sup>.

In this part of our analysis, we assess the potential impact of Demand Substitution due to Carbon Risk. For the (coal) dry bulk carriers and oil tankers, we simulate Demand Substitution by adding extra waiting time at sea before being assigned to a new voyage. Due to the nature of container freight (time sensitive and/or perishable goods), container vessels have to remain scheduled frequency. Therefore, Demand Substitution is simulated by adjusting the cargo utilization rate of the vessel. As already mentioned, the scale of Demand Substitution could be significant but remains uncertain. For this analysis, we will assess a 20 [%] drop in demand. The result shows how big the impact of Demand Substitution could be if Substitution Risk materializes. The impact of Demand Substitution will be determined with and without the presence of a Carbon Tax.

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<sup>26</sup> However, keep in mind that the demand/use of fossil fuels can vary between regions. In some regions, an increase in use/demand of fossil fuel is expected. Therefore, local depended entities (i.e. with location bounded infrastructure) can be impacted differently depending on the region/location they are in. Also, even though demand is expected to rise in certain regions, it does not necessary mean that the shipping sector will benefit from increased demand. In addition, due to fast growing economies and increasing human population, it is even possible that regulatory measures only slow down the growth of fossil fuels. However, we assume that OECD member countries will gradually shift away from the most GHG intensive fuels.

### **3.2.5. Scenarios**

As shown in Figure 3.2, four scenarios are tested, differentiating between the state of the economy and the regulatory regime.

The state of the economy over time is hard to predict and involves a large amount of uncertainty. As will be explained below, the impact is hypothesized to differ according to the state of the economy. Stopford (2009) already emphasized the importance to build up cash reserves during average and booming economic times to survive a recession. Therefore, it is important to understand the impact of Carbon Risk under average economic conditions and during a recession. For these scenarios, the impact on profit and travelling speed will be determined and also compared between the two predefined economic states.

A recession implies decreasing demand causing lower freight rates and smaller parcel sizes. Lowering speed to maximize profits or limit losses is a well-known mitigation measure. While decreasing fuel consumption and costs it will negatively impact the ships productivity due to increased voyage time. Operating already at a low speed, there is little room to cut back extra fuel and Carbon related costs because fuel consumption is related to the cube of the speed. In combination with financial stress due to the recession, Carbon Risk can result in a high impact. Especially when freight rates do not compensate accordingly and less cash reserves are available due to the impact under average economic conditions before the recession.

In general, under average economic conditions the fleet operates at higher speeds compared to a recession in order to maximize its profit. It is hypothesized that the costs due to a Carbon tax are higher compared to a recession. Disproportionate more fuel will be burned and thus Carbon emitted due to the relative high travelling speed compared to a recession. Therefore, the impact of a Carbon tax on profit and speed compared to the BAU scenario is hypothesized to be high and significant. Hence, the drop in speed can cause more demand for cargo carrying capacity. As a result, it can cause higher freight rates until the demand is met with greater supply of freight capacity (Stopford, 2009).

### **3.2.6. Impact assessment**

As already discussed, we will assess the impact of Regulatory Risk across subsectors, the impact on different sizes within a subsector, the effect of technological adjustments, and the impact of Substitution Risk.

#### **Minimum cost assessment**

For all predefined scenarios, the impact of a Carbon Tax on the minimum transport costs will be determined. This will be done by calculating the break-even price per unit of cargo over the ships speed range. The impact on the minimum break-even price will be used as a proxy for the level of Carbon Risk a shipowner faces. The relative changes can be easily compared between sub segments. The minimum cost assessment excludes freight rates and will be used to discover basic trends without economic uncertainty.

### **Profit maximizing assessment**

In general, shipowners try to maximize profit throughout the economic cycle. When losses are unavoidable, shipowners try to minimize their losses, which in essence is also a form of profit maximization. For all cases, the maximum profit before interest and taxes will be determined under the predefined scenarios. The impact on profit will be used as a proxy for the level of Carbon Risk a shipowner faces. The profit will be assessed on a yearly basis because this metric is transparent and relative profit changes can be easily compared between sub segments. As will be explained below, in this analysis, the ships are subjected to the spot market and all costs (capital, operational, and voyage costs) and profits are allocated to the shipowner.

### **Spot market**

In reality, ships operate under a variety of contract types. Typical contract types are bare boat, time charter, voyage charter, and liner service. Between the different contract types there is a difference in which costs are allocated to the shipowner. In this analysis, the ships are subjected to the spot market and all costs (capital, operational, and voyage costs) are allocated to the shipowner. Therefore, costs due to a Carbon Tax or revenue decrease due to Demand Substitution will be accounted for in this analysis. Also, the spot market reflects the economic conditions through the freight rate price and parcel size which is easy to include in the analysis. This gives us the opportunity to assess the total impact in profit but also allows to determine changes in optimal speed (in reality, dependent on the type of contract, the impact may also be subdivided to parties in the value chain).

### **Route**

Although ships are constrained by canal sizes and port depths, they are not route bounded. In reality, driven by demand, ships sail to many different ports to deliver cargo. For this analysis, typical routes, cargo, and parcel sizes are used for the analysis. For each sub segment one of the most typical type of cargo and route will be used in order to cover the largest part of the fleet within the sub sector. It is common to bring cargo to the destination port and subsequently pick up cargo from the destination port (or a neighboring port) and bring it back to the start port. In general, shipowners will not sail back empty loaded in order to maximize profits. Therefore, we assess a roundtrip; bringing typical cargo from port A to B and typical cargo from port B to A.

### **Impact on voyage time**

The impact on voyage will be assessed. During the assessment, readjustments of the freight price via the demand and supply function are ignored.

### 3.3. Modelling method

In this section, the mathematical formulation of the model will be explained. First, section 3.3.1 explains how ships are specified, to be used as input in the four-step approach. Subsequently, in step 3.3.2, it is specified how the ships are tested in the scenarios.

#### 3.3.1. Method to establish typical vessel characteristics

The method to determine the typical main dimensions of the vessel can be found in paragraph 3.3.1.1. The method behind the corresponding vessels fuel consumption speed relation of the main engine under different loading conditions can found in paragraph 3.3.1.2. Subsequently in paragraph 3.3.2.3, the fuel consumption of the auxiliary engines and generators will be given.

##### 3.3.1.1. Main dimensions of the vessel

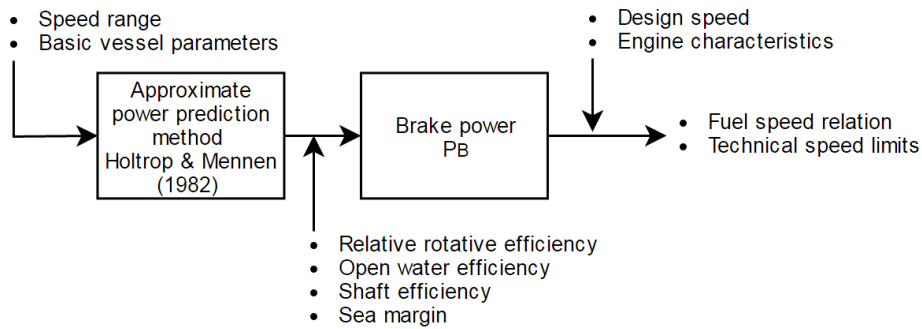
As already discussed in paragraph 3.2.1., for each sub segment, the typical main dimensions are based on peer group analysis from Clarksons SIN database. The peer group analysis will be done for vessels which are close to the average capacity within their own sub segment. In addition, the peer group consists of relative new vessels to account for the latest trends, technologies, and design considerations.

##### 3.3.1.2. Fuel consumption of the main engine and speed limit

In our model, we use the approximate power prediction method from Holtrop and Mennen (1982) to determine the resistance of the vessel with respect to service speed. Based on empirical evidence from random model experiments and full-scale data, this method is very suitable for this assessment because little parameters have to be known to make a first good estimate of the required propulsive power. The resistance is subdivided into several resistance components, see Equation 3.1 (Holtrop & Mennen, 1982).

$$R_{total} = R_F * (1 + k_1) + R_{APP} + R_W + R_B + R_{TR} + R_A \quad (\text{eq. 3.1})$$

According to Holtrop and Mennen (1982),  $R_F$  is the frictional resistance according to the ITTC 1957 friction formula,  $(1 + k_1)$  the form factor describing the viscous resistance of the hull form in relation to  $R_F$ ,  $R_{APP}$  the resistance of appendages,  $R_W$  the resistance of wave making and wave breaking resistance,  $R_B$  the additional pressure resistance of bulbous bow near the water surface,  $R_{TR}$  the additional pressure resistance of immersed transom stern, and  $R_A$  the model ship correlation resistance. A sea margin of 15 [%] is applied to account for increased resistance due to wind, current, and waves. Figure 3.3 illustrates the method which is used to determine the fuel consumption speed relation.



**Figure 3.3 - Method to determine the fuel consumption of the main engine and minimum and maximum speed limits (own composition)**

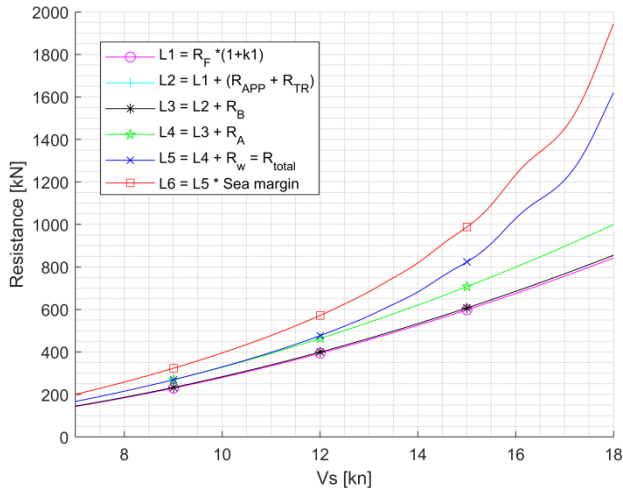
The resistance differs per loading condition. Therefore, we determine the fuel consumption speed relation per ship for each loading- and ballast condition. Note that the loading condition can differ per scenario. To illustrate the intermediate results of the model, see Figure 3.4 for the structure of the resistance components determined with the Holtrop and Mennen (1982) method for ship 1.1 under the loaded condition (port A to B) from scenario A. Subsequently, the required shaft power is determined by adding the relative rotative efficiency (Holtrop & Mennen, 1982), open water efficiency, shaft efficiency (0.99), and a sea margin<sup>27</sup> of 15 [%], see Figure 3.5. The absolute minimum and maximum power, and therefore the speed, is restricted by respectively 45 [%] and 95 [%] Maximum Continuous Rating (MCR) of the maximum main engine power. Subsequently, the Specific Fuel Oil Consumption (SFOC) characteristics related to the percentage of MCR of a large slow speed main engine (Figure 3.6)<sup>28</sup> is used to determine the fuel consumption of the vessels, see Figure 3.7.

In order to determine the installed main engine power for each ship, we determine/set the required speed (taken into account the sea margin) of the ship related to 80 [%] MCR. Then, based on the relationship between the required shaft power versus the speed of the ship, the model determines the required main engine power in order to satisfy the required speed at 80 [%] MCR. Partly based on the average design speed of the peer group analysis (see Tabel 3.1), we set the speed related to 80 [%] MCR to 13.5 [kn] for the bulk carriers and oil tankers, and to 20 [kn], 21.5 [kn], and 22 [kn] for respectively the containerships with reference number 1.7, 1.8, and 1.9 (Neo Panamax ship).

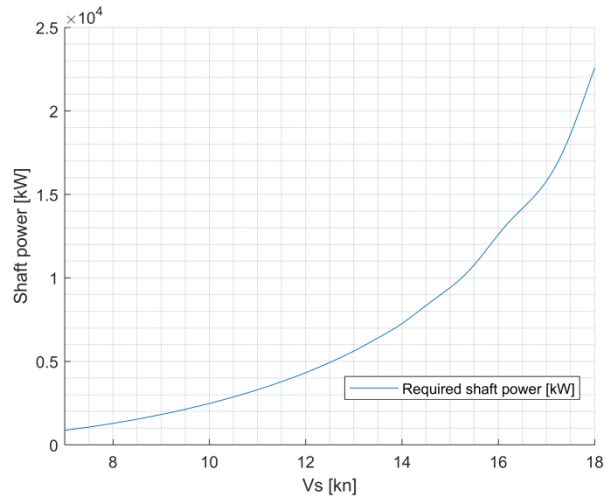
<sup>27</sup> A provision for an increased resistance caused by wind, sea state, fouling of hull and propeller, shallow water, currents, etc. Usually a sea margin of 10-25% is applied (Wärtsilä, n.d.).

<sup>28</sup> SFOC curve of a MAN B&W 6S60ME-C8.2 engine.

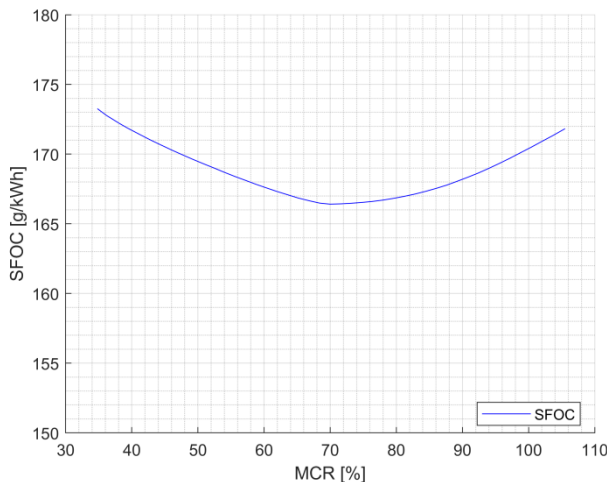




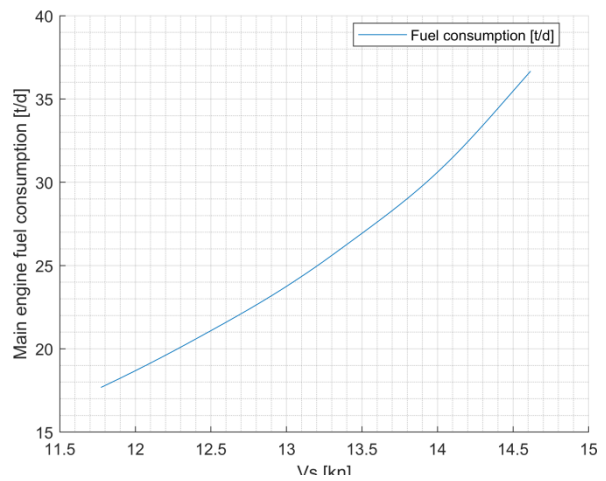
**Figure 3. 4 - Sum of the resistance components over speed, ship/case 1.1, scenario A, loaded from port A to B (own figure)**



**Figure 3. 5 - Required shaft power over speed, ship/case 1.1, Scenario A, loaded from port A to B (own figure)**



**Figure 3. 6 – Specific Fuel Oil Consumption (SFOC) (own figure)**



**Figure 3. 7 - Fuel consumption over speed, ship/case 1.1, scenario A, loaded from port A to B (own figure)**

The fuel consumption-speed relationships which are used for step 1 of the analysis, can be seen in Figure 3.8. We account for differences in draft due to the loading condition of the ship (i.e. fully loaded or ballast condition). In this analysis, most ships sailing from port A to B are loaded with cargo (uninterrupted line) and are in ballast condition (dotted line) sailing back from port B to A. Ships in ballast condition have a higher minimum and maximum speed.

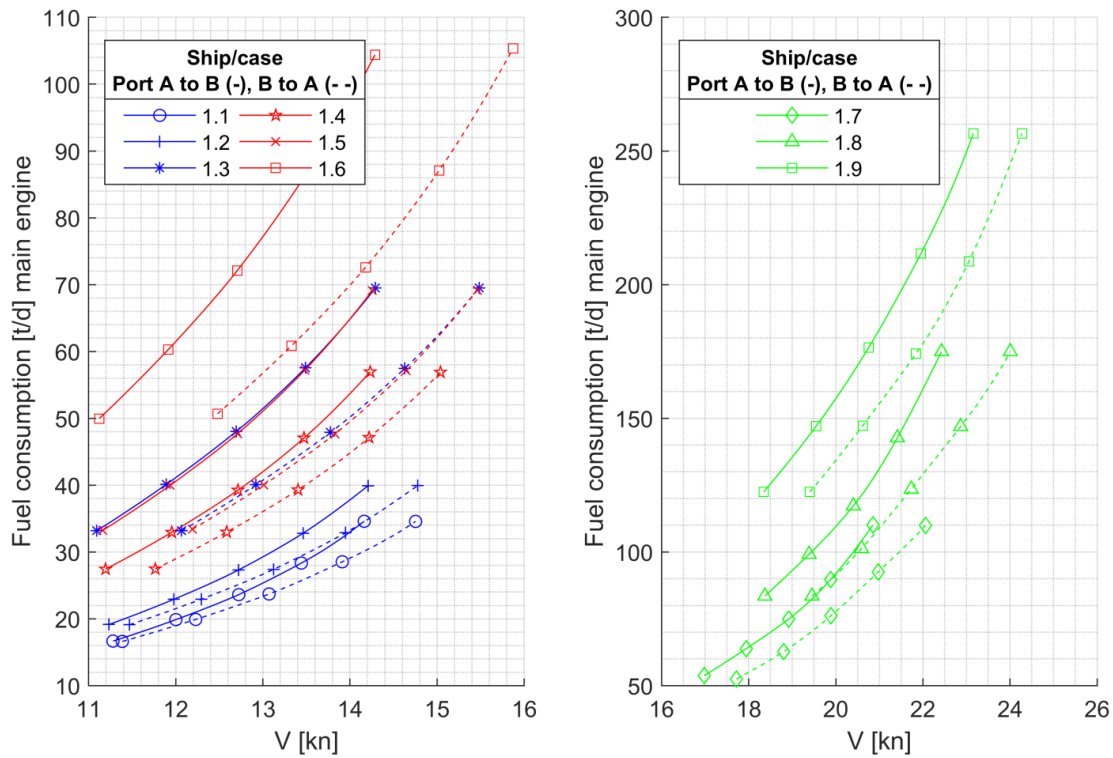


Figure 3.8 - Fuel – speed relations for step 1 under loading condition scenario A (own figure)

### 3.3.1.3. Changing the fuel efficiency upward in step 3

There are many ways to reduce the Carbon emissions of ships. For example, by incorporating energy efficient measures related to auxiliary power, aerodynamics, thrust efficiency, engine efficiency, and hydrodynamics (Wang & Lutsey, 2013). However, all measures have a different effect on the fuel consumption speed curve. The added value of detailed modelling of each of these adjustments is limited compared to the amount of complexity it will add to the model. For this analysis, the efficiency will be changed upward (see section 4.3). Which effectively means that the ship is 10% more efficient compared to its predecessor at all speeds. This method will give a good insight in the added value of technical adjustments as a mitigant for Carbon Risk, leaving detailed modeling to further studies in this field.

### 3.3.2. Scenario testing

The impact of a Carbon Tax will be assessed for two economic conditions. Under these conditions, the ship-owners optimize their profits under various circumstances. Also, we will assess the minimum transport costs per unit of cargo. Therefore, most of section 3.3.2 covers the profit and minimum cost function, and its components. Thereafter, the scenario variables are explained. The variables, definitions, and equations in this section are to a certain extent based on Chen, Frouws, & Voorde (2010) and Stopford (2009).

### 3.3.2.1. Profit function

Profit ( $P_y$ ) will be modeled as a function of capital costs, operating/running costs, voyage costs, and revenue, see Equation 3.1. While some costs are assumed to be fixed others can be written as a function of the speed of the vessel. Also, the ships productivity and thus revenue is depended on the speed of the vessel. This allows us to determine the new optimum in profit as well as the change in speed due to a Carbon Tax.

$$P_y = (R_r - (C_{fuel_r} + C_{carbon_r} + C_{other_r})) * \left(\frac{T_y}{t_r}\right) - C_{fixed_y} \quad (\text{eq. 3.1})$$

Where  $P_y \left[\frac{\$}{y}\right]$  is the profit per year,  $R_r \left[\frac{\$}{r}\right]$  is the revenue per roundtrip (further specified in Equation 3.6),  $C_{fuel_r} \left[\frac{\$}{r}\right]$  is the fuel consumption cost per roundtrip (function of the speed of the vessel) (Eq. 3.7),  $C_{carbon_r} \left[\frac{\$}{r}\right]$  is the Carbon emission cost per roundtrip (function of the speed of the vessel) (Eq. 3.8),  $C_{other_r} \left[\frac{\$}{r}\right]$  are the remaining voyage costs per round trip (Eq. 3.9),  $T_y [d]$  stands for the service time in days per year,  $t_r [d]$  is the total time per round trip in days (function of service speed) (Eq. 3.3), and  $C_{fixed_y} \left[\frac{\$}{y}\right]$  represents all the assumed fixed costs on a yearly basis (Eq. 3.10).

The maximum profit, on a yearly basis, and optimum speed for each part of the roundtrip will be determined for each unique set of parameters within the technical and operational limits of the vessel, see Figure 3.9 and Figure 3.10. MATLAB is chosen to model the impact of a Carbon Tax on profit (and minimum costs, see chapter 3.3.2.2) because of its algorithm, visualization, and matrix/array handling capabilities. An algorithm will be developed to determine the profit, related service speed, voyage time, and Carbon emissions for each unique set of parameters (i.e. ship type and characteristics, economic scenario, height of the Carbon Tax) over its speed range.

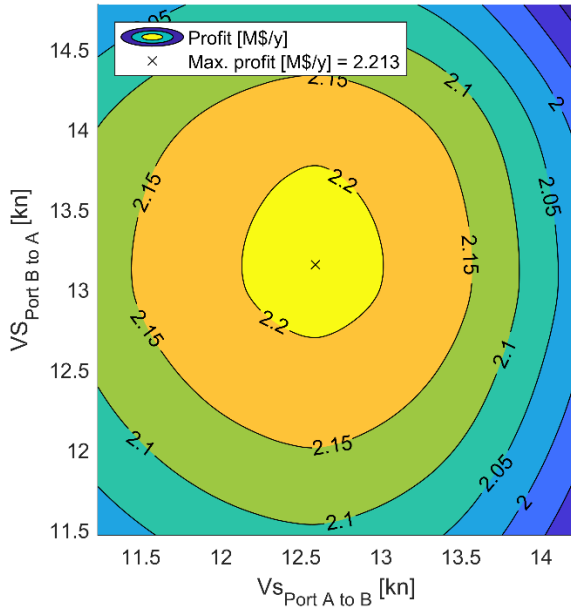


Figure 3. 9 - Profit for ship 1.2 under scenario A without a Carbon Tax (own figure)

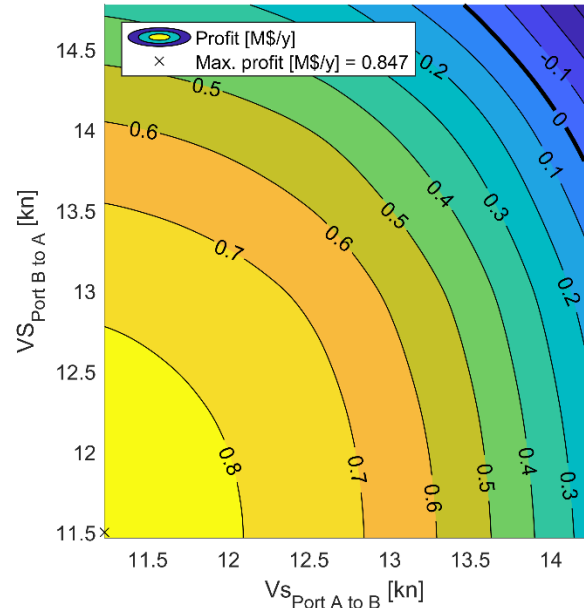


Figure 3. 10 - Profit for ship 1.2 under scenario A with a 50 [\$/Tonne CO<sub>2</sub>] Carbon Tax (own figure)

### 3.3.2.2. Cost function

The minimum transport costs allocated to one unit of cargo will be modeled as a function of capital costs, operating costs, and voyage costs, see Equation 3.2. While some costs are assumed to be fixed others can be written as a function of the speed of the vessel. Also, the ships productivity and thus the amount of cargo that can be shipped per year is dependent on the service speed. This allows us to determine the minimum costs (minimum break-even price) as well as the change in speed due to a Carbon Tax for each unique set of parameters (i.e. ship type and characteristics, economic scenario, height of the Carbon Tax).

$$C_{unit} = \frac{(C_{fuel_r} + C_{carbon_r} + C_{other_r}) * \left(\frac{T_y}{t_r}\right) + C_{fixed_y}}{\text{Amount of cargo units per roundtrip} * \left(\frac{T_y}{t_r}\right)} \quad (\text{eq. 3.2})$$

Where  $C_{unit} \left[\frac{\$}{y}\right]$  is the costs allocated to one unit of cargo,  $C_{fuel_r} \left[\frac{\$}{r}\right]$  is the fuel consumption cost per roundtrip (function of service speed) (Eq. 3.7),  $C_{carbon_r} \left[\frac{\$}{r}\right]$  is the Carbon emission cost per roundtrip (function of service speed) (Eq. 3.8),  $C_{other_r} \left[\frac{\$}{r}\right]$  are the remaining voyage costs per round trip (Eq. 3.9),  $T_y [d]$  stands for the service time in days per year,  $t_r [d]$  is the total time per round trip in days (function of service speed) (Eq. 3.3), and  $C_{fixed_y} \left[\frac{\$}{y}\right]$  represents all the assumed fixed costs on a yearly basis (Eq. 3.10).

The minimum transport costs allocated to one unit of cargo will be determined for each unique set of parameters within the technical and operational limits of the vessel, see Figure 3.11 and Figure 3.12. An algorithm will be developed to determine the transport costs/price, related service speed, voyage time, and Carbon emissions for each unique set of parameters (i.e. ship type and

characteristics, economic scenario (i.e. utilization of the ship), height of the Carbon Tax) over its speed range.

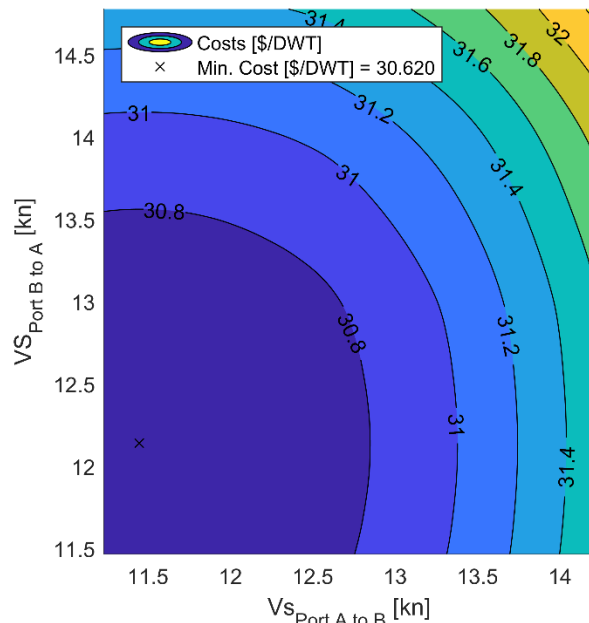


Figure 3.11 - Minimum transport costs for ship 1.2 under scenario A without a Carbon Tax (own figure)

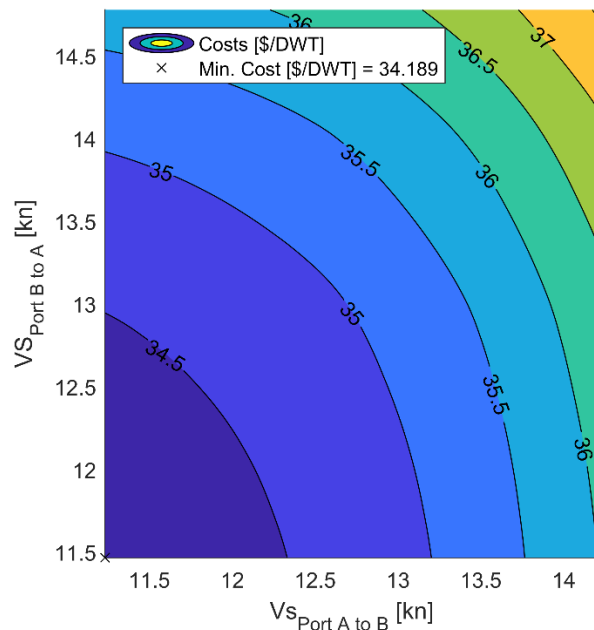


Figure 3.12 - Minimum transport costs for ship 1.2 under scenario A with a 50 [\$/Tonne CO<sub>2</sub>] Carbon Tax (own figure)

### 3.3.2.3. Underlying function variables

The underlying variables for both the profit function as well as the minimum transport cost function are stated below.

#### Time ( $t_r$ )

The total time per roundtrip ( $t_r$  [d]) is subdivided into five parts, see Equation 3.3.

$$t_r = t_s + t_c + t_h + t_t + t_e \quad (\text{eq. 3.3})$$

Where  $t_s$  [d] represents the total sailing time per roundtrip which is a function of the speed of the vessel and round trip distance (see Equation 3.4),  $t_c$  [d] represents the total canal transit time per round trip,  $t_h$  [d] is the cargo handling time and includes loading and discharging,  $t_t$  [d] includes the turnaround time between loading and discharging, and  $t_e$  [d] the extra time spent at sea and in port for each round trip.

$$t_s = \frac{L_{AB}}{24 * V_{SAB}} + \frac{L_{BA}}{24 * V_{SBA}} \quad (\text{eq. 3.4})$$

Here,  $L$  [nmile] is the distance between ports in nautical mile and  $V_s$   $\left[\frac{kn}{h}\right]$  denotes the speed of the vessel in knots per hour.

The cargo handling time ( $t_h$  [d]) (Equation 3.5) includes the total amount of cargo carrying capacity in DWT for a particular type of cargo, a utilization factor  $\alpha$  is included which gives the opportunity to adjust the amount of cargo per trip according to the scenario. Loading ( $t_{hL} \left[ \frac{DWT}{h} \right]$ ) and discharging ( $t_{hD} \left[ \frac{DWT}{h} \right]$ ) rates of the cargo from point A to B (indicated by a 1) and from B to A (indicated by a 2) are included in the equation.

$$t_h = \alpha_1 * DWT_1 * (t_{hL1} + t_{hD1}) + \alpha_2 * DWT_2 * (t_{hL2} + t_{hD2}) \quad (\text{eq. 3.5})$$

### Revenue ( $R_r$ )

The revenue per roundtrip ( $R_r \left[ \frac{\$}{r} \right]$ ) will be determined by the freight rate per unit ( $FR \left[ \frac{\$}{\text{Tonne}(DWT)} \right]$ ) and the freight parcel size which the ship is carrying as can be seen in Equation 3.6. For containerhips, the unit [TEU] is used instead of [DWT]. The cargo flow from port A to B is indicated by a 1 and from port B to A is indicated by a 2.

$$R_r = \alpha_1 * DWT_1 * FR_1 + \alpha_2 * DWT_2 * FR_2 \quad (\text{eq. 3.6})$$

### Fuel costs ( $Cfuel_r$ )

The fuel costs per roundtrip ( $Cfuel_r \left[ \frac{\$}{r} \right]$ ) is the product of the fuel consumption of the main and auxiliary engines/systems (chapter 3.3.1.2 and 3.3.2.3) and the fuel price (chapter 3.3.2.3), see Equation 3.7.

$$Cfuel_r = ((FC_{main AB} + FC_{main BA}) * Cfuel_{main} + (FC_{aux AB} + FC_{aux BA}) * Cfuel_{aux}) * t_s \quad (\text{eq. 3.7})$$

Where  $FC_{main} \left[ \frac{\text{tonne}}{\text{day}} \right]$  represents the daily fuel consumption of the main engine (prime mover) from port A to B (AB) and from port B to A (BA),  $Cfuel_{main} \left[ \frac{\$}{\text{tonne}} \right]$  the fuel costs of the fuel of the main engine,  $FC_{aux} \left[ \frac{\text{tonne}}{\text{day}} \right]$  the daily fuel consumption of the auxiliary engines and systems on board, and  $Cfuel_{aux} \left[ \frac{\$}{\text{tonne}} \right]$  the fuel costs of the fuel of auxiliary engines and systems.

### Carbon costs

The carbon costs ( $Ccarbon_r \left[ \frac{\$}{r} \right]$ ) (Equation 3.8) are calculated in a similar way as fuel costs (Equation 3.7). The Carbon emission price is used instead of the fuel price and a conversion factor ( $c$ ) of 3.114<sup>29</sup> (IMO, 2015) is added to convert the amount of fuel which is burned to the amount of Carbon emission<sup>30</sup>.

<sup>29</sup> This conversion factor is based on the conversion factor for HFO. However, the conversion factor of MGO/MDO is around the 2.95 [%] higher. In the model, we use 3.114 as carbon conversion factor for all fuel types for simplicity reasons.

<sup>30</sup> "The carbon content of each fuel type is constant and is not affected by engine type, duty cycle or other parameters when looking on the basis of kg CO<sub>2</sub> per tonne fuel" (IMO, 2015).

$$C_{carbon_r} = ((FC_{main AB} + FC_{main BA}) * c * C_{carbon} + (FC_{aux AB} + FC_{aux BA}) * c * C_{carbon}) * t_s \quad (\text{eq. 3.8})$$

### Remaining voyage costs ( $C_{other_r}$ )

As can be seen in Equation 3.9, the remaining voyage costs per trip consists of three other cost items, namely: 1) cargo handling costs per round trip ( $C_{cargohandeling_r}$  [\$]), 2) canal costs per round trip ( $C_{canal_r}$  [\$]), and 3) port costs per round trip ( $C_{port_r}$  [\$]).

$$C_{other_r} = C_{cargohandeling_r} + C_{canal_r} + C_{port_r} \quad (\text{eq. 3.9})$$

### Fixed costs ( $C_{fixed_y}$ )

The fixed costs ( $C_{fixed_y}$ [\$]) are the sum of capital costs ( $C_{capital_y}$ [\$]) and operational costs ( $C_{operational_y}$ [\$]) on a yearly basis, see Equation 3.10. The average yearly capital costs ( $C_{capital_y}$  [\$]) include interest and depreciation. The operating costs include crew costs, stores and lubricants, maintenance, administration and insurance.

$$C_{fixed_y} = C_{capital_y} + C_{operational_y} \quad (\text{eq. 3.10})$$

#### 3.3.2.4. Impact on voyage time

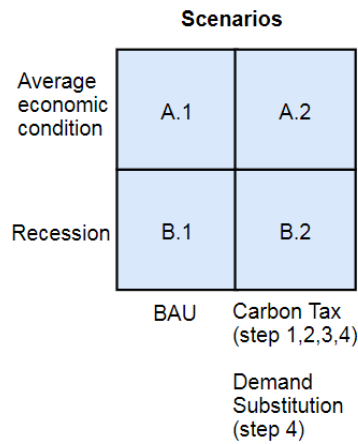
Equation 3.11 will be used to assess the relative impact on voyage time (RIVT) [%]. The impact on voyage time can also be used as proxy for the use of extra needed fleet capacity and/or the stimulus for new builds.

$$RIVT = \frac{t_{r_{REG}} - t_{r_{BAU}}}{abs(t_{r_{BAU}})} * 100 \quad (\text{eq. 3.11})$$

Were  $t_{r_{REG}}$  [d] is the total time per roundtrip under the regulatory regime and  $t_{r_{BAU}}$  [d] the total time per roundtrip under BAU circumstances.

#### 3.3.2.5. Scenario input variables

This paragraph gives the reasoning behind the scenario variables for the scenarios A.1, A.2, B.1, and B.2 (see Figure 3.13). The economic conditions (average and recession) are expressed in the freight rate, cargo utilization factor, and fuel price. The freight rate is driven by demand and supply. Where demand is largely driven by the world economy and supply partially influenced by the scrapping market, new build market, and fuel prices. The Carbon Tax is included as static price per unit of Carbon emission and Demand Substitution expresses itself in a downward adjusted freight rate and utilization factor.



**Figure 3. 13 - Scenarios**

To assess the impact of a Carbon tax and Demand Substitution, real life market dynamics should ideally be accounted for. For example, the freight rate, but also the fuel price, depends on many variables and circumstances. Relative low freight rate levels are sometimes accompanied with relatively high and sometimes with low fuel prices<sup>31</sup>. Because both are impacted by multiple different variables, a clear trend between the two is difficult to assess. Including all second- or third-order impacts is impossible as it would add additional layers of complexity and uncertainty while being strongly assumption driven. To the extent that assumptions are made, a sensitivity analyses is performed to assess the influence of key assumptions, input variables and model parameters.

To account for real life market dynamics (equilibrium between demand and supply, influence of fuel price), we use historical averages (static) for the fuel price and freight rate. We assume that by taken the averages over time for both the freight rate and the fuel price, the scenarios are a good proxy for real life circumstances. The impact of a 25 [%] lower and higher fuel price on the output of the model (maximum profit) will be assessed in the sensitivity analysis.

### **Fuel price**

Because fuel costs are significant in the total transportation costs, a representative fuel price needs to be determined for the assessment. However, fuel prices are highly volatile over time and hard to predict. Fuel prices are driven by demand and supply of crude oil. Demand is largely driven by the world economy and supply is regulated by OPEC and non-OPEC countries. Producers frequently affect oil prices (EIA, n.d.) by setting production targets or limits. Bunker prices in shipping (for 180cst, 380cst, MDO, and MGO) are highly correlated to each other over the last 40 years (Clarkson SIN database). However, fuel prices of the same fuel type differ per location as much as 10 [%] (approximately). The amplitude of the fluctuations differ materially over time. The fluctuations pre-2000 are small compared to after- 2000. Steep rises (2007 - 2008, 2010 - 2011) and free falls (2008 - 2009, 2014 - 2015) in price are not uncommon.

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<sup>31</sup> For the Dry Bulk sector, we compared the fuel price with coal, ore, and grain voyage prices (for multiple routes and parcel sizes) and the Baltic Dry Index (BDI) (BDI is based on time charter rates) from 2000 to 2018 (source: Clarksons SIN database). In the analysis, the year 2000 is chosen as baseline year were all values are set to 100%. We observed (by sight) that the voyage and time charter rates accelerated compared to the fuel price between 2000 and 2005, showed the same trend between 2005 and 2010, were out of sync between 2010 and 2015, and showed the same trend again the next two years. Also, the container freight indexes do not show the same trend compared to the fuel prices over 2000 - 2018.



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. For the main engines we take heavy fuel oil 380cst LFSO as fuel and for the auxiliary engines we use MGO<sup>32</sup>.

For MGO, prices from at least three bunker locations are available from [Removed due to copyright issues], see Table 3.2. The price for MGO will be set at 584 [\$/t] (rounded up), see Table 3.3.

As for the heavier fuel oils (180cst and 380cst) we will use the low sulphur fuel oil 380cst (LSFO) variant to comply with the 2020 global sulphur limit set by IMO (IMO, n.d.). However, data from 2000 to 2018 is not available for these fuel types. Therefore, we take the average price of the non-LSFO over 2000 - 2018 and multiply this average with the relative difference between the average price of 380cst and 380cst LFSO over 2008 - 2014 (which is 3.37 [%]). The price we take for 380cst LFSO will be 370 [\$/t].

**Table 3. 2 - Average bunker prices**

Fuel type	Time range	Average bunker price [\$/t]	Comprises price averages over time from the following locations
MGO	Data removed due to copyright	Data removed due to copyright	Data removed due to copyright
380cst			
380cst			
380cst LSFO			
Source: [Removed due to copyright]			

**Table 3. 3 - Bunker prices used in the model**

Fuel type	Bunker price [\$/t]
MGO	584
HFO: 380cst LFSO	370

## Route

Among other things, voyage distance is an influential parameter with respect to the cost structure/ratio between fuel and Carbon costs on total costs. To account for real life circumstances, we assess typical voyage distances per sub segment. The typical voyage distance is large for large vessels, medium to large for medium sized vessels, and short to medium for the small sized ships (source: Clarksons SIN database). See Table 3.4 for the selected voyage distances.

## Freight rate and utilization factor

For the two economic scenarios, the freight rate per piece of cargo and the utilization of the ship's cargo carrying capacity will be adjusted accordingly. Compared to the average economic condition (scenario A, see Figure 3.2), the recession (scenario B) expresses itself in a fall in demand and results in lower freight rates. We assume that the fall in demand will be partially absorbed by decreasing cargo carrying capacity of the supply side due to a decrease in speed of the vessel (in order to save costs and/or to maximize profit). The utilization factor  $\alpha$  will be adjusted downward to incorporate the other portion of the decrease in demand. In the model, the ship is always able to pick up cargo

<sup>32</sup> Although we do not use MDO or 180cst LFSO in the model, the difference between the average price of MDO and MGO is only -1.03 [%] and 6.5 [%] between 180cst LFSO and 380cst LFSO.

at any time. In this analysis, we do not account for extra wait time due to losing a bid on a contract or temporarily unavailability of cargo for shipment at the given port.

As well as for the fuel price, freight rates are highly volatile over time and hard to predict. Freight rates are driven by demand and supply of cargo carrying capacity, both are impacted by multiple sector specific variables. The amplitude of the fluctuations differ materially over time. As well as for the fuel price, the fluctuations pre-2000 are small compared to after-2000. As already been said, freight rates are highly volatile over time and are hard to predict. In addition, freight rates fluctuate asynchronously with respect to the fuel price. Since both are impacted by multiple sector specific variables, it is hard to determine if, and how much, the freight rate compensates for fuel price fluctuations. This extra layer of complexity makes it even harder to determine freight rates for the average economic condition and for the recession scenario since the model uses only one average historical fuel price. In addition, we have to determine accurate freight rates with respect to: 1) the sub segment where the ship is operating in, and 2) its specific voyage (i.e. distance, destination). Besides, historical freight rates are no guarantee for the future. It is very well possible that market dynamics change over time due to new builds, scrapings, or improved economic circumstances within a particular sub segment.

For this assessment we need to establish freight rate proxies in order to simulate real life behavior. The average economic condition has to allow for a higher travelling speed than the recession scenario. Meaning that there is more room to mitigate the impact of the Carbon Tax by speed adjustments in the average economic condition compared to the recession. We developed a model to determine the freight rate levels for the average ship (technical and dimensional characteristics) of each sub segment under its specific scenario and voyage distance. Because we use the average ship characters we assume that the freight rates will be a good proxy allowing to assess/discover basic trends due to a Carbon Tax. These freight rates, based on the average ship under step 1, will also be used in step 2 and 3. However, the technical and dimensional ship characteristics differ in step 2 and 3 which allows us to discover the competitiveness of ships deviating in terms of size and efficiency compared to the average ship within their segment.

First, the model determines the absolute lowest break-even price over its speed range by seeking the optimal speed where the costs per single unit of cargo is the lowest, see Figure 3.14. A higher speed results in more cargo shipped from A to B on a yearly basis but also higher costs. By definition, if the freight rate is lower than the minimum break-even price the shipowner will have financial losses, on the other hand, if the freight rate is higher the shipowner makes profit. In general, when the economy worsens, shipowners reduce their speed to reduce their costs. In case of average economic circumstances; we assume that the average ship/shipowner makes profit. Therefore, the freight rate must be higher than the minimum break-even price. The productivity (and thus service speed) is also higher under those circumstances compared to the productivity at minimum cost. For the recession scenario it works the opposite.

To determine the level of the freight rate, an 'willingness to pay' factor is introduced which will be used as multiplier for the lowest break-even price, see Figure 3.14. The 'willingness to pay' factor is higher than 1 for the average economic scenario and lower than 1 for the recession scenario.

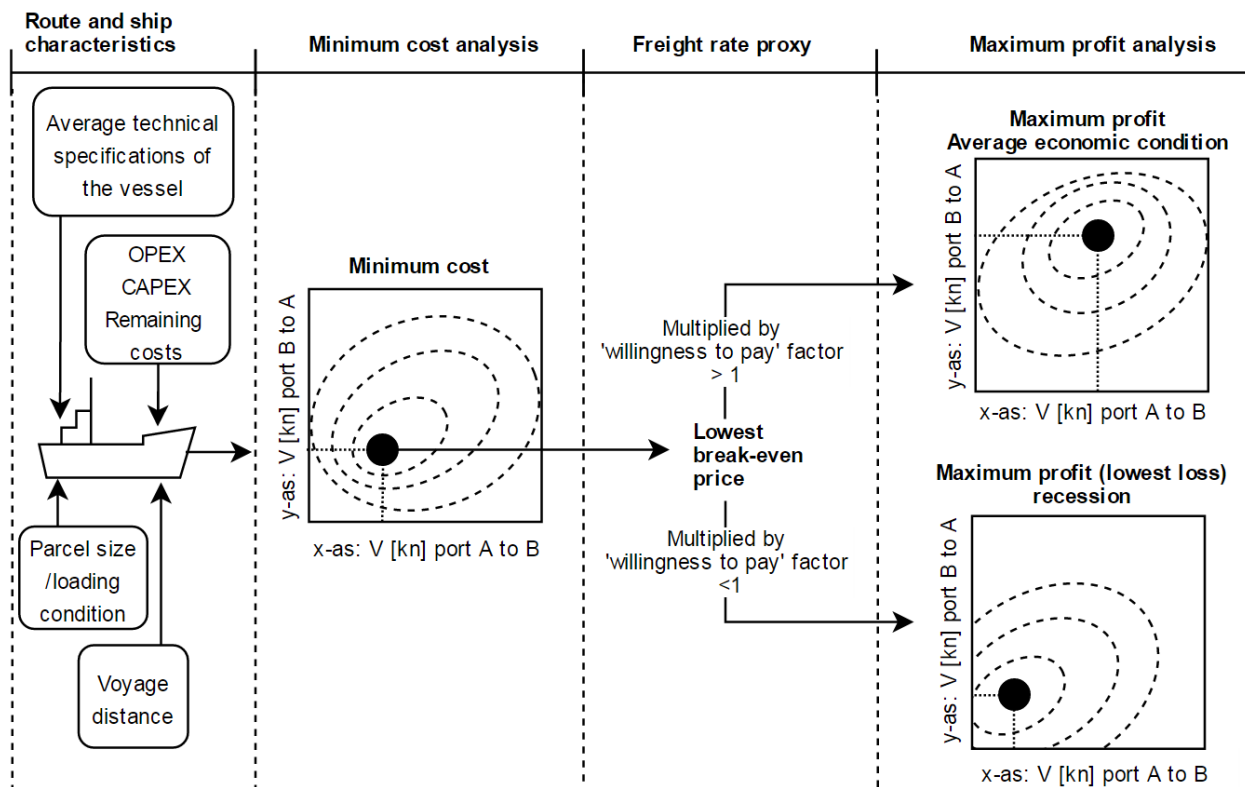


Figure 3.14 - Freight rate proxy model for step 1 (own composition)

For the average economic condition (scenario A), the ‘willingness to pay’ factor is 1.20 which effectively means that the freight rate is 20 [%] higher than the lowest break-even price. In contrast to the bulk carriers and crude tankers, the containerships also bring some cargo on the way back. However, due to the unbalance in demand and supply (on the way back) the ‘willingness to pay’ factor is 1.1 from port B to A. Because the economic circumstance factor is higher than 1, a profitable situation is simulated which expresses itself in a higher productivity and travelling speed compared to its minimum cost working point. The ‘economic circumstance factor’ is set on 0.95 (0.85 for containerships on the way back) for the recession (scenario B), simulating an unprofitable, loss making, situation. The loss given BAU for the recession scenario is still smaller than when the ships are laid-up. See Table 3.4 for the corresponding freight, and utilization factor per sub segment for both economic conditions.

Overall, due to the methodology behind our freight rate proxy model, we are able to determine economic input variables per sub segment under comparable economic conditions. Therefore, we are able to compare the relative impact between the sub segments.

Table 3. 4 - Cargo and economic specifications per sub segment for both economic conditions

Segment	Dry Bulk			Crude			Container		
Sub segment	Handymax	Panamax	Capesize	Aframax	Suezmax	VLCC	Intermediate Containership	Intermediate Containership	Neo-Panamax
Ref. no.	1.1	1.2	1.3	1.4	1.5	1.6	1.7	1.8	1.9
<b>Ports roundtrip (A = pickup/start port, B = destination port)</b>									
Typical haul distance <sup>1</sup>	Short	Medium Long	Long	Short Medium	Medium Long	Long	Short Medium	Medium	Long
Via canal	-	Panama	-	-	Suez	-	-	-	Suez
<b>Distance [nmile] between ports<sup>2</sup> (A = pickup port, B = destination port) (distance penalty is included if the route is not a roundtrip)</b>									
Distance A.1 to B.1	3517 <sup>3,12</sup>	8861 <sup>4</sup>	12081 <sub>5,17</sub>	509 <sup>6,13</sup>	6771 <sup>7,14</sup>	11378 <sup>8,15</sup>	1048 <sup>9,16</sup>	5667 <sup>10</sup>	10525 <sup>11</sup>
Distance A.2 to B.2	3517 <sup>3,12</sup>	8861 <sup>4</sup>	12081 <sub>5,17</sub>	509 <sup>6,13</sup>	6771 <sup>7,14</sup>	11378 <sup>8,15</sup>	1048 <sup>9,16</sup>	5667 <sup>10</sup>	10525 <sup>11</sup>
Total distance roundtrip	7034	17722	24162	1018	13542	22756	2096	11334	21050
<b>Type of cargo (A = pickup port, B = destination port)</b>									
Type of cargo port A.1 to B.1	Coal			Crude Oil			Containers		
Type of cargo port A.2 to B.2	-			-			Containers		
<b>Parcel size (P.S.), 1.1-1.6: [DWT], and 1.7-1.9: [TEU], scenario A = average economic conditions, and scenario B = recession</b>									
Cargo capacity vessel [DWT], 1.7-1.9: [TEU]	60147	81556	192141	111904	156851	308925	4651	6651	13530
Util. fac. [α] Port A.1 to B.1 (scen. A; scen. B)	0.80 0.80	0.80 0.80	0.80 0.80	0.80 0.80	0.80 0.80	0.80 0.80	0.80 0.60	0.80 0.60	0.80 0.60
Util. fac. [α] Port A.2 to B.2 (scen. A; scen. B)	0.00 0.00	0.00 0.00	0.00 0.00	0.00 0.00	0.00 0.00	0.00 0.00	0.40 0.32	0.40 0.32	0.40 0.32
P.S. port A.1 to B.1 scenario A	48118	65245	153713	89523	125481	247140	3721	5321	10824
P.S. port A.2 to B.2 scenario A	-	-	-	-	-	-	1860	2660	5412
P.S. port A.1 to B.1 scenario B	48118	65245	153713	89523	125481	247140	2791	3991	8118
P.S. port A.2 to B.2 scenario B	-	-	-	-	-	-	1488	2128	4330
<b>Freight Rate (F.R.), 1.1-1.6: [\$/tonne], and 1.7-1.9: [\$/TEU] (based on own freight rate model)</b>									
F.R. A.1 to B.1 scenario A	16.5	36.7	23.8	5.7	24.7	21.7	115.5	282.3	429.1
F.R. A.2 to B.2 scenario A	-	-	-	-	-	-	105.9	258.8	393.4
F.R. A.1 to B.1 scenario B	13.1	29.1	18.8	4.5	19.6	17.2	110.5	284.0	435.5
F.R. A.2 to B.2 scenario B	-	-	-	-	-	-	98.9	254.1	389.7
1) Clarksons SIN database 2) Source: <a href="https://sea-distances.org/">https://sea-distances.org/</a> 3-11: Distance based on real voyage distance: 3) "Samarinda - Pipavav 50,000t Coal Supramax", 4) "Roberts Bank - Rotterdam 72,000t Coal Panamax", 5) "Banjarmasin - Rotterdam 166,000t Coal Capesize", 6) "Kozmino - Ulsan Aframax", 7) "Marsa El Hariga - Ningbo Suezmax", 8) "Bonaire - Singapore VLCC", 9) "SCFI Shanghai-E Japan (base port)", 10) "SCFI Shanghai-Persian Gulf (Dubai)", 11) "SCFI Shanghai-Europe (base port)". 12-16): Distance based on nearby port: 12) Mumbai instead of Pipavav, 17) Balikpapan instead of Banjarmasin, 13) Vladivostok instead of Kozmino and Busan instead of Ulsan, 14) Zhejiang, 15) Aruba instead of Bonaire, 16) Tokyo in Japan.									

## Capital costs

The average yearly capital costs ( $C_{capital}$ , [\\$]) include interest and depreciation. The average yearly capital costs are based on average values, between the period 2000 and 2018, of the new build price, scrap price, and the lifetime of the vessel (based on the average demolition age). Also, we account for a payback time of 18 years<sup>33</sup> and an interest rate of 4.5 [%]. We assume a linear depreciation over time. Based on the information above, the average yearly capital costs are calculated by dividing the sum of the yearly cumulative capital costs by the lifetime of the vessel, as can be seen in Table 3.5.

## Operating costs

The operating costs are based on average operating costs from Marsoft Inc. The operating costs (Table 3.5) include crew costs, stores and lubricants, maintenance, administration and insurance.

Table 3. 5 - Capital costs and operational costs

Segment	Dry Bulk			Crude			Container		
Sub segment	Handymax	Panamax	Capesize	Aframax	Suezmax	VLCC	Intermediate Containership	Intermediate Containership	Neo-Panamax
Ref. no.	1.1	1.2	1.3	1.4	1.5	1.6	1.7	1.8	1.9
<b>Capital costs</b>									
Avg. new build price [M\$] (yr. 2000 – 2018) <sup>1</sup>	Data removed due to copyright								
Demolition age [y]	25	25	25	25	25	25	25	25	25
Scrap price [\$] (10% of new build value)	Data removed due to copyright								
Financing [%]	65	65	65	65	65	65	65	65	65
Interest rate [%]	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5
Payback time [y]	18	18	18	18	18	18	18	18	18
Capital costs [M\$/y]	Data removed due to copyright								
<b>Operational costs</b>									
Operating costs [\$/d] <sup>2</sup>	Data removed due to copyright								
(1) Clarksons SIN database									
(2) Marsoft Inc.									

## Remaining voyage costs

The remaining voyage costs include port and cargo handling costs as well as pilot and tug service costs, see Table 3.6. The costs are given per roundtrip, meaning that it covers all costs entering and leaving port A and port B. The payable port dues are based on tariffs of the port of Rotterdam using the Gross Tonnage (GT) of the vessel and the amount of cargo that has to be loaded and unloaded. The pilot costs depends for a large extent on the draft of the vessel and the distance between the current location and the go to area. The tug costs depends on the amount of tugs that are needed and the duration of the operation. Suez and Panama Canal costs are calculated for ships travelling via these canals. The canal transit costs are partly based on the draft/loading condition of the vessel. See Table 3.6 for an overview of the aggregated costs per ship per roundtrip.

<sup>33</sup> Accelerated depreciation could have financial advantages in some cases. However, for this analysis, we only account for a payback time of 18 years using linear depreciation.

**Table 3. 6 - Remaining voyage costs**

Segment	Dry Bulk			Crude			Container		
Sub segment	Handymax	Panamax	Capesize	Aframax	Suezmax	VLCC	Intermediate Containership	Intermediate Containership	Neo-Panamax
Ref. no.	1.1	1.2	1.3	1.4	1.5	1.6	1.7	1.8	1.9
<b>Costs per roundtrip (sum of all costs entering and leaving port A and port B)</b>									
Gross Tonnage ship [GT] <sup>1</sup>	Removed due to copyright								
Sum of payable port dues [\$] <sup>2</sup>	65915	85252	195255	154794	203731	401763	94242	138151	280029
Sum of pilot costs [\$] <sup>3</sup>	17506	20268	27447	21192	25054	30582	17261	20268	21923
Sum of tug costs [\$] <sup>4</sup>	28000	30400	36000	30400	32800	37600	31200	33200	40800
Sum of canal costs [\$] <sup>5</sup>	-	430535	-	-	494434	-	-	-	1112948
(1) The average of 5 peer ships compared to the main dimensions (see Table 3.1) from the Clarksons SIN database (2) Based on port and cargo handling tariffs of the port of Rotterdam (Port of Rotterdam Authority, 2018) (3) (Loodswezen Rotterdam-Rijnmond, n.d.) (4) Raw estimates based on the length of the vessel, additional waiting time of the tug, number of tugs (Port of Rotterdam Authority, 2018) (5) (Wilhelmsen, (a)) & (Wilhelmsen, (b))									

### Service time, cargo handling time, and additional voyage time

We account for 350 service days ( $T_y$ ) per year leaving 14 off-days (i.e. for maintenance). We assume that the canal transit time ( $t_c$ ) is 6 hours; resulting in 0.5 days for a complete roundtrip. The turnaround time ( $t_t$ ) between loading and discharging is set at 9 hours; resulting in 0.75 days per roundtrip. Also, we account for extra time spent at sea and in port ( $t_e$ ) which is assumed to be 1 day in total for each round trip.

The cargo handling time for each vessel depends on the amount of cargo (scenario depend) and the (un)loading productivity of the cranes/piping infrastructure.

For the bulk carriers, cranes with an unloading capacity of 1800 (Liebherr, n.d.) and 1500 (E-Crane Floating Bulk Handling Terminals, 2009) Tonne coal per hour are found. The most conservative figure is used for the model, therefore, the unloading capacity per crane is set at 1500 Tonne per hour. Two cranes are used for the smallest bulk carrier (ship 1.1), two cranes for ship 1.2, and three cranes for ship 1.3. It is assumed that the loading capacity is higher due to conveyor belt systems. Therefore, the loading capacity is set at 2000 Tonne per hour. Two loaders are used for both ship 1.1 and ship 1.2, and three loaders for ship 1.3.

For the crude oil tankers, the unloading and loading capacity is greatly dependent on the amount of cargo pumps on board, the unloading capacity per pump, the length of the pipes to the shore, the pressure the pump can deliver, and of course the capacity the shore facility can receive. The ratio of pump capacity onboard ships compared to its cargo capacity differs to a great extent. Also, the discharging system arrangement differs a lot, some ships have multiple smaller pumps and others have less pumps but with a higher capacity (Tankers, n.d.). The unloading capacity per pump is set at 2000 Tonne per hour. Three pumps are used for the smallest crude tanker (ship 1.4), four pumps for ship 1.5, and six pumps for ship 1.6.

For container ships we assume that each crane can handle 30 containers per hour<sup>34</sup>. Due to the length of the ship, three cranes are used for the smallest containership (ship with reference number 1.7), five cranes are used for ship 1.8, and seven cranes for ship 1.9.

### Fuel consumption of the auxiliary engines and boilers

Auxiliary engines provide electricity on board for all the (technical) systems but also for the hotel. In addition, heavy bunker fuel needs to be kept warm with the use of boilers. Two other fuel consuming processes are: 1) cargo heating by crude oil tankers with the use of heating coils, and 2) cooling reefer containers on board of containerships. For this analysis, the additional fuel consumption for the processes described above are approximated for two conditions: 1) sailing/maneuvering, and 2) for being in port/waiting at sea. An average of five peer ships per ship type/case are used to determine the installed auxiliary engine power. Five assumptions are made to approximate the fuel consumption of the auxiliary engines: 1) two-thirds of the total installed auxiliary power is used at full load and one-third is installed as a backup, 2) 40 [%] of the power at full loading condition is used during sailing, 3) for the dry bulk carriers and containerships, 20 [%] of the power at full loading condition is used while being at port or waiting at sea, 4) for the oil tankers, due to the use of cargo pump systems and heating coils while discharging, 70 [%] of the power at full loading condition is used while being at port, and 5) all auxiliary engines use MGO as fuel with an Specific Fuel Oil Consumption of 227 [g/kWh] (IMO, 2015). The additional fuel consumption figures can be found in Table 3.7.

Table 3. 7 - Additional fuel consumption

Segment	Dry Bulk			Crude			Container		
	Handymax	Panamax	Capesize	Aframax	Suezmax	VLCC	Intermediate Containership	Intermediate Containership	Neo-Panamax
Ref. no.	1.1	1.2	1.3	1.4	1.5	1.6	1.7	1.8	1.9
<b>Additional fuel consumption, sum of auxiliary engines, boilers, and heating coils</b>									
Average installed auxiliary engine power [kW] <sup>1</sup>	Removed due to copyright								
Additional fuel consumption during sailing [Tonne/day]	2.9	3.5	3.8	3.9	4.7	5.0	10.3	14.4	20.5
Additional fuel consumption in port/idle/waiting at sea [Tonne/day]	1.4	1.7	1.9	6.9	8.3	8.8	5.2	7.2	10.3

1) Based on five peer ships with similar dimensions as the base case ship from step 1, source: Clarksons SIN Database

### Carbon Tax

Several studies take a variety of potential Carbon prices into account. Among others, Carbon prices which are mentioned are: 10, 20, 25, 30, 40, 50, and 200 [\$/Tonne CO<sub>2</sub>] (IMO, 2010) (Faber, Markowska, Eyring, Cionni, & Selstad, 2010) (Raucci, et al., 2017). In this study, we analyze the trend of the impact on profit, minimum cost, and voyage time for Carbon prices ranging from 1 up to 100 [\$/Tonne CO<sub>2</sub>]. If ships are compared among each other, we do so at the mid of this range, i.e. 50 [\$/Tonne CO<sub>2</sub>]. Note that no carbon price is currently in place for international shipping and that the price, if introduced, will be dependent on the design of the policy instrument and framework.

<sup>34</sup> "QCs are currently able to realize about 30-50 moves per hour in practice..." (Bartošek & Marek, 2013). The most conservative figure is used for the model.

However, the assumed carbon prices in this study do allow for a sensitivity analysis under a range of possible outcomes.





## 4. Results

This section provides the model results and analysis of all four steps of the methodology. As already discussed in the methodology, cargo price readjustments are not included in the model. Therefore, we classify the impact as: ‘first order impact’. However, the model allows for speed adjustments and determines the maximum profit (best combination between revenue and costs) for each Carbon Tax level and/or demand substitution level. Since we want to rank sub segments between each other according to the impact in step 1, we assume that the first order impact shows an adequate indication/trend of the severity/magnitude of the impact. The same yields for step 2 and 3 because we focus on the difference in impact between slightly different vessels within a competitive sub segment. First, the first order impact of Regulatory Risk across sub sectors will be discussed (step 1). Second, the effect of economies of scale/competitive position within a sub segment is tested (step 2). Third, the impact of technological adjustments (room to invest in efficiency improvements) is tested (step 3). Finally, we assess the impact of demand substitution to understand the financial impact of lower demand for cargo.

### 4.1. Step 1 – First order impact of Regulatory Risk across sub sectors

In step 1 we determine the first order impact of the average vessel of each sub segment. Cargo price readjustments are not included in the model. Therefore, we classify the impact as: ‘first order impact’. However, the model allows for speed adjustments and determines the maximum profit (best combination between revenue and costs) for each Carbon Tax level and/or demand substitution level.

First, the results of the minimum cost assessment will be addressed. Subsequently, we will address the results of the maximum profit assessment for both the average economic condition (scenario A), and the recession scenario (scenario B).

#### 4.1.1. Minimum cost assessment

The first order impact on minimum transport costs is significant for almost all ship types. The minimum cost analysis shows that the minimum transport costs will rise with an average of around 13.5 [%] (low: 4.9 [%], high: 20.8 [%]) due to a Carbon Tax of 50 [\$/Tonne CO<sub>2</sub>], see Figure 4.1 subplot 1. The impact is the highest for ship/case 1.8 and 1.9 (medium and large container ships), followed by ship/case 1.3 (large bulk carrier), and ship/case 1.6 (large crude tanker). The impact on ship/case 1.4 (small crude tanker) is relatively low due to the relative short voyage distance.

As already been explained in the methodology section, all ships do have minimum and maximum speed limits due to their technical specifications. To minimize transport costs, the containerships, the largest bulk carrier (ship/case 1.3), and the largest VLCC crude carrier (ship/case 1.6) already sail at minimum speed. Therefore, voyage time remains the same when subjected to a Carbon Tax (see Figure 4.1 subplot 2) because these ships cannot sail slower. For the small and medium bulk carriers (ship/case 1.1 and 1.2) and small and medium crude tankers (ship/case 1.4 and 1.5), we observe a

reduction of voyage time of respectively: 4.8 [%], 3.6 [%], 1.3 [%], and 1.2 [%] before reaching the minimum speed limit<sup>35</sup>.

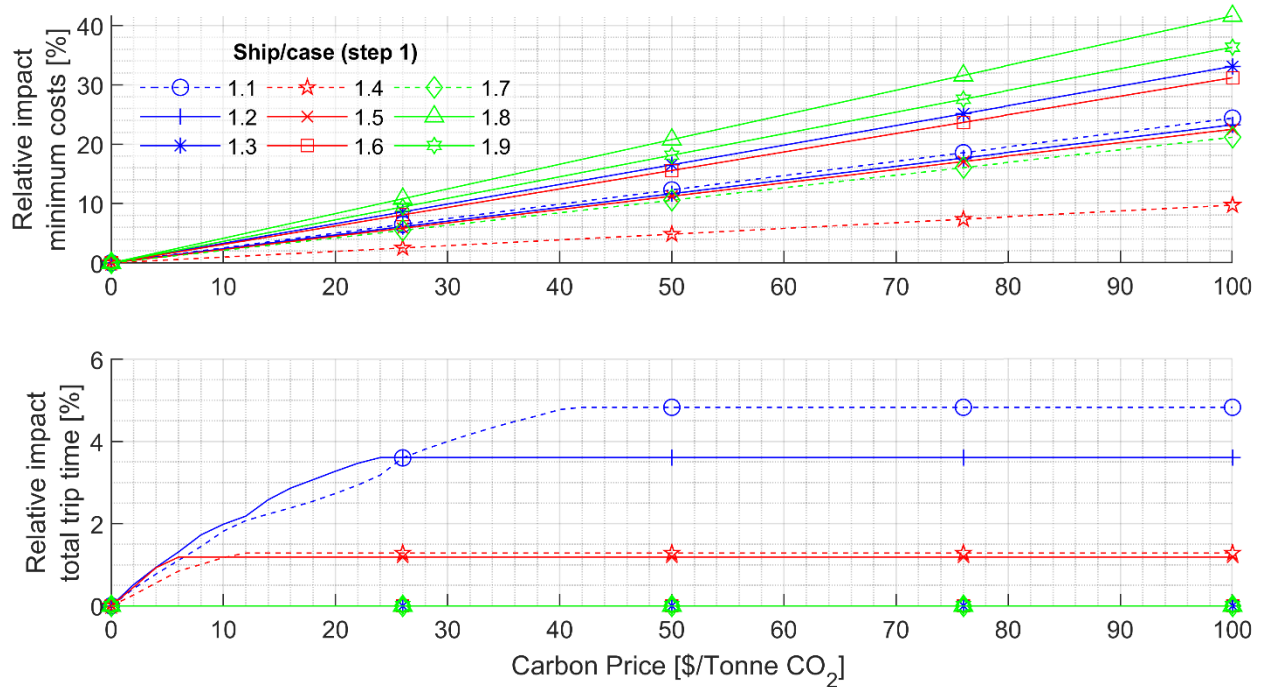


Figure 4. 1 - Step 1, scenario A, minimum cost assessment

#### 4.1.2. Maximum profit assessment - scenario A

The first order impact of a Carbon Tax is significant for all ship types. The average impact in percent of a Carbon Tax of 50 [\$/Tonne CO<sub>2</sub>] is around -74.6 [%] on maximum profit given a simulated (positive) economic condition ('willingness to pay' factor of 1.2), see Figure 4.2 subplot 2. More in detail, the average impact on maximum profit for the three bulk carriers (ship/case 1.1, 1.2, and 1.3) is respectively: -64.7 [%], -61.7 [%], and -82.9 [%], for the crude tankers (ship/case 1.4, 1.5, and 1.6) respectively: -27.9 [%], -59.2 [%], and -78.4 [%], and for the container ships (ship/case 1.7, 1.8, 1.9) respectively: -63.3 [%], -124.7 [%], and -108.8 [%]. The results indicate that the large containerships, tankers, and bulk carriers are the most susceptible to a Carbon Tax. The main reason is that these vessels have a high share of fuel costs on total costs/revenue (around the 50 [%] on total costs), as can be seen in Table 4.1. This is driven by 3 factors, namely: relatively longer voyage distances, travelling speed, and additional fuel consumption. Another way to express the sensitivity/impact of a Carbon Tax is to determine the Carbon price at the ships financial break-even point. The results show relatively low break-even Carbon prices for the ships which have a high share of fuel costs on total costs/revenue, as can be seen in Table 4.1.

Given the input variables for this economic scenario; the modelled containerships already sail at their minimum speed and cannot mitigate the financial impact by reducing speed. Therefore, the results show that there is no impact of a Carbon Tax on voyage time because the modelled containerships cannot sail slower, as can be seen in Figure 4.2 subplot 3. Containerships able to sail

<sup>35</sup> In some cases, the impact on voyage time would be higher when the ships were able to reach lower speeds.

slower than the modelled ships in this analysis may be in favor. For the bulk carriers and crude tankers, the average impact on voyage time due to a Carbon Tax of 50 [\$ /Tonne CO<sub>2</sub>] is around the 9.0 [%] (low: 5.5 [%], high: 12.4 [%]).

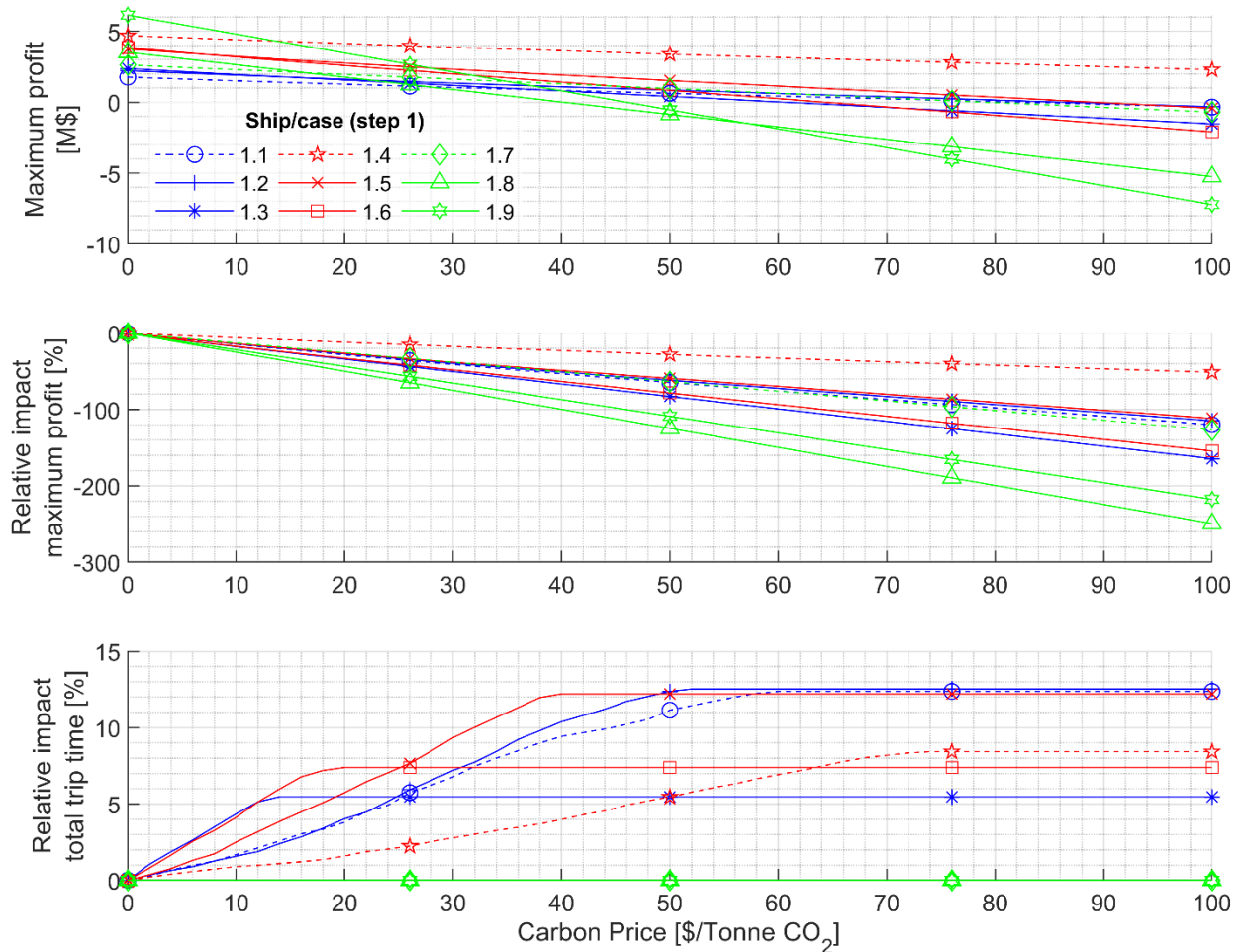


Figure 4. 2 - Step 1, scenario A, maximum profit assessment<sup>36</sup>

<sup>36</sup> Given the input variables for this average economic scenario (scenario 1 out of 2); the containerships already sail at their minimum speed and cannot mitigate the financial impact by reducing speed. Containerships which are able to sail slower than the modelled ships may be in favor.

**Table 4. 1 - Financial figures of Step 1, scenario A, maximum profit assessment**

Segment	Dry Bulk			Crude			Container		
	Handymax	Panamax	Capesize	Aframax	Suezmax	VLCC	Intermediate Containership	Intermediate Containership	Neo-Panamax
Ref. no.	1.1	1.2	1.3	1.4	1.5	1.6	1.7	1.8	1.9
<b>Scenario A maximum profit assessment</b>									
<b>Carbon Tax break-even point [\$/Tonne CO<sub>2</sub>]</b>	82	86	61	207	89	64	79	40	46
<b>Yearly costs [M\$]<sup>2</sup>:</b>									
at 0 [\$/Tonne CO <sub>2</sub> ]	9.10	11.49	12.41	24.17	19.70	20.33	15.73	21.08	36.81
at 50 [\$/Tonne CO <sub>2</sub> ]	9.15	11.35	13.60	23.98	19.36	21.69	17.39	25.46	43.49
<b>Yearly fuel costs [M\$]<sup>2</sup>:</b>									
at 0 [\$/Tonne CO <sub>2</sub> ]	3.30	3.98	5.53	3.73	6.63	8.72	4.55	11.41	17.32
at 50 [\$/Tonne CO <sub>2</sub> ]	3.57	4.23	6.80	4.30	6.96	10.25	6.21	15.79	23.99
<b>Yearly revenue [M\$]:</b>									
at 0 [\$/Tonne CO <sub>2</sub> ]	10.86	13.70	14.77	28.86	23.44	24.19	18.35	24.59	42.95
at 50 [\$/Tonne CO <sub>2</sub> ]	9.77	12.19	14.01	27.37	20.89	22.52	18.35	24.59	42.95
<b>Yearly profit [M\$]:</b>									
at 0 [\$/Tonne CO <sub>2</sub> ]	1.76	2.21	2.37	4.69	3.74	3.85	2.62	3.51	6.14
at 50 [\$/Tonne CO <sub>2</sub> ]	0.62	0.85	0.41	3.38	1.53	0.83	0.96	-0.87	-0.54
<b>Fuel costs plus Carbon costs on total costs ratio [-]<sup>1</sup>:</b>									
at 0 [\$/Tonne CO <sub>2</sub> ]	0.36	0.35	0.45	0.15	0.34	0.43	0.29	0.54	0.47
at 50 [\$/Tonne CO <sub>2</sub> ]	0.39	0.37	0.50	0.18	0.36	0.47	0.36	0.62	0.55
<p>1) Note that both denominator (total costs including Carbon costs) and numerator (due to Carbon costs) increase when a Carbon Tax is applied.</p> <p>2) Note that the total yearly costs, including the yearly fuel costs, are higher for the container ships (ref. no.: 1.7 – 1.9) under scenario B compared to scenario A. Given the simulated economic circumstances, the containerships already sail at their lowest speed without a Carbon Tax to maximize profit and/or minimize losses. However, under scenario B (recession) the ships transport less containers per voyage resulting in less cargo handling time. Therefore, the costs are higher because these ships spent more time sailing at sea resulting in a fraction more roundtrips per year.</p>									

### 4.1.3. Maximum profit assessment - scenario B

The simulated recession scenario, scenario B ('willingness to pay' factor of 0.95), shows large losses. Because all ships are already subjected to losses under BAU, the Carbon Tax increases the need for larger cash reserves to survive economic downtimes. To illustrate the sensitivity/impact of a Carbon Tax the Carbon price at the ships financial laid-up point is determined. The laid-up point is defined as the point is the point when the revenue does not weigh up to the costs of operating the ship, less losses are made if the ship is out of service (usually anchored or moored). For this analysis, if the losses are higher than the yearly capital costs (see Table 3.5) multiplied with a factor 1.1 (to account for a couple of technicians, berth place, and overhead costs) the ship will be laid-up. Keep in mind that we determine the average impact on the sub segment in this step. It is likely that due to the demand for transport the cargo transport prices rise to make it attractive for shipowners to ship the goods. Nevertheless, the Carbon price at the ships financial laid-up point without transport price readjustments illustrate the relative sensitivity/impact of a Carbon Tax. For the containerships (ship/case 1.7, 1.8, and 1.9), the losses due to the first order impact of a Carbon Tax of 50 [\$/Tonne CO<sub>2</sub>] are higher than just the capital costs alone. For reference, the losses increase from -1.4 [M\$] to -3.2 [M\$] for ship 1.7, -1.8 [M\$] to -6.3 [M\$] for ship 1.8, and -3.2 [M\$] to -10.0 [M\$] for ship 1.9, where the yearly capital costs are respectively: 2.9 [M\$], 4.0 [M\$], and 6.4 [M\$]. In such cases,

shipowners can lay up their vessels to limit losses or it is likely that the impact may (partly) be priced through to the customer. For all modelled ships/cases, the proxy of the Carbon Tax laid-up price point, which is the Carbon Tax level where the revenue does not weigh up to the costs of operating the ship, can be found in Table 4.2.

Even without a Carbon Tax, most ships sail at their minimum technical speed limit (model assumptions) to minimize losses, except for the small and medium bulk carriers (ship/case 1.1 and 1.2). Therefore, for most ships, there is no impact of a Carbon Tax on voyage time because these ships cannot sail slower, as can be seen in Figure 4.3 subplot 2.

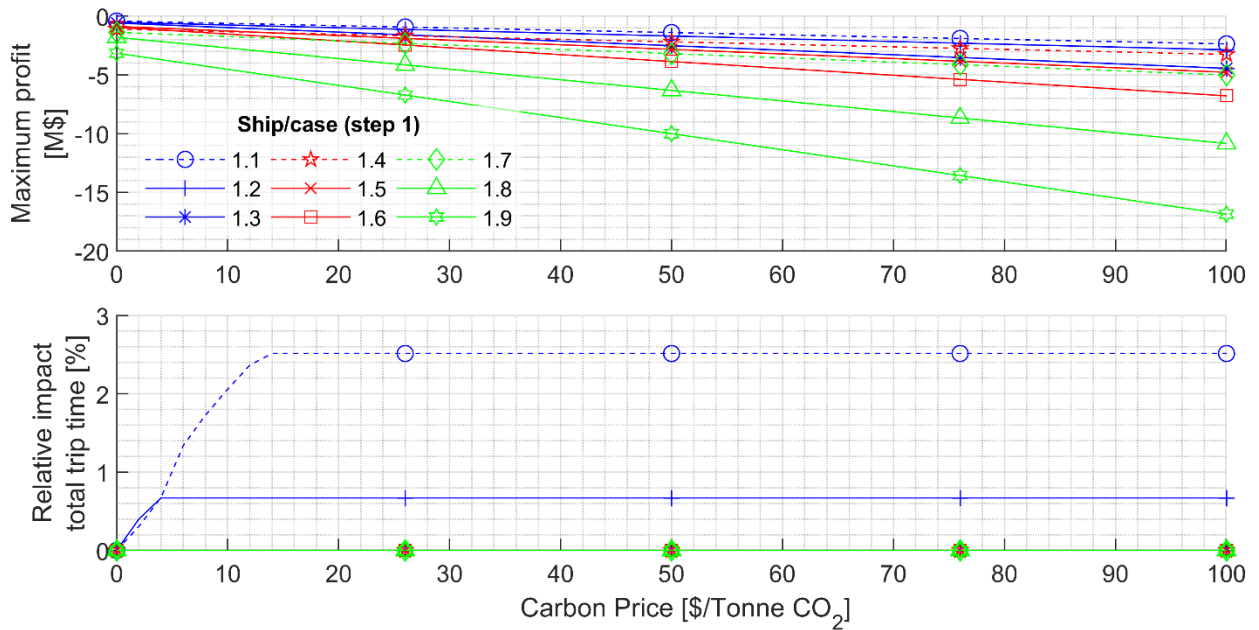


Figure 4.3 - Step 1, scenario B, maximum profit assessment

**Table 4. 2 - Financial figures of Step 1, scenario B, maximum profit assessment**

Segment	Dry Bulk			Crude			Container		
Sub segment	Handymax	Panamax	Capesize	Aframax	Suezmax	VLCC	Intermediate Containership	Intermediate Containership	Neo-Panamax
Ref. no.	1.1	1.2	1.3	1.4	1.5	1.6	1.7	1.8	1.9
<b>Scenario B maximum profit assessment</b>									
<b>Proxy of Carbon Tax laid-up price point [\$ /Tonne CO<sub>2</sub>]</b>	63	58	68	92	73	84	50	29	28
<b>Yearly costs [M\$]:</b>									
at 0 [\$ /Tonne CO <sub>2</sub> ]	8.26	10.22	11.67	22.23	17.41	18.77	16.21	21.24	37.20
at 50 [\$ /Tonne CO <sub>2</sub> ]	9.04	11.33	13.60	23.30	19.36	21.69	18.02	25.76	44.05
<b>Yearly fuel costs [M\$]:</b>									
at 0 [\$ /Tonne CO <sub>2</sub> ]	2.65	3.09	4.87	2.88	5.01	7.33	4.94	11.75	17.74
at 50 [\$ /Tonne CO <sub>2</sub> ]	3.48	4.22	6.80	3.95	6.96	10.25	6.76	16.27	24.59
<b>Yearly revenue [M\$]:</b>									
at 0 [\$ /Tonne CO <sub>2</sub> ]	7.84	9.71	11.09	21.12	16.54	17.83	14.83	19.44	34.04
at 50 [\$ /Tonne CO <sub>2</sub> ]	7.65	9.64	11.09	21.12	16.54	17.83	14.83	19.44	34.04
<b>Yearly profit [M\$]:</b>									
at 0 [\$ /Tonne CO <sub>2</sub> ]	-0.42	-0.52	-0.58	-1.11	-0.87	-0.94	-1.37	-1.80	-3.15
at 50 [\$ /Tonne CO <sub>2</sub> ]	-1.39	-1.69	-2.51	-2.18	-2.83	-3.86	-3.19	-6.32	-10.00
<b>Fuel costs plus Carbon costs on total costs ratio [-]<sup>1</sup>:</b>									
at 0 [\$ /Tonne CO <sub>2</sub> ]	0.32	0.30	0.42	0.13	0.29	0.39	0.31	0.55	0.48
at 50 [\$ /Tonne CO <sub>2</sub> ]	0.39	0.37	0.50	0.17	0.36	0.47	0.38	0.63	0.56
1) Note that both denominator (total costs including Carbon costs) and numerator (due to Carbon costs) increase when a Carbon Tax is applied.									

#### 4.1.4. Sensitivity analysis

In this section we test the sensitivity of the model output (step 1) of the maximum profit assessments to changes in fuel price, capital costs, and installed power/design speed. The share of fuel costs can be as high as approximately 50 [%] of the total costs (see Table 4.1 and Table 4.2). Due to the large share of fuel costs on total costs; small changes in fuel price can affect the outcome of the model. In addition, fuel prices are highly volatile over time. Newbuild costs fluctuate significantly over time affecting the level of yearly capital costs. Therefore, the sensitivity of the yearly capital costs will be tested. Installed power/design speed can differ between ships with the same size due to design choices. Therefore, the sensitivity of the design speed of the ship will be tested<sup>37</sup>. When the design speed is changed in the model, it will affect the fuel consumption speed relation as well as the minimum and maximum speed. The outcome of the analysis will not only show the sensitivity of the parameters but also the competitive (dis)advantage of such a design choice.

The selected parameters will be adjusted with plus and minus 25 [%], see Table 4.3 for the tested parameter values. Fuel prices and new build prices fluctuate significantly over time and it is not uncommon that the price levels fluctuate with 25 [%] from the average levels over the selected time period (2000 – 2018). Therefore, it is worthwhile to test the impact of such fluctuations on the model outcome. The design speed of the ship will also be varied with 25 [%] because: 1) such variations do exist, and 2) in order to compare the sensitivity of the selected parameters.

<sup>37</sup> The installed main engine power changes accordingly but capital costs keep unchanged.

Different sensitivity indicators are used for scenario A and scenario B. The Carbon Tax price [\$/Tonne CO<sub>2</sub>] at which the total cost and total revenue are equal (break-even point) will be compared among the different sensitivity cases in scenario A. For scenario B, we use the Carbon Tax price [\$/Tonne CO<sub>2</sub>] at which the revenue does not weigh up to the costs of operating the ship, and thus when less losses are made if the ship is out of service (usually anchored or moored).

**Table 4. 3 - Selected sensitivity parameters**

Segment	Dry Bulk			Crude			Container		
Sub segment	Handymax	Panamax	Capesize	Aframax	Suezmax	VLCC	Intermediate Containership	Intermediate Containership	Neo-Panamax
Ref. no.	1.1	1.2	1.3	1.4	1.5	1.6	1.7	1.8	1.9
<b>Values for sensitivity analysis</b>									
<b>Fuel price HFO/MGO [\$]:</b>									
-25 [%]	277.5 (HFO)/438.0 (MGO)								
Base case	370.0 (HFO)/584.0 (MGO)								
+25 [%]	462.5 (HFO)/730.0 (MGO)								
<b>Capital costs [M\$/y]:</b>									
-25 [%]	1.1	1.3	2.2	2.1	2.6	4.0	2.2	3.0	4.8
Base case	1.5	1.7	2.9	2.8	3.4	5.3	2.9	4.0	6.4
+25 [%]	1.9	2.1	3.6	3.5	4.3	6.6	3.6	5.0	8.0
<b>Design speed [kn]:</b>									
-25 [%]	10.1	10.1	10.1	10.1	10.1	10.1	15.0	16.1	16.5
Base case	13.5	13.5	13.5	13.5	13.5	13.5	20.0	21.5	22.0
+25 [%]	16.9	16.9	16.9	16.9	16.9	16.9	25.0	26.9	27.5

As an example, a physical representation of the sensitivity results for ship/case 1.1 under scenario A are presented in Figure 4.4. The figure shows the maximum profit value over a range of Carbon prices for all the different sensitivity cases. The value used for the sensitivity analysis can be found at the intersection between the maximum profit line and the break-even reference line. The ship with less installed main engine power due to a lower design speed is less profitable compared to the base case but becomes more profitable after a Carbon Tax of 50 [\$/Tonne CO<sub>2</sub>] under scenario A (see Figure 4.4) and 6 [\$/Tonne CO<sub>2</sub>] under scenario B (see Appendix B).



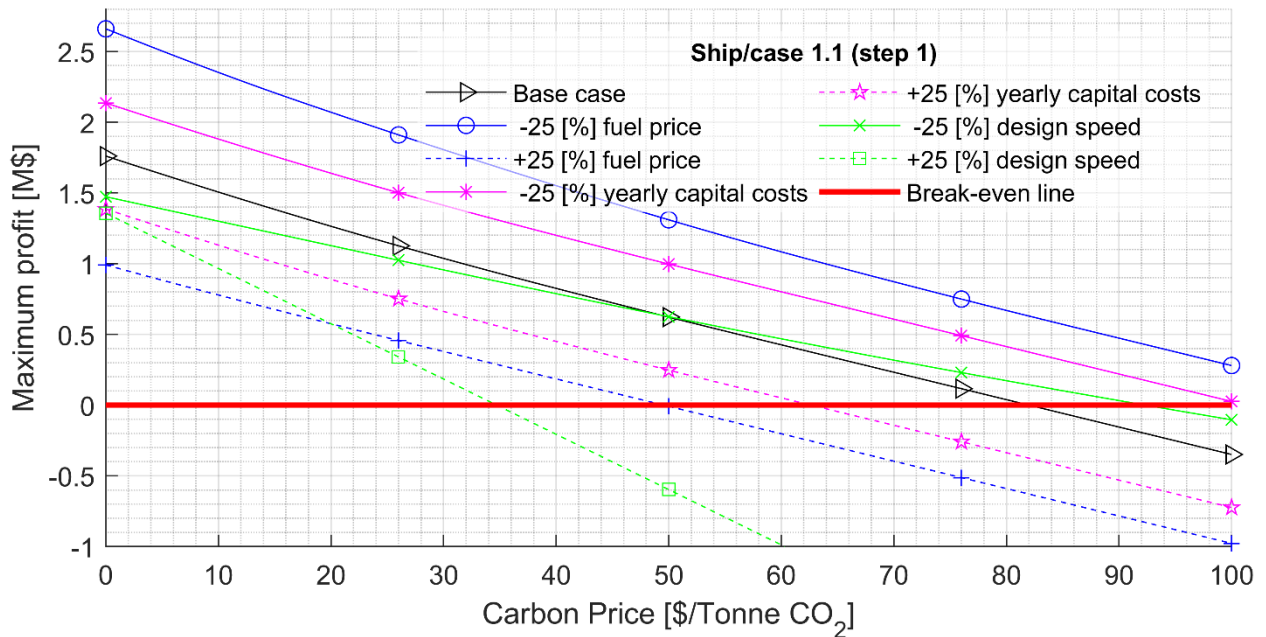


Figure 4. 4 - Sensitivity results for ship/case 1.1 under scenario A

The relative difference between the sensitivity indicator of the sensitivity case and the base case is used as proxy for the sensitivity, see Figure 4.5 for scenario A and Figure 4.6 for scenario B (for absolute values see Appendix A). As already is discussed earlier, we test the sensitivity of the model output (step 1) of the maximum profit assessments to changes in fuel price, capital costs, and installed power/design speed.

The sensitivity of the fuel price is higher for the ships/cases which have a high share of fuel costs on total costs (i.e. ship/case 1.3, 1.6, 1.8, and 1.9) and vice versa. The sensitivity due to changes in capital costs are significant but the least dominant compared to the other selected sensitivity parameters. The model output is more sensitive to upward changes of the design speed (installed main engine power) than to downward changes. Ships which are equipped with more installed main engine power are bounded by higher minimum and maximum speed limits. The results from step 1 show that the ships do not sail at their maximum speed under both scenarios, even without a Carbon Tax. The ship with the higher design speed/more installed power is less/not able to mitigate the Carbon Tax by reducing speed because it already operates in the ships lower speed region. Also, the sensitivity analysis shows that ships designed with a 25 [%] lower design speed (able to operate at lower speed due to less installed main engine power) compared to the base case are more resistant to high Carbon Taxes.

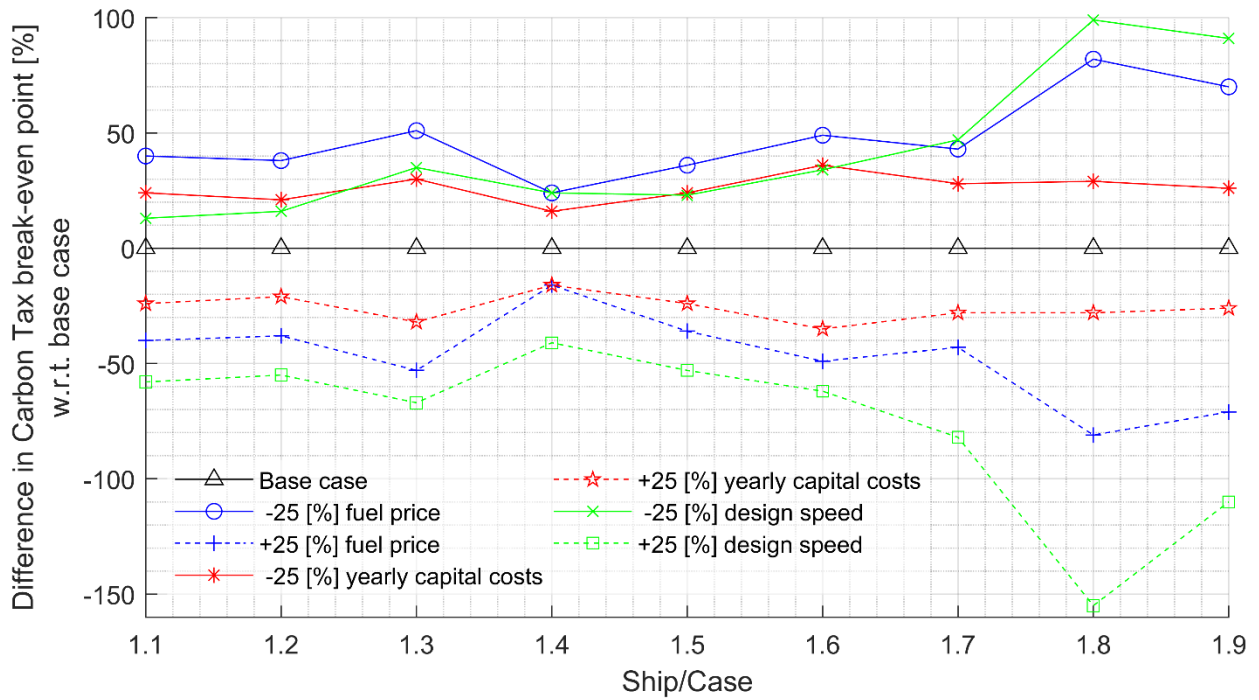


Figure 4.5 - Relative difference between the sensitivity indicator of the sensitivity case and the base case. Sensitivity indicator: the Carbon Tax price [\$/Tonne CO<sub>2</sub>] at which the total cost and total revenue are equal (break-even point).

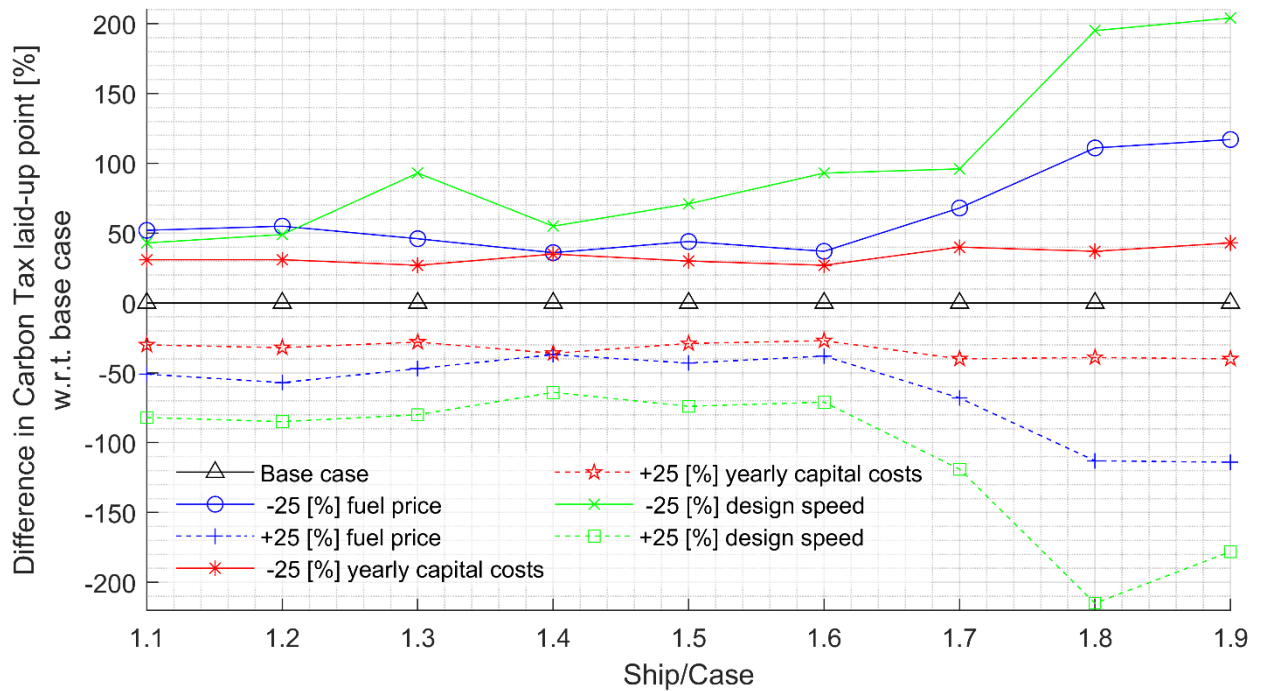


Figure 4.6 - Relative difference between the sensitivity indicator of the sensitivity case and the base case. Sensitivity indicator: the Carbon Tax price [\$/Tonne CO<sub>2</sub>] at which the revenue does not weigh up to the costs of operating the ship.

#### **4.1.5. Intermediate conclusion**

Step 1 of the assessment indicates that the first order impact of a Carbon Tax of 50 [\$/Tonne CO<sub>2</sub>] is significant for all sub segments. In addition, the impact increases with the Carbon Tax. The minimum cost assessment shows that transport costs rise with an average of at least 13.5 [%]. Scenario A of the maximum profit assessment shows that the impact on profit ranges between the -27.9 [%] and -124.7 [%]. Scenario B indicates that the first order impact of a Carbon Tax could result in laid-up to limit losses. However, it is possible that the impact can (partly) be priced through to the customer. The results indicate that large containerships, tankers, and bulk carriers are the most susceptible to a Carbon Tax due to a high share of fuel costs on total costs/revenue.

Overall, ship-owners will/want to lower their speed to maximize profits and reduce costs due to a Carbon Tax as is indicated by the increased voyage time in the model, see Figure 4.1 subplot 2, Figure 4.2 subplot 3, and Figure 4.3 subplot 2. In the short term, unused ships (overcapacity in supply) will/can be used which can improve the financial health of underperforming and unused vessels to a certain extent. Also, the demand and supply equilibrium will possibly change which can result in higher freight rates<sup>38</sup>, partly mitigating the first order impact. In the medium to long term, a Carbon Tax can cause an increase in demand for new build ships which are able to operate at lower speeds than their predecessors. In general, without price readjustments, the profitability of shipping assets will decrease which can result in a negative impact on asset value. However, step 1 on itself is not an accurate reflection of the impact of Carbon Risk. All four steps are needed to determine the level/magnitude of Carbon Risk.

#### **4.2. Step 2 – Effect on competitive position within the sub segment**

In this step, we verify whether the impact of a Carbon Tax is significantly different for ships 15 [%] larger and smaller than our base case ship. Ship/case 1.9 (large containership) will be used as base case for this step because the relative first order impact is the largest compared to the other ships/cases. Between the smaller and larger ships, the model accounts for differences in: cargo capacity, fuel consumption, port and canal costs, OPEX and CAPEX (for more details, see Appendix C). Note that, the ships in this step are subjected to the same route, cargo type, and cargo utilization rate (scenario dependent).

The minimum cost analysis shows that the larger ship (2.2) has the lowest transport cost per unit of cargo and the smaller ship the highest transport cost prices. Compared to the base case (1.9), we observe a small increase in costs for the smallest ship (2.1) and a small decrease of costs for the larger ship (2.2), see Figure 4.7 subplot 2.

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<sup>38</sup> In general, if fuel prices increase, ship-owners will/want to lower their speed to maximize profits and reduce costs. The reduction in voyage speed reduces the transport supply in the market. As a result, higher transport prices can be set due to relatively higher demand in the market.

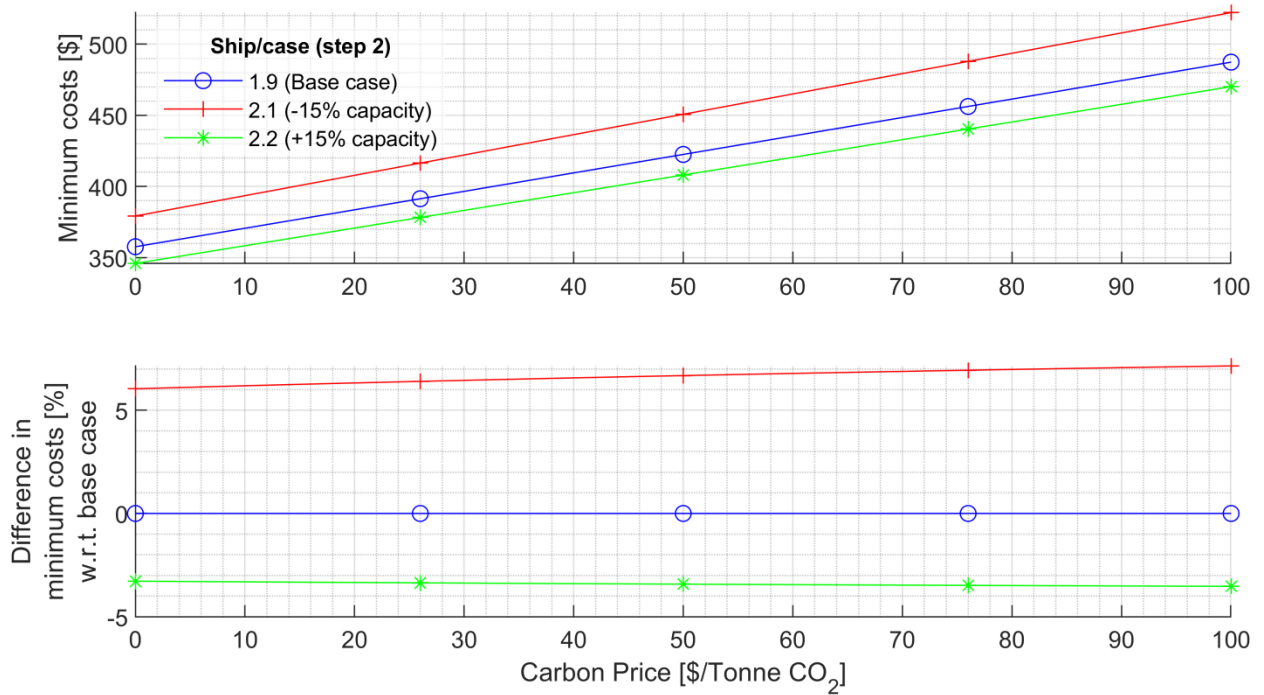


Figure 4. 7 - Step 2, scenario A, minimum cost assessment

Different than step 1, we assess ships within a competitive sub segment. For this step, the freight rates (which are used for scenario A and B) are determined using the freight rate model (see chapter 3.3.2.3) based on the base case ship (1.9). Given the same utilization rate of the ship's cargo capacity, scenario A shows that the largest ship can withstand higher Carbon Tax levels before making a loss, see Figure 4.8. Moreover, for scenario A, Carbon prices leading to the breakeven point are 26 [\$/Tonne CO<sub>2</sub>] for ship 2.1, 46 [\$/Tonne CO<sub>2</sub>] for ship 1.9, and 58 [\$/Tonne CO<sub>2</sub>] for ship 2.2.

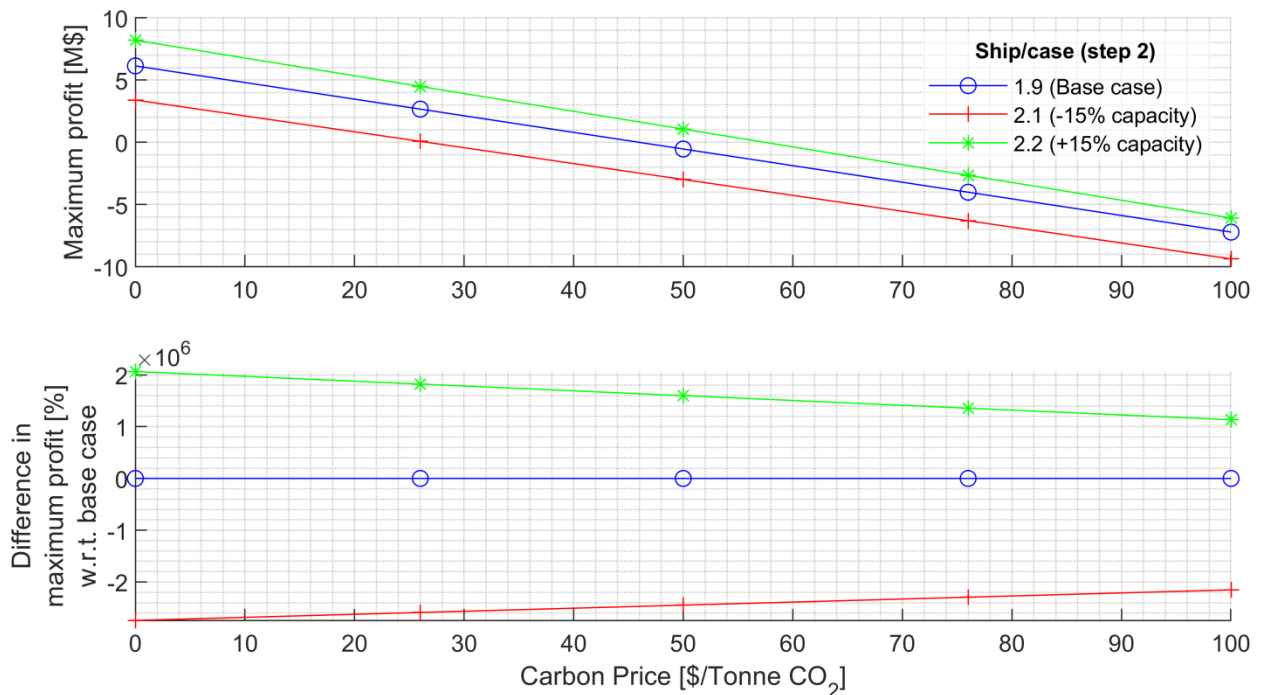


Figure 4. 8 - Step 2, scenario A, maximum profit assessment

The maximum profit assessment from scenario B (Figure 4.9) shows that the smaller ship makes significant higher losses and also reaches the critical laid up point sooner. Note that, at the end of the conceivable range of the Carbon Tax, losses are higher than losses under laid-up. However, the results show a clear trend in favor of the larger ship compared to the smaller competitors.

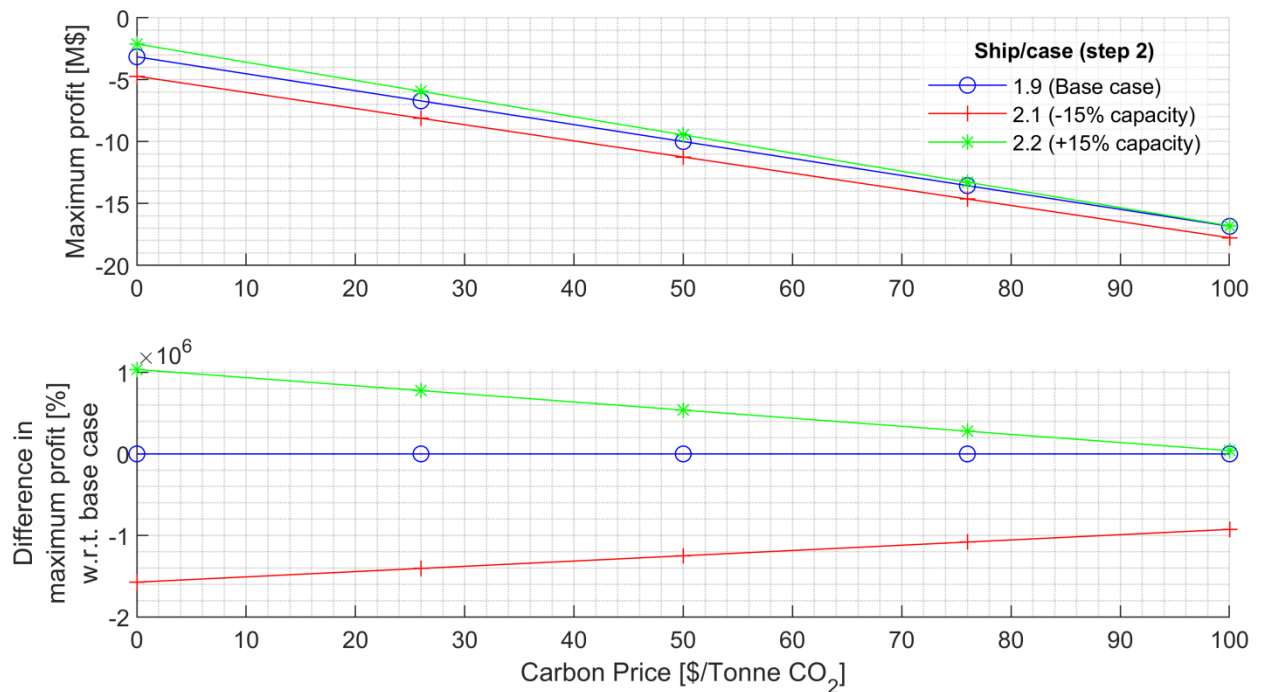


Figure 4.9 - Step 2, maximum profit assessment, scenario B

Step 1 showed that larger ships do have a higher first order impact (without price readjustments) than smaller ships. Step 1 results are only used as proxy for differences due to technical ship characteristics, market conditions, and route distances. However, step 2 showed that, within a competitive sub segment, larger ships have an advantage over smaller ships. The advantage of economies of scale results from lower transport costs compared to its smaller competitors due to a smaller increase in OPEX, CAPEX, and voyage costs compared to the increase of cargo capacity. The results show that the advantage of the two larger ships (2.2 and 1.9) is decreasing compared to the smaller ship as the Carbon Tax increases because costs are increasing disproportionate with respect to the revenue since all three ships already operate at minimum speed (consequences: fixed revenue and no possibility to mitigate the impact by reducing speed). However, if the impact of the Carbon Tax is (partly) priced through (resulting in higher freight rates and revenue levels), the advantage of larger ships is more stable. Also, it is possible that there will be a shift in the utilization of cargo capacity between the small, medium, and large ship which can either increase or decrease the advantage of economies of scale.

### 4.3. Step 3 – Impact of technological adjustments on Regulatory Risk

In this step, we determine to which extent energy efficient investments can act as a mitigate of Carbon Risk and/or to what extent such investments would be economically feasible. Ship/case 1.9 (large containership) will be used as base case for this step because the relative first order impact is the largest compared to the other ships/cases. By changing the operational efficiency upward, but keeping capital costs unchanged, we will calculate the discounted annual profit under the four predefined scenarios. The outcome will be compared with the original ship without the adjusted fuel efficiency (from step 1). As was observed in the maximum profit assessment from step 1, ship/case 1.9 sails at minimum speed under both scenario A and B. Therefore, the relative difference in profit/loss between the higher efficient sister ship and the base case ship is the same under both scenarios. For simplicity, we will only show the results of scenario A.

#### 4.3.1. Results

By adjusting efficiency related technical input parameters of our base case ship we have created a 10 [%] higher fuel-efficient sister ship, named: ship 1.9.1. The Specific Fuel Oil Consumption (SFOC) of the main engine is reduced by 10 [%] to simulate a more efficient main engine, less losses of the propeller and shaft, and/or a more fuel-efficient hull shape. The Specific Fuel Oil Consumption (SFOC) of the auxiliary engines is also reduced by 10 [%] to simulate efficiency improvements of the auxiliary engines and/or systems on board.

Even apart from a Carbon Tax, the results show a significant difference in yearly profit between the more efficient sister ship (ship 1.9.1) and the base case (ship 1.9), see Figure 4.10 subplot 1 and 2.

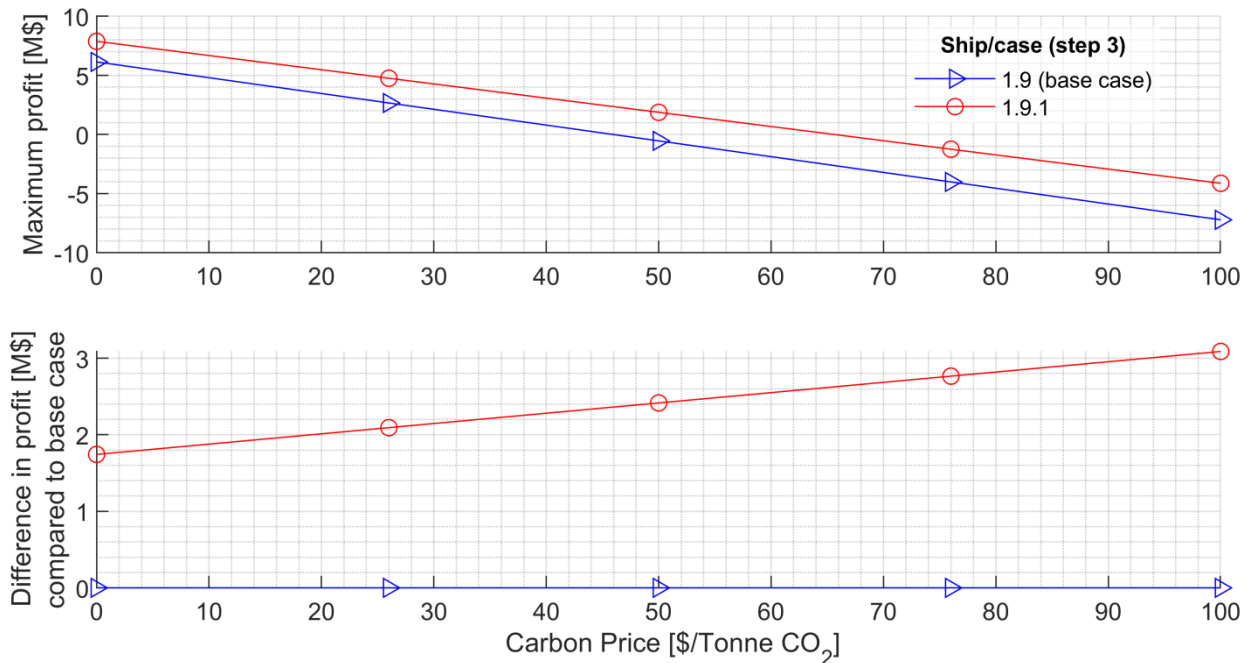


Figure 4. 10 - Step 3, efficiency improvements of ship 1.9 (base case), scenario A, maximum profit assessment

Given a 10-year investment horizon and a 10 [%] discount rate, a 10 [%] improvement in fuel economy of the ship results in a discounted cash flow (DCF) of 10.7 [M\$]. For reference, the new build price of ship 1.9 (Neo-Panamax containership) is 121 [M\$], hence a DCF of 10.7 [M\$] is 8.8 [%]



of the new build price. The DCF could be used for the actual investment to improve the fuel efficiency. See Table 4.4 for the DCF under other discount rates. Note that if the investment is larger than the DCF; the investment may not be economically feasible. The DCF of the fuel efficiency investment is positive related to a Carbon Tax: the higher the Carbon Tax, the larger the DCF (e.g. given a 10-year investment horizon, a 10 [%] discount rate, and a Carbon Tax of 50 [\$/Tonne CO<sub>2</sub>], the DCF becomes 14.9 [M\$] which is 39.1 [%] higher than without a Carbon Tax).

**Table 4. 4 - Discounted additional profit of ship 1.9.1 compared to 1.9 (base case) for several future points in time**

Carbon Tax [\$/Tonne CO <sub>2</sub> ]	Difference in yearly profit compared to base case [M\$]	Discount rate [%]	Discounted cash flow of added profit [M\$] due to a 10 [%] improvement in fuel efficiency							
			5 [y] <sup>1</sup>		10 [y] <sup>1</sup>		15 [y] <sup>1</sup>		20 [y] <sup>1</sup>	
			DCF [M\$]	Δ <sup>2</sup> [%]	DCF [M\$]	Δ <sup>2</sup> [%]	DCF [M\$]	Δ <sup>2</sup> [%]	DCF [M\$]	Δ <sup>2</sup> [%]
0	1.74	5	7.5	-	13.4	-	18.9	-	23.5	-
		10	6.6		10.7		14.5		17.5	
		15	5.8		8.7		11.7		13.9	
25	2.08	5	9.0	19.5	16.1	19.5	22.6	19.5	28.1	19.5
		10	7.9		12.8		17.4		20.9	
		15	7.0		10.4		13.9		16.7	
50	2.42	5	10.5	39.1	18.7	39.1	26.3	39.1	32.6	39.1
		10	9.2		14.9		20.2		24.3	
		15	8.1		12.1		16.2		19.4	
75	2.75	5	11.9	58.1	21.2	58.1	29.9	58.1	37.1	58.1
		10	10.4		16.9		22.9		27.6	
		15	9.2		13.8		18.4		22.0	

(1) Assumed time horizon of the investment  
(2) Increase of economic viability due to a Carbon Tax

### 4.3.2. Sensitivity analysis

Cost savings are positively related to the fuel price and the Carbon Tax. The extent of which energy efficient investments can act as a mitigate of Carbon Risk and/or to what extent such investments would be economically feasible are among others dependent on the fuel price. Therefore, we test the sensitivity of the model output (step 3) to changes of plus and minus 25 [%] in fuel price. For this analysis, we assume comparable economic conditions with respect to the base case meaning that freight rates will be adjusted accordingly using our developed freight rate model from section 3.3.2.5. To determine the sensitivity/main trend, it is not necessary to generate results for all discount rates.

The results show that the DCF of the fuel efficiency investment is positively related to the fuel price: the higher the fuel price, the larger the DCF (e.g. given a 10-year investment horizon, a 5 [%] discount rate, a Carbon Tax of 50 [\$/Tonne CO<sub>2</sub>], and 25 [%] higher fuel prices, the DCF becomes 22.0 [M\$] (see Table 4.5) which is 17.6 [%] higher than under normal fuel price conditions (see Table 4.4)). On the other hand, the share on total costs due to the Carbon Tax increases when the fuel prices decrease. Therefore, the relative added attractiveness (financial benefits) of fuel efficient investments due to a Carbon Tax increases when the fuel price decreases (e.g. given a 10-year investment horizon, a 5 [%] discount rate, a Carbon Tax of 50 [\$/Tonne CO<sub>2</sub>], and 25 [%] lower fuel prices, the DCF becomes 51.2 [%] higher compared to its conditions without a Carbon Tax (see Table 4.5) instead of only 39.1 [%] under normal fuel price conditions (see Table 4.4)).

**Table 4. 5 – Sensitivity analysis: discounted additional profit of ship 1.9.1 compared to 1.9 (base case) for several future points in time**

Carbon Tax [\$/Tonne CO <sub>2</sub> ]	Difference in yearly profit compared to base case [M\$]	Discount rate [%]	Discounted cash flow of added profit [M\$] due to a 10 [%] improvement in fuel efficiency							
			5 [y] <sup>1</sup>		10 [y] <sup>1</sup>		15 [y] <sup>1</sup>		20 [y] <sup>1</sup>	
			DCF [M\$]	Δ <sup>2</sup> [%]	DCF [M\$]	Δ <sup>2</sup> [%]	DCF [M\$]	Δ <sup>2</sup> [%]	DCF [M\$]	Δ <sup>2</sup> [%]
<b>Fuel price -25 [%] and adjusted freight rates to simulate comparable economic conditions</b>										
0	1.31	5	5.7	-	10.1	-	14.2	-	17.7	-
25	1.64	5	7.1	25.2	12.7	25.2	17.8	25.2	22.1	25.2
50	1.98	5	8.6	51.2	15.3	51.2	21.5	51.2	26.7	51.2
75	2.34	5	10.1	78.6	18.1	78.6	25.4	78.6	31.6	78.6
<b>Fuel price +25 [%] and adjusted freight rates to simulate comparable economic conditions</b>										
0	2.18	5	9.4	-	16.8	-	23.7	-	29.4	-
25	2.51	5	10.9	15.1	19.4	15.1	27.3	15.1	33.9	15.1
50	2.85	5	12.3	30.7	22.0	30.7	31.0	30.7	38.5	30.7
75	3.19	5	13.8	46.3	24.6	46.3	34.7	46.3	43.1	46.3
(1) Assumed time horizon of the investment										
(2) Increase of economic viability due to a Carbon Tax										

#### 4.4. Step 4 – Impact of Substitution Risk

In this step we assess the financial impact (no price readjustments) of 20 [%] demand substitution on maximum profit levels. For the (coal) dry bulk carriers and oil tankers, we simulate demand substitution by adding extra waiting time at sea ( $t_e$  [d]) before being assigned to a new voyage. The added waiting time is determined iteratively in order to achieve a drop of 20 [%] of yearly transported cargo. Due to the nature of container freight (time sensitive and/or perishable goods), container vessels have to remain scheduled frequency. Therefore, demand substitution is simulated by adjusting the cargo utilization rate of the vessel. The model only accounts for a fall in demand. We do not account for decreasing transport prices due to a disequilibrium of demand and supply (oversupply of demand) for ships.

##### 4.4.1. Results

The results show that containerships have the highest first order impact on maximum profit due to demand substitution, see Table 4.6. The higher impact for the containerships is partly due to the simulation method for demand substitution which is described above, see section 4.4.2. For all vessels, yearly revenue levels drop with 20 [%]. Dry bulk carriers and crude oil tankers have limited fuel consumption while waiting to be assigned to a new voyage, which is not the case for container ships because they have to remain scheduled frequency. Also, given the simulated economic scenarios, the container ships are not able to reduce fuel costs to maximize profit because they are already operating at their minimum technical speed limits. Containerships able to sail slower than the modelled ships are in favor.

However, the likelihood of demand substitution between the sub segments is not included. Therefore, the risk (impact and likelihood) could deviate from the impact trend that is observed by a 20 [%] fall in demand. For example, it is possible that the risk could turn out to be higher for (coal) dry bulk carriers or oil tankers if the demand of fossil fuels will drop quickly due to e.g. climate change regulation.



**Table 4. 6 - First order impact on maximum profit due to demand substitution**

Carbon Tax [\$ /Tonne CO <sub>2</sub> ]	Ship/case	Scenario A			Scenario B		
		BAU Max profit [M\$] (results from step 1)	Profit under demand substitution (step 4)		BAU Max profit [M\$] (results from step 1)	Profit under demand substitution (step 4)	
			Max Profit [M\$]	Δ <sup>2</sup> [%] w.r.t BAU		Max Profit [M\$]	Δ <sup>2</sup> [%] w.r.t BAU
0	1.1	1.76	0.87	-50.5	-0.42	-0.98	-135.6
	1.2	2.21	1.18	-46.7	-0.52	-1.19	-130.1
	1.3	2.37	1.24	-47.7	-0.58	-1.55	-165.4
	1.4	4.69	2.91	-37.9	-1.11	-2.03	-82.4
	1.5	3.74	2.10	-43.8	-0.87	-2.04	-134.2
	1.6	3.85	2.02	-47.6	-0.94	-2.49	-165.1
	1.7	2.62	-1.05	-140.0	-1.37	-4.34	-215.9
	1.8	3.51	-1.41	-140.0	-1.80	-5.67	-215.9
	1.9	6.14	-2.45	-140.0	-3.15	-9.96	-215.9
25	1.1		0.38	-78.4		-1.41	-237.6
	1.2		0.59	-73.4		-1.70	-228.0
	1.3		0.38	-83.9		-2.37	-306.0
	1.4		2.35	-49.8		-2.49	-124.1
	1.5		1.14	-69.4		-2.88	-230.0
	1.6		0.71	-81.5		-3.73	-297.3
	1.7		-1.88	-171.7		-5.25	-282.0
	1.8		-3.60	-202.3		-7.95	-341.3
	1.9		-5.79	-194.4		-1,3E+07	-324.5
50	1.1		-0.058	-103.3		-1.83	-339.6
	1.2		0.065	-97.1		-2.20	-325.9
	1.3		-0.47	-120.0		-3.19	-446.6
	1.4		1.86	-60.4		-2.96	-165.8
	1.5		0.28	-92.6		-3.71	-325.8
	1.6		-0.58	-115.1		-4.97	-429.4
	1.7		-2.71	-203.4		-6.16	-348.0
	1.8		-5.79	-264.7		-1E+07	-466.7
	1.9		-9.13	-248.8		-1.7E+07	-433.1

#### 4.4.2. Sensitivity analysis

The results of step 4 have shown that the containership cases have a significant higher first order impact on maximum profit due to demand substitution. However, the impact of the containership cases is significantly lower if the same modelling method as for the bulk carriers and oil tankers is used to simulate demand substitution, see Table 4.7. For example, for ship/case 1.9, the impact on profit under demand substitution is -140 [%] with respect to BAU compared to ‘only’ -55 [%] if Demand Substitution is simulated by adding extra wait time before being assigned to a new voyage such as for bulk carriers and oil tankers. The impact difference comes due to fuel costs savings if ships are able to wait till they are fully loaded. But also due to port, tug, and pilot cost savings. The implication of the above is that it matters for ship owners how they (can) respond to Demand Substitution. If shipowners of containerships are able to allow for longer wait times in port or at sea, they may be able to mitigate the financial impact to a large extent. On the other hand, if shipowners of containerships are not able to allow for longer wait times in port or at sea (due to the nature of the liner service), smaller vessels within the sub segment may be in favor.

**Table 4. 7 – Sensitivity analysis: impact difference due to Demand Substitution simulation method**

Carbon Tax [\$/Tonne CO <sub>2</sub> ]	Ship/case	Scenario A			Scenario B		
		BAU Max profit [M\$] (results from step 1)	Profit under demand substitution (step 4)		BAU Max profit [M\$] (results from step 1)	Profit under demand substitution (step 4)	
			Max Profit [M\$]	$\Delta^2$ [%] w.r.t BAU		Max Profit [M\$]	$\Delta^2$ [%] w.r.t BAU
<b>Method: adjusted cargo utilization rate</b>							
0	1.7	2.62	-1.05	-140.0	-1.37	-4.34	-215.9
	1.8	3.51	-1.41	-140.0	-1.80	-5.67	-215.9
	1.9	6.14	-2.45	-140.0	-3.15	-9.96	-215.9
<b>Method: added waiting time at sea before being assigned to a new voyage</b>							
0	1.7	(see above)	0.90	-65.55	(see above)	-2.43	-76.58
	1.8		1.28	-63.48		-3.15	-74.67
	1.9		2.77	-54.88		-4.97	-57.68



## 5. Conclusion and recommendations

The shipping industry accounts for a significant share in global GHG emissions<sup>39</sup>. Especially since Business as Usual (BaU) scenario studies project that the emissions due to shipping could increase by 50 [%] to 250 [%] in the period to 2050 (IMO, 2015), shipowners face a potential regulatory threat. Major climate regulations for shipping already entered into force, and a range of possible instruments may be applied going forward. Possible instruments are among others, tightened EEDI limits, port discounts, ETS, or a Carbon Tax. Besides the risk of direct regulation, there is also a risk of being indirectly impacted by energy and/or climate regulation in other sectors. The direct and indirect regulations can adversely impact the operations, cashflow, and economic value of enterprises of existing shipowners and charterers of ships. Shipowners and financiers that are unaware of these developments, or that do not take timely mitigating actions, may potentially face considerable financial losses.

This research investigated and ranked the level of Carbon Risk for shipowners across several sub sectors. The objective of the research was to: define, measure, and reveal the level of Carbon Risk for shipowners and to assess mitigating strategies as part of the assessment of the bank's exposure to Carbon Risk. Typical core drivers, factors, and dependencies have been studied from literature in order to come up with an effective approach to capture the threat of Carbon Risk. As a result, a Carbon Risk framework is been developed, showing (inter)dependencies between all Carbon Risk factors. We found that Carbon Risk factors can be divided in two categories, namely: 1) Structural Risk, and 2) Event Driven Risk. Structural Risk targets all GHG intensive firms and/or value chains whereas Event Driven Risk can occur very sudden and/or can target specific firms. By developing the framework, this research contributed to the current understanding of the (inter)dependencies between Carbon Risk factors. In addition to the framework, typical Carbon Risks have been identified for the shipping industry.

Carbon Risk is a complex risk due to the many different risk factors and interdependencies. This research focuses on Structural Risk. A Carbon Tax is used as a proxy for Regulatory Risk and demand substitution (i.e. a 20 [%] reduction of cargo) is used as proxy for Substitution Risk. By distinguishing vessels by type and size, we account for different technical, operational, and market characteristics. We focus on crude oil tankers, container ships, and bulk carriers because they are the three most significant sectors from a CO<sub>2</sub> perspective (IMO, 2015). To cover the key drivers of Carbon Risk, as identified in the framework, the method is divided into four steps, with each step providing further information on the impact and mitigating actions available to a ship owner. In the first step, the first order impact of a Carbon Tax (Regulatory Risk) across 9 sub sectors is assessed. Then, in the second step, the effect of economies of scale on the competitive position within a sub segment is been determined. Subsequently, in step 3, technical adjustments to the ship are accounted for by estimating the added cash flow due to an improvement in fuel efficiency. The outcome of step 3 can be used to determine to what extent energy efficient investments can mitigate the impact of a

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<sup>39</sup> "For the period 2007–2012, on average, shipping accounted for approximately 3.1% of annual global CO<sub>2</sub> and approximately 2.8% of annual GHGs on a CO<sub>2</sub>e basis using 100-year global warming potential conversions from the IPCC Fifth Assessment Report (AR 5)." (IMO, 2015)

Carbon Tax and to which extent such investments would be economically feasible. At last, in step 4, the impact of 20 [%] demand substitution is investigated.

### **Impact of a Carbon Tax**

The first order financial impact<sup>40</sup> of a Carbon Tax of 50 [\$/Tonne CO<sub>2</sub>] is significant (for all cases). Note that other levels of the tax have also been tested, for which results are shown in the results section. However, assuming a Carbon Tax of 50 [\$/Tonne CO<sub>2</sub>], the minimum cost assessment shows that transport costs rise with an average of at least 13.5 [%]. In addition, the economical speed decreases due to a Carbon Tax. The maximum profit assessment shows that the first order impact on profit (without freight price readjustments) can range between the -27.9 [%] and -124.7 [%] (impacts lower than -100 [%] indicate ships no longer generate profit). The results indicate that the containerships, large tankers, and large bulk carriers are the most susceptible to a Carbon Tax. The main reason is that these vessels have a high share of fuel costs on total costs/revenue. This is driven by 3 factors, namely: travelling speed, additional fuel consumption, and relatively longer voyage distances. The higher the typical share of fuel costs (read: fuel consumption) of a particular sub segment/voyage the larger the impact on the modelled transport costs and profit. Mitigating the impact of a Carbon Tax by lowering the ship's speed will go at the expense of the ship's productivity.

For ships operating within a competitive sub segment (step 2 of the analysis), given an equal utilization rate of the available cargo capacity of the ship, larger ships have an advantage over smaller ships<sup>41</sup>. The main reason is that the larger ship has lower transport prices compared to its smaller competitors due to a smaller increase in OPEX, CAPEX, and voyage costs compared to the increase of cargo capacity.

In addition, within the sub segment, the financial impact of a Carbon Tax is the highest for the least fuel-efficient vessels (step 3 of the analysis). In general, fuel efficiency related investments have a significant positive impact, and the financial benefits of such adjustments increase substantially after the introduction of a Carbon Tax (e.g. for ship/case 1.9 (Neo Panamax containership), given the scenario variables, a 10-year investment horizon, a 10 [%] discount rate, and a Carbon Tax of 50 [\$/Tonne CO<sub>2</sub>], the DCF becomes 14.9 [M\$] which is 39.1 [%] higher than without a Carbon Tax). However, it needs to be investigated if the (extra) attractiveness of fuel-efficient measurements weighs up to the investment costs. In other words, it needs to be investigated what mitigation options are available and what the related CAPEX need and financing costs are. Note that if the investment is larger than the DCF; the investment may not be economically feasible. The availability of technical mitigation measures and corresponding investments costs may differ between ship types/sub segments. The availability of effective and economical viable mitigation measures can affect the level of Carbon Risk and the ranking between the sub segments.

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<sup>40</sup> Cargo price readjustments are not included in the model. Therefore, we classify the impact as: 'first order impact'. However, the model allows for speed adjustments and determines the maximum profit before interest and taxes (best combination between revenue and costs) for each Carbon Tax level and/or demand substitution level. For the maximum profit assessment, two economic scenarios are defined in order to determine key trends and Carbon Risk drivers to rank ships and sub segments accordingly. Note that the economic variables (i.e. willingness to pay) may differ in reality.

<sup>41</sup> Within a competitive sub segment, the larger ship is at a disadvantage when the parcel size is smaller than its own cargo carrying capacity.

### **Impact of demand substitution**

The financial impact of Demand Substitution is significant (for all cases). Containerships have the highest first order impact on maximum profit due to 20 [%] demand substitution. The sensitivity analysis showed that the impact is higher for containerships compared to bulk carriers and oil tankers due to the differences in nature of demand substitution (see section 4.4.2). The impact of the containership cases is significantly lower if the same modelling method as for the bulk carriers and oil tankers is used to simulate demand substitution. The implication of the above is that it matters for ship owners how they (can) respond to Demand Substitution. However, the likelihood of substitution demand is not included in the analysis and can differ between sectors. The scale of future demand substitution remains uncertain (see section 3.2.4). Therefore, it is possible that the risk (impact and likelihood) can be higher for (coal) dry bulk carriers and/or oil tankers if the demand of fossil fuels will drop quickly due to e.g. climate change regulation.

### **Managerial implications/recommendations**

This study has gone some way towards enhancing our understanding of Carbon Risk drivers, interdependencies, and the difference in impact between sub segments due to a Carbon Tax. The presented findings about the difference in impact between sub segments could have implications for risk premiums which financiers can set on loans. Also, given that the DCF of fuel-efficient investments is positive related to a Carbon Tax, it is assumed that fuel efficient technologies and retrofits become more viable. Even before regulatory certainty, it is advised that shipowners and financiers (as part of their Carbon Risk mitigation strategy) research fuel efficient mitigation options (technological investments) under different Carbon Tax levels. Even without Carbon pricing, efficiency measures generate significant cost savings. When there is certainty about future market-based measures, early adaptors/investors of viable fuel-efficient measures (under future regulatory conditions) will benefit most of the investment and improve their competitive position. Also, when shipowners act sooner than competitors, they lower the risk of scarcity of resources (yards, engineers).

### **Context of the conclusion**

Models are simplifications of reality, and therefore there are limitations to its explanatory power. All sub segments are subjected to comparable economic scenarios via our newly developed freight rate model. This enabled us to compare the relative impact between the sub segments and it also allowed us to find main drivers responsible for the impact. However, the current state between demand and supply of each of the sub segments is not included into the model. Neither, do we incorporate freight rate adjustments to mitigate the financial impact of Carbon Risk. If shipowners are able to pass-on a substantial part of the cost increase, the financial impact may be substantially below the levels we have estimated. Also, the model optimizes revenue and costs under the assumption that the ship is always able to pick up cargo at any time. The model does not account for losing a bid on a contract or temporarily unavailability of cargo for shipment at the given port. Driven by these factors, financial performance of ships may be worse than estimated here.

### **Future research**

Among others, adoption of regulatory instruments depends on the effectiveness and (side) effects. To determine the risk of Carbon Tax regulation, the effectiveness of such a measure should be determined. It is worthwhile to use our Carbon Risk framework to model the impact on GHG

emissions. However, we hypothesize that the GHG reduction potential of a Carbon Tax is limited. Three reasons why we think that the GHG reduction potential of a Carbon Tax is limited are: 1) shipowners do not sail at maximum speed given our used economic scenarios; resulting in a limited speed reduction potential, 2) fuel consumption due to increased voyage time needs to be taken into account, and 3) extra ships are needed to transport the same amount of goods<sup>42</sup>. However, the effect of a Carbon Tax on the uptake of fuel efficiency measures is not taken into account. It should be interesting to model the impact of the uptake of such measures and to determine the potential GHG savings. In addition, it is recommended to include the following into the model/analysis: 1) the current state between demand and supply of the different sub segments, and 2) the effect of market dynamics/forces such as transport price readjustments.

At the end, fuel efficiency becomes more important if a Carbon Tax comes into place. But also due to increased efficiency awareness driven by: 1) a negative view with respect to climate change by entities in the value chain, and 2) the potential of cost savings. Given the potential impact of Carbon Risk, risk assessment tools for maritime related investment firms become more and more important. Therefore, we encourage future research to develop accurate metrics reflecting the operational fuel efficiency of a ship in order to be able to compare and rank ships accordingly.

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<sup>42</sup> The full life cycle of the ship should be considered (i.e. extraction of raw materials, transport, assembly, operational life, and recycling).





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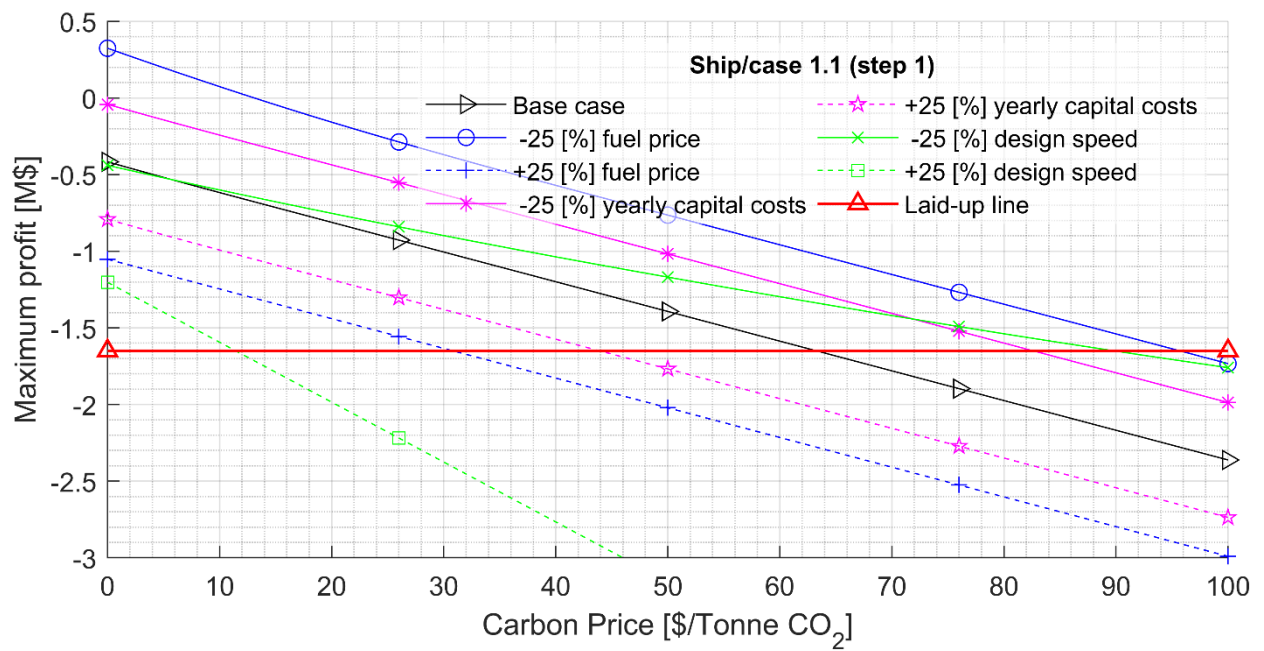
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## Appendix A – Step 1 sensitivity indicator values

Segment	Dry Bulk			Crude			Container		
Sub segment	Handymax	Panamax	Capesize	Aframax	Suezmax	VLCC	Intermediate Containership	Intermediate Containership	Neo-Panamax
Ref. no.	1.1	1.2	1.3	1.4	1.5	1.6	1.7	1.8	1.9
<b>Values for sensitivity analysis</b>									
<b>Fuel price HFO/MGO [\$]:</b>									
-25 [%]	277.5/438.0								
Base case	370.0/584.0								
+25 [%]	462.5/730.0								
<b>Capital costs [M\$/yr]:</b>									
-25 [%]	1.1	1.3	2.2	2.1	2.6	4.0	2.2	3.0	4.8
Base case	1.5	1.7	2.9	2.8	3.4	5.3	2.9	4.0	6.4
+25 [%]	1.9	2.1	3.6	3.5	4.3	6.6	3.6	5.0	8.0
<b>Design speed [kn]:</b>									
-25 [%]	10.1						15.0	16.1	16.5
Base case	13.5						20.0	21.5	22.0
+25 [%]	16.9						25.0	26.9	27.5
<b>Results sensitivity analysis maximum profit assessment under scenario A</b>									
	<b>Carbon Tax break-even point [\$/Tonne CO<sub>2</sub>]</b>								
Base case	82	86	61	207	89	64	79	40	46
Fuel price -25 [%]	114	119	92	257	121	96	113	73	78
Fuel price +25 [%]	50	54	29	173	57	33	45	8	14
Yearly capital costs -25 [%]	101	104	79	239	111	87	101	52	58
Yearly capital costs +25 [%]	63	68	42	174	67	42	57	29	34
Maximum speed -25 [%] (less installed main engine power)	92	100	83	256	110	86	116	80	88
Maximum speed +25 [%] (more installed main engine power)	35	38	20	123	42	24	15	-22	-5
<b>Results sensitivity analysis maximum profit assessment under scenario B</b>									
	<b>Proxy of Carbon Tax laid-up point [\$/Tonne CO<sub>2</sub>]</b>								
Base case	63	58	68	92	73	84	50	29	28
Fuel price -25 [%]	96	90	99	126	105	115	84	61	61
Fuel price +25 [%]	31	25	36	58	41	52	16	-4	-4
Yearly capital costs -25 [%]	(61) 83	(56) 76	(66) 86	(89) 125	(71) 95	(81) 106	(48) 70	(28) 40	(27) 40
Yearly capital costs +25 [%]	(65) 44	(59) 40	(69) 49	(95) 59	(76) 52	(86) 61	(52) 30	(30) 18	(30) 17
Maximum speed -25 [%] (less installed main engine power)	90	86	131	143	125	162	98	85	85
Maximum speed +25 [%] (more installed main engine power)	11	9	14	33	19	24	-10	-33	-22

## Appendix B – Step 1 sensitivity results for ship/case 1.1 under scenario A



## Appendix C – Step 2 ship specifications

Segment	Container		
Sub segment	Neo-Panamax		
Ref. no.	2.1	1.9	2.2
<b>Vessel dimensions and capacity</b>			
LOA [m] <sup>2</sup>	359.7	366.8	385.6
Draft [m] <sup>2</sup>	15.3	15.3	15.8
Breadth [m] <sup>2</sup>	45.8	49.6	52.7
Capacity [TEU] <sup>5</sup>	11557	13530	15340
GT <sup>4</sup>	Data removed due to copyright		
<b>Auxiliary fuel consumption</b>			
Auxiliary engine power [kW] <sup>4</sup>	Data removed due to copyright		
Fuel consumption during voyage [Tonne /d] <sup>3</sup>	18.0	20.5	23.9
Fuel consumption in port [Tonne /d] <sup>3</sup>	9.0	10.3	12.0
<b>Port and canal costs</b>			
Sum of payable port dues [\$]	243704	280029	320512
Sum of pilot costs [\$]	21923	21923	22841
Sum of tug costs [\$]	40800	40800	40800
Sum of canal costs [\$]	918889	1112948	1209646
<b>OPEX and CAPAX</b>			
OPEX [\$ /dy] <sup>1</sup>	Data removed due to copyright		
CAPEX [M\$/y] <sup>6</sup>	Data removed due to copyright		
(1) Marsoft reference OPEX (2) Based on peer group analysis Clarksons (3) SFOC of 227 [g/kWh], (2/3) of installed power used and (1/3) as backup, utilization factor voyage and port respectively: 0.4 and 0.2 (4) Based on 5 peer ships (5) 12420 TEU (-15.0%), 15560 TEU (+15.0%) but the average of the peer group analysis is a bit different, namely: -14.6% and + 113.4% (6) 10 [%] larger and smaller than ship 1.9			