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Analysis of economic impact of MARPOL Annex IX on different types of ship / s by Konoplev Mikhail Alexandrovich.

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ANALYSIS OF ECONOMIC IMPACT OF MARPOL ANNEX VI ON DIFFERENT TYPES OF SHIPS

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DECLARATION

I certify that all the material in this dissertation that is not my own work has been identified, and that no material is included for which a degree has previously been conferred on me.

The contents of this dissertation reflect my own personal views, and are not necessarily endorsed by the University.

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ABSTRACT

Title of Dissertation: Analysis of economic impact of Marpol Annex VI on different types of ships

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This dissertation is an empirical study on the statistical data that are used for identification of the economic impact of Marpol Annex VI on different types of ships through market analysis and investment appraisal.

A brief overview of the Revised Marpol Annex VI is carried out to identify the problems that the shipping industry faces nowadays and will meet in the nearest future regarding the legal regime of air emissions.

Statistical data are used for forecasting economic activity of Panamax, Capesize, VLCC and Aframax ships. Forecast is used for investment appraisal of these four projects. Investment appraisal is based on three different Scenarios regarding implementation of environmental regulations in accordance with the Revised Annex VI of Marpol. These Scenarios describe following situations: the situation without environmental regulations, the situation that exists in present time and the situation with modernization of ships that allow reduce economic impact from new regulations. Comparative analyses of these Scenarios allow identifying the economic impact and analyze how this impact can be diminished.

Comparative analysis through investments appraisal is based on comparison of payback time, earnings before interest taxation depreciation and amortization, and return on investments according to different Scenarios. Results of this comparative analysis are analyzed to identify what type of ships will be more affected by new environmental regulations and what measures should be taken to eliminate the negative economical impact from these regulations.

The concluding chapter presents an overview of results that were found and based on these results recommendations for decision-making that will allow to avoid negative economic influence from regulations of Marpol Annex VI.

KEYWORDS: Air emissions, Economic impact, Investment appraisal, Market forecast, Fuel oil cost, Modernization, Energy saving technologies.

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List of Abbreviations

Abbreviation	Meaning
BCI	Baltic Capesize Index
BDTI	Baltic Dirty Tanker Index
BPI	Baltic Panamax Index
CO_2	Carbon dioxide
DWT	Deadweight
EBITDA	Earnings before Interests Taxation Depreciation and Amortization
ECA	Emission Control Area
EEDI	Energy Efficiency Design Index
EEOI	Energy Efficiency Operational Indicator
FO	Fuel Oil
FOB	Free on Board
FOC	Fuel Oil Consumption
GDP	Gross Domestic Product
HFO	Heavy Fuel Oil
IMO	International Maritime Organization
LNG	Liquefied natural gas
LSFO	Low Sulfur Fuel Oil
MARPOL	International Convention for the Prevention of Pollution from Ships
MCR	Maximum continuous rating

MDO	Marine diesel oil (distillate marine fuel with possible residual fuel traces)
ME	Main Engine
MEPC	Marine Environment Protection Committee
METS	Maritime emissions trading scheme
MGO	Marine gas oil (distillate marine fuel)
NOx	Nitrogen oxides
NPV	Net Present Value
PM	Particulate matter/material
ROI	Return on Investment
SECA	Sulfur Emission Control Area
SFOC	Specific fuel oil consumption
SOx	Sulfur oxides
VLCC	Very Large Crude Carrier

Chapter 1. Introduction

In the past, during long period of time shipping remained the area without proper standards and regulations regarding emissions of harmful substances to the atmosphere. However, such situation was changed after Annex VI of Marpol came into force. Generally the provision of Annex VI introduces the legal platform to manage the problem of permanent increasing of emissions of harmful substances to the atmosphere. Of course a new legal platform creates new problems for ship owners because to comply with new regulations they have to use different fuel oil and invest in modernization of the engine. Very often legislation which is good on paper in real life creates uncertainty, extra risk and finally can not achieve its goals. The latest discussion about a global regime of CO_2 emissions, which was made in Copenhagen in December 2009, showed that compromise decision in the climate regulations are extremely complicated to reach between countries due to their different economic orientation and industrial development (Vidal, 2009). The same parallel can be also done for analysis of Marpol Annex VI regarding shipping companies. Some areas of the world Ocean and some trading routes will be more affected by new regulations than others; different types of ships as well will not be affected in the same way. The main objective of this paper is to analyze what type of ships will be more affected from an economical point of view by the new environmental regime regarding air emissions from ships. Another goal of this paper that is closely related with the first goal is appraisal of investments that ship owners have to do to make their ships eco-suitable for new regulations.

1.1 Background

On October 2008 the Marine Environment Protection Committee (MEPC) of the International Maritime Organization (IMO) adopted Amendments to the Annex of the Protocol of 1997 to amend the international Convention for the Prevention of Pollution from Ships, as Modified by the protocol of 1978 relating thereto (Revised MARPOL Annex VI). The goal of this Annex of the IMO is limitation and reduction emissions of harmful substances to the atmosphere, such as sulfur and nitrogen oxides (SOx, NOx) and particulate matter (PM) from ships. The regulations will reduce the harmful influence of emissions to human health and the environment. According to the tacit acceptance procedure the revised Marpol Annex VI entered into force on July 01, 2010. According to the provision of this Annex reduction of emissions from ships will be taken in 3 tiers during the period from 2010 to 2020. As a result level of NOx emissions will be reduced to 80%, and sulfur emissions in more than 90%. At the same time regarding SOx emissions in accordance with Annex VI the Baltic Sea, the North Sea and the English Channel are claimed as Sulfur Emission Control Area. Within this area after 2015 the maximum percentage of sulfur in the fuel will be 0.1%. (IMO, 2008)

A the same time during the 58th and the 59th sessions of MEPC of IMO on July 2009 and March 2010 a deep discussion was made about limitation of greenhouse gases from shipping. IMO prepared the Greenhouse Gas Study that presents a thorough analysis about present and future situation with harmful emissions from shipping. There is almost no question about the new regime for CO_2 emissions, and as soon as details are settled a legal framework for greenhouse gas limitation will be imposed on shipping. (Buhaug, 2009)

Obviously protection of the environment and a legal framework which will motivate ship-owners to be ecologically friendly is a wonderful project. However, it is very difficult to estimate the price of this good initiative. Regulations regarding NOx emissions are connected with investment to engine modernization, while SOx limitations are connected with change of fuel from relatively cheap heavy fuel to expensive distillate fuel. Another option regarding SOx emissions is the use of sulfur scrubbers, which are legally allowed according to an IMO resolution, but installation of scrubber requires huge investments. However, in particular period of time question of investments is not so easy, nowadays shipping market is weak and trading volumes fall down due to world economic crisis that started on September 2008.

This paper is dedicated to the analysis of the economic impact of new environmental regulations on different types of ships. Analysis will be done of four types of ships such as: Panamax dry bulk, Capesize, Aframax tanker and VLCC.

1.2 Objectives

This paper has three main objectives.

The first objective is to make a forecast for the dry bulk cargo market and tanker market and to identify how these markets will be affected by the new environmental regulations; and what extra cost ships will have to pay due to new regulations and how this extra cost will be reflected in the freight rates.

The second objective is investment appraisal of Panamax, Capesize, VLCC and Aframax ships. This assessment shows how in the long term perspective particular type of ships will be affected by new regulations. This assessment identifies possible strategies for investors regarding their investment in a particular type of ships.

Finally the third objective of this paper is identification of solutions that should be implemented for Panamax, Capesize, VLCC and Aframax vessels to diminish the economical impact from new regulations regarding air emissions from ships; how these solutions can be implemented, at which price, and how effective they should be.

1.3 Organization of research

To reach the goals mentioned above the paper is divided into five chapters. The first chapter is subdivided in three parts; the first part provides introduction, background information and justification of research, the second part describes main objectives of this paper, while the third part has general information about organization of research.

The second chapter is dedicated to present emissions from shipping, and provide detailed overview of the revised Marpol Annex VI, and present greenhouse gas limitations. Another important issue which is described in this chapter is options that determine effective solutions for making fleet compliant for new environmental regulations. An overview of new technologies which can be implemented for shipping are also presented in this chapter. The goal of this chapter is to identify the real changes that shall be done to make a fleet compliant regarding limitations of NOx, SOx, and coming limitations of CO_2 emissions from shipping.

The third chapter is dedicated to market analysis. The main goal of this chapter is forecasting of main economic variables for the period from 2010 till 2030. Regarding analysis of the economic impact of Annex VI these variables are: freight earnings, price of different types of bunker fuel (HFO, LSFO, MDO, and MGO), fuel oil consumption per year, price and amount of CO_2 emissions. The price of fuel oil is important to calculate the price difference, which will be paid when heavy fuel has to be changed for low sulfur and distillate fuel. A 'freight earning' is variable that shows economic activity of the particular type of ship regarding the market situation. It is assumed that if freight rate is low, the activity of fleet exploitation is also low. Thus variable 'freight earning' is important for forecasting fuel oil consumption per year, which has a crucial meaning in economic analysis. The level of air emissions is related with combustion of fuel oil, thus assessment of fuel consumption will give the real figures regarding the level of emissions and the extra price that will be imposed for shipping. Also fuel oil consumption data is used to calculate the level of CO_2 emissions; forecast of prices for CO_2 emissions plays important role for appraisal of investments in new installments which reduce fuel consumption and consequently CO_2 emissions.

The forth chapter is dedicated to the analysis of the economical impact from air emissions regulations on ships of different types. This analysis is performed based on results derived in chapter 3. The economical impact from new regulations is found through the appraisal of investment in new dry cargo ships and tankers. The main goal of this chapter is identification of the best investment strategy regarding investment in to different types of ships. This chapter helps to identify what type of ships during the next 20 years will be less or more affected by the new environmental regulations and what changes for investors (ship owners) new regulations will bring. Finally, this chapter provides solutions for reduction of the economic impact from new regulations, their cost and effectiveness analysis.

The fifth chapter is the final part which is subdivided into an overview of results and recommendations for decision-making regarding investment in particular type of ships which will be affected in different ways by the new regulations. These recommendations, based on the data found in Chapter 4, can be implemented in a medium and long term strategies of a shipping company that operates in a different segment of the shipping market.

Chapter 2. Legal background: Options to reduce air emissions from shipping

This chapter describes legislation and technical aspects regarding emissions from shipping. The main objectives of this chapter are: overview of legislation which will regulate air emissions from shipping and overview of options that will be done to make a fleet compliant according to the new regulations; options will be described and evaluated from the effectiveness and cost point of view. To reach this goal the chapter is divided in five parts. The first part is dedicated to the situation with SOx emissions and describes the legislative framework and options for reduction of SOx emissions. Part 2 and 3 describe legal background and technical features to comply with new regulations for NOx and CO_2 emissions accordingly. The fourth part of the chapter is dedicated to overview of the Green Ship Project, a Danish research and approach for ship's modification to make it compliant according to the regulations presented in the chapter. The last part of chapter is conclusion of the information presented in the chapter.

2.1. SOx emissions: Legal background

According to regulation 14 of the revised Marpol Annex VI, emissions of SOx from ships are globally limited by maximum content of sulfur in fuel at 4.5% till 2012. This share will be reduced to 3.5% during the period from 2012 to 2020, and will finally reach 0.5% after 2020. At the same time according to regulation 14 of the revised Marpol Annex VI in the SECA, the content of sulfur in fuel oil is limited by 1.5% till 2012. During the period from 2012 till 2015 the maximum amount of sulfur must not exceed 1% and after 2015 0.1%. The following table presents three tiers of the reduction of SOx emissions.

Table 2.1. Marpol Annex VI limitation of SOx emissions.

SOx	SECA	Globally
Tier I (till 2012)	1.5%	4.5%
Tier II (2012-2020; for SECA 2012 - 2015)	1.0%	3.5%
Tier III (after 2020; for SECA after 2015)	0.1%	0.5%

Source: Marpol Annex VI.

2.1.1 SOx emissions: Options for reduction

Generally, regarding emissions of SOx they originate in the sulfur that is chemically bound to the hydrocarbon fuel. When the fuel is burned, the sulfur is oxidized to SOx. In order to reduce SOx emissions, it is necessary to use a fuel with lower sulfur content or to remove SOx that is formed in the combustion process. This method seems to be the easiest approach and does not require investments to an existing fleet (Buhaug, 2009, p. 49).

An exhaust gas-scrubbing system that can be employed to reduce the level of sulfur dioxide is an alternative to using low-sulfur fuels (Wärtsilä Corporation, 2009). There are two main principles for scrubbers. The first type of scrubber is open-loop seawater scrubbers that use seawater directly. The second type is closed-loop scrubbers that use water with chemicals for SO_2 removal. Both types use water for contact with the exhaust gases (Buhaug, 2009, p. 52). The revised IMO Scrubber Guidelines (IMO, 2008) provide limits for the effluent, of pollutant substances that are removed from exhaust with help of wash water. To meet these regulations a treatment system should be installed in addition to scrubbers to clean the effluent. For use of scrubbers extra energy is required that will lead to fuel consumption growth; the average extra amount of energy is equal 1% - 2% of the maximum continuous rating (Buhaug, 2009, p. 105). Contrary to the fuel change the installation of scrubbers is connected with large investments. Appraisal of this investment will be done in the following chapters of this dissertation.

Use of alternative fuels or sources of energy is one more option for reduction of SOx emissions. For example, there are several initiatives to use LNG for shipping;

however, this approach is still not widely accepted. Also several projects are connected with use of solar power, sails and kites, but they also have only a small share for SOx reduction in comparison with scrubbers and low sulfur fuels. (Buhaug, 2009, p. 45)

2.2. NOx emissions: Legal background

In accordance with regulation 13 of the revised Marpol Annex VI, emissions of NOx from ships are limited according to 3 tiers. Tier I limits the amount of NOx emissions from ships built on or after 1 January 2000; and also according to paragraph 7 from ships' engine with power more than 5,000 kW and a per cylinder displacement at or above 90 liters installed on a ship constructed on or after 1 January 1990 but prior to 1 January 2000. Tier II limits NOx emissions from ships that will be built from 2011 till 2016. For example, for low-speed engines NOx emissions must be reduced to 15% of the Tier I (1-(14.4/17) = 15%). Tier III, will apply to ships built after 2016 NOx emissions from engines of these ships are assumed to operate close to the emission limit. For example, for low-speed engines NOx emissions must be reduced to 80% in comparison with Tier I (1-(3.4/17) = 80%).

Table 2.2. Marpol Annex VI limitation of NOx emissions.

NOx	n < 130 rpm	130<n<2000	n>2000
Tier I (2000-2011)	17.0 g/kWh	45 · n(-0.2) g/kWh	9.8 g/kWh
Tier II (2011-2016)	14.4 g/kWh	44 · n(-0.23) g/kWh	7.7 g/kWh
Tier III (2016-2020)	3.4 g/kWh	9 · n(-0.2) g/kWh	2.0 g/kWh

Source: Marpol Annex VI

According to the regulations the principle of NOx emissions reduction is different from the SOx emissions reduction. In such situation Tier II and III will not have a significant impact on ships which were built after 2000, or even 1990. However, when a ship owner invests in new building for ships which will start service after

2011 or 2016 he should pay extra cost for several installments to make the ships compliant with the NOx emission regulations.

2.2.1 NOx emissions: Options for reduction

As far as NOx emissions are formed in the engine, due to reactions between nitrogen and oxygen from the combustion air, the formation of NOx is mainly dependent on the combustion temperature. To reduce emissions of NOx, peak temperatures in the engine should be reduced, as well as the time for which gases are at high temperatures. Finally, the concentration of oxygen in the charge air should also be diminished. This can be achieved through a range of approaches. Some of them are: fuel modification, e.g. water emulsion; modification of the charge air, e.g. humidification and exhaust gas recirculation, modification of the combustion process; and treatment of the exhaust gas, e.g., selective catalytic reduction.

For example, modifications of the internal-combustion process may reduce NOx emissions up to 15-20% from the current level, which will be enough to comply with Tier II. However, 80% reduction from Tier I (Tier III limits) can only be performed with selective catalytic reduction or by using LNG. At the same time potential for reductions for two-stroke engines is not yet cleared and documented, and most of the methods are proven in relation to four strokes engine. (Buhaug, 2009)

2.3. CO_2 emissions: Legal framework

Shipping contributes more than 3% of the global CO_2 emissions, and the share of emissions is going to increase due to development of global trade. At the same time there is not yet a legal framework regarding CO_2 emissions limitation as well as trading. However, new regulations regarding CO_2 emissions are going to be implemented for shipping in the nearest future. Generally, policy options regarding limitations of CO_2 emissions can be divided in 3 groups: technical, operational and market based. At the same time technical and operational can also be determined as command and control measures. (Buhaug, 2009, p. 35)

Technical options are assumed to be implemented through an Index that will determine CO_2 efficiency of the design of the ship. The Energy Efficiency Design Index is the main technical instrument of CO_2 legislation. The EEDI shows the amount of CO_2 emitted from a particular ship in relation to a nominal transport work rate. The unit for EEDI expressed in grams of CO_2 per capacity-mile, where "capacity" for majority of the ships is deadweight cargo capacity. At the same time, the establishment of the baseline for EEDI is still an open process. However, during the 60^{th} session of the MEPC the baseline was determined by the following formula: EEDI (baseline) = $a*(DWT)^{-c}$, where DWT is the deadweight tonnage, a and c are positive coefficients determined by regression from the world fleet database, per main ship type. For example, for Panamax a= 1354, c= -0.5117, thus EEDI baseline is equal 4.33 $gCO_2/t*nm$. Mandatory EEDI is going to be applicable only for new ships and voluntary for all ships (IMO, 2010).

The operational group of policy option is presented in an Energy Efficiency Operation Indicator. The EEOI shows CO_2 efficiency per unit of transport work. The EEOI is calculated in grams of CO_2 per capacity-mile, where "capacity" is an expression of the actual amount of cargo that the ship is carrying. EEOI depends on the operational condition, consequently, EEOI is different for every voyage and can be calculated on average base by the following formula:

$$\frac{\sum_j FC_j \times C_{Fj}}{m_{cargo} \times D}$$

Where: FC_j is fuel consumption on voyage j; C_{Fj} is the carbon content of the fuel used; m_{cargo} is the mass of cargo transported on voyage j; and D is the distance of voyage j. (IMO, 2009). However, the introduction of baseline for CO_2 limitations based on EEOI is very difficult to achieve, thus this index seems to be not so relevant in the nearest future (Buhaug, 2009, p. 64).

Market-based instruments that are going to be implemented by IMO are presented by two different approaches: maritime emissions trading scheme (METS) and International Compensation Fund for Greenhouse gases Emissions from Ships that will be based on a global levy on marine bunkers. Both of these approaches are focused on actual emissions of CO_2 from ships, and they are not directly related with efficiency indexes. Both of these proposals have a direct effect on the operation cost of the ship. Levy and taxation system will be implemented via extra price for the bunker fuel that ship owners will have to pay. Another option assumes that shipping will be a part of the Global Emissions Trading System, so ship owners will have to buy a quota for CO_2 emissions from their ships. Both of these systems will motivate ship owners to invest in different technologies that will allow saving money that are assumed to be paid as taxes on bunker fuel, or as money spend on quota purchasing (Buhaug, 2009, p. 71).

2.3.1. CO_2 emissions: Options for reduction

Generally, the amount of CO_2 emitted from ship is determined by the amount of fuel that is burned. Thus reduction of CO_2 emissions depends on fuel oil consumption and quality of fuel oil. Reduction of energy losses on the stage of ship design is one of the strategies of reduction of fuel oil consumption and CO_2 emissions. For example, the energy efficiency of a ship is related with the main features of the ship, such as length, breadth and draught, improvement of design which can be very urgent for new buildings. One more option for reduction of CO_2 emissions is connected with the design of power and the propulsion system and its efficiency, so power turbines driven by exhaust side-stream can save up to 10% of the total power, while a large propeller rotating at low speed gives higher efficiency. Further reduction of blade area and frictional resistance increases the energy efficiency. Improvement of the propulsion system on the stage of design can increase energy efficiency of a ship to 5% - 15% (Buhaug, 2009, p. 45).

The proper maintenance of a ship can reduce energy losses. Mainly this reduction can be achieved through proper maintenance of underwater part of the ship’s hull and of the main engine. Proper maintenance of the main engine can save up to 2% of energy, while hull coating itself can get 5% of energy savings (Buhaug, 2009, p. 49).

Use of low carbon fuels such as bio fuels or LNG is one more group of CO_2 saving options which is related to technical aspects. At the same time, use of bio fuels may lead to an increase from 7% to 10% in the NO_x emissions; this can be explained by different combustion characteristics of bio fuels in comparison with diesel of heavy fuel oil. Another problem of this reduction option is high cost of bio fuel and large investments for use of LNG. However, this option can save up to 10% of CO_2 emissions (Buhaug, 2009, p. 51)

Finally, one more important group of options is proper operation of the ships. For example, weather routing, i.e. use of winds and current or reduction of time in port may lead to energy savings up to 50%. Ship owners should arrange proper schedule and motivate all parties of the voyage to not waste time in port. This measure will allow using slow steaming, where 20% of the speed reduction results in 50% of fuel consumption and CO_2 emissions savings (Buhaug, 2009, p. 47)

2.4. Green Ship Project

This part of the chapter is dedicated to an overview of the concept of a ship that includes different options for reductions of emission, which have been described in previous parts. The goal of this chapter is to show the effectiveness and costs of these options, to have real figures for further economic analysis of the Annex VI impact on different types of ships. Furthermore, this project will be used like a benchmark for economic analysis and appraisal of investment in Chapter 4.

"Green Ship of the Future. Concept study", is an empirical study performed by the Danish engineer Søren Schnack. The study describes the modification of a typical bulker with the following characteristics: deadweight 35,000 tons, main engine power output 7,410 KW, maximum speed 14 knots corresponds to at 6,300KW, i.e. 85% of maximum continuous rating. Specific fuel oil consumption 159.3 g/KWh at 6,300KW, level of CO_2 emissions 523.6 g/KWh at 6,300KW, level of NOx emissions is 17g/KWh at 6,300KW, level of SOx emissions 10g/KWh at 6,300KW. The goal of the study was to reduce emissions of harmful substances to allow the ship to operate when all regulations mentioned above enter into force. According to the objectives of the study emissions of CO_2 are going to be reduced to 30 %, NOx to 90 % reduction and SO_2 to 90 %. However, in the reality, engineers could achieve only the following reductions: FO consumption and CO_2 for 7.7%, NOx for 81.6% and SOx for 98.7%. The total cost of this modernization in 2009 was $4,310,000. The following measures were taken to achieve this result. (Schnack, 2009)

2.4.1 Options for CO_2 emissions and fuel oil consumption reduction, effectiveness and cost

The first group of options for reductions of emissions is related with ship design. To making propeller more efficient the diameter was changed from 5.6m to 5.8m, also speed nozzle was installed. For increasing energy efficiency the de-rating of the main engine was done, so that specific oil consumption was reduced by the reduction of specified maximum continuous rating from 6,300 KW to 6,050 KW at 117RPM. The total cost of these devices is $700,000. Another reduction option related to design is the twisted spade rudder with Costa bulb. The twisted rudder allows aligning the rudder blade to the flow direction in the propeller wash, while the Costa bulb is a streamlined body fitted on the rudder that provides a more homogeneous flow distribution behind the hub area, thus minimizing the hub vortex and its related loss. Installation of these devices gives total reduction in propulsive power at service speed (85 % MCR), to 4 % or 250 kW (reduced from 6,500 to 6,250 kW). The total cost of these devices is $160,000.

The waste Heat Recovery system with a cost $1,250,000 has been used on ships for a long time and has provided the best emission reduction of CO_2, Such system can save up to 10-15 % of the main engine power.

Finally, coolers and cooling pumps should be optimized. Pumps, with coated interior and pumping wheels, give 10% of power reduction of engine auxiliaries when the ship operates at service speed. Cost of this option $150,000 (Schnack, 2009, p. 35).

2.4.2 Options for NOx and SOx emissions reduction and their cost

To reduce NOx and SOx emissions and make ships compliant with new regulations the following options and technologies has been done:

Water in fuel is technology that allows reducing up to 30%-35% emissions of NOx. The principle of this technology is to add 50% of water to the fuel. However this option increases CO_2 emissions for 1% - 2%. The total cost of this technology is $200,000. Making 30% - 35% reduction of NOx emissions from the current level ship becomes suitable to Tier II for NOx emissions regulations. At the same time, water in the fuel system requires more fresh water, thus a high capacity fresh water generator with a cost of $50,000 should be installed.

The exhaust gas scrubber with a cost of $1,200,000 removes 98% of SOx and 80% particle matters from the exhaust gas. The scrubber operates with seawater. Sulfuric acid and particles from the exhaust gas are thrown into the sea, where the acid is converted to harmless sulfate.

The exhaust gas recirculation technology with a cost of $600,000 provides a reduction of NOx emissions from internal combustion engines. The main principle of such technology is decreasing the peak combustion temperature, thus reducing thermal formation of NOx. This technology allows reaching 80% of NOx reduction from the current level and making ship compliant for the Tier III (Schnack, 2009, p. 35).

2.5. Conclusion

The main objectives of this chapter was to describe new regulations regarding air emissions from shipping and to identify several options that will be implemented to make the fleet compliant with these regulations. Among different limitations the most urgent problem for the existing fleet is reduction of SOx emissions, while NOx limitations are mostly related to the fleet that will be built. As to CO_2 limitations they are still in process of discussion and going to be implemented in the nearest future. Regarding options that will be implemented for compliance with regulations most of them are related with new technologies and fleet modernization and should be assumed as long-term investments. However, most of these investments can be related with new buildings, while for the existing fleet investments are not so obvious, e.g. NOx limitations.

In the next chapters a detailed economic analysis of these regulations and their impact for different types of ship will be made.

Chapter 3. Forecast of main economic variables - Methodology

To assess the economic impact of the new regulations several parameters need to be forecasted. For this research the main economic variables are: freight earnings, fuel oil price, fuel oil consumption, price and amount of CO_2. A forecast of freight earnings is an important part of analysis because it reflects the economic activity on the shipping market. Freight earning is a variable which shows a potential use of the fleet so it has a crucial meaning for appraisal of investment in new technologies. Fuel consumption and bunker prices impact the operational costs of vessel. Furthermore, emissions from shipping are related with the fuel combustion process, thus fuel consumption, its cost and amount of CO_2 per year are factors that are directly related with investment in new environmental technologies.

This chapter is subdivided into 5 parts; the first part is about forecasting of freight earnings, while the second part is dedicated to the forecasting of fuel oil prices. Both forecasts are based on a statistical analysis. The third part describes estimated consumption of fuel oil and total fuel oil cost; this forecast is done with an activity based model. The forth part is dedicated to the forecast of price of CO_2, while the amount of CO_2 is calculated based on the fuel consumption data. The last part is conclusion based on the results of this chapter.

3.1. Freight earnings forecast

Shipping is a part of the global market which is driven by demand and supply and correlated with the main global market indicators, such as commodity prices and world economy GDP. Forecasting in shipping is the most difficult part of the whole business planning (Stopford, 2009, p. 697). For proper forecast it is necessary to analyze past market situations and assuming that there are some laws and trends, to be used them for predicting the future. For forecasting in shipping business it should be taken into account that the shipping industry is derived from other industries. Consequently, to forecast the freight earnings for VLCC, Aframax, dry bulk

Capesize and Panamax, they should be related with changes in prices of the main commodities.

However, one of the most difficult things in forecasting appears because the market economy has cycles in its origin and the shipping sector has as well several cycles. According to Stopford (2009), the cycle in shipping markets follows 4 stages: trough, recovery, peak plateau and collapse. Describing the periods of the cycles Stopford concludes that the average time from one peak to another is about 7 years (Stopford, 2009, p. 73). From this it is possible to conclude that ship owners who do not go for speculations may not take into account the stages of the cycles while planning the investment or analyzing an impact from new regulations. Another assumption is that demand and supply for the shipping sector are related to the price of the main commodities.

3.1.1 Correlation with main commodities

Shipping as an industry can not be separated from production so it is obvious that the dry bulk shipping industry is dependent on the demand on the main commodities. As to Panamax and Capesize dry cargo bulkers most of them are engaged in carrying mostly coal and iron ore commodities. Panamax ships also carry grain. The geography of trade for Capesize ships is from Australia, Brazil or South Africa to China or to Europe. A vital point is that these ships can pass through neither Panama Canal, nor Suez. Panamax ships at the same time trade almost worldwide except the Great lakes region and some shallow ports with a depth less than 14 meters (Institute of Chartered Shipbrokers, 2003, p. 155).

The following figures present a correlation between Panamax freight earnings and main commodities carried by Panamax ships as monthly average from June 1995 till May 2009; an equation which shows relationship between earnings and commodity prices, and its R^2, derived from 163 data. Figure 3.1 presents a relationship between freight earnings for Panamax ship ($/day) and price for wheat. Relatively low R^2 = 0.4862 can be explained by different reasons, one of which is seasonal influence. As far as, storage of the grain for farmers is expensive and difficult, the period of yield is a boom in grain transportation, so in summer for example the demand for Panamax ships for carriage of grain increases in the northern semi sphere, while in winter demand goes down (Stopford, 2007, p.98).

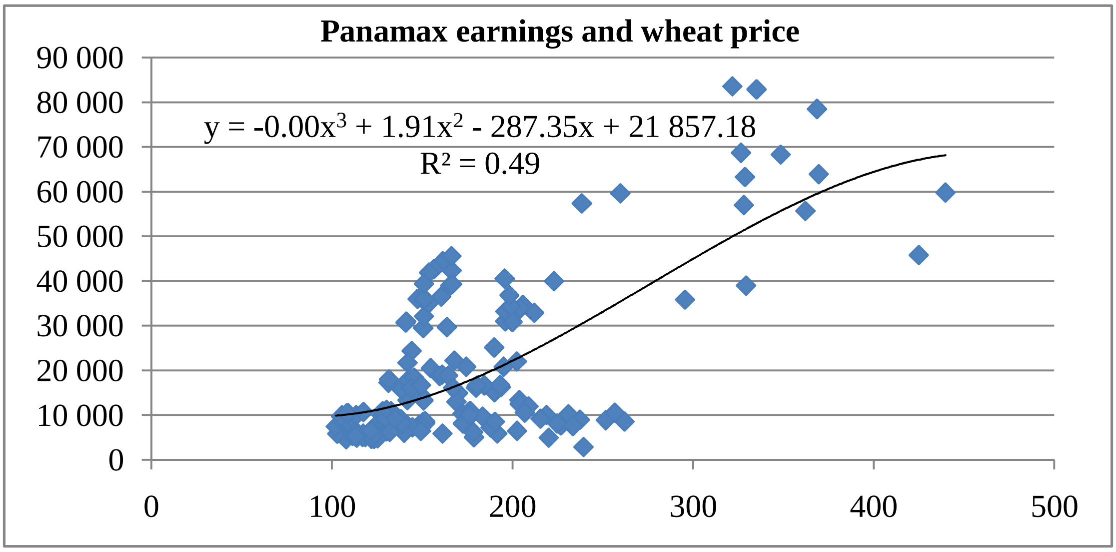

Figure 3.1 Earnings for Panamax ship ($/day) and price for the Wheat, No,1 Hard Red Winter, ordinary protein, FOB Gulf of Mexico, $/mt, ; monthly average data 06.1995 – 04.2009
Source: author and author and Index Mundi, Drewery Shipping Consultant

However, for other main commodities carried by Panamax ships, factors that effect demand are not related with seasonal factors but mostly related with a general situation on the markets. Coal can be used either for steel production or for heating. However, the price for coal and iron ore is mainly related with a situation in the metallurgy industry. If there is high demand for steel production, the transportation of iron ore and coal also increases. Increasing demand for transportation of iron ore and coal pushes freight rates for Panamax and Capesize ships and increase their earnings. For example in the recent years, China is a leading country in steel production and does not have enough own resources, coal and iron ore, thus almost all of them are imported from Australia and Brazil, so the demand for Panamax ships is closely related with the situation in Chinese metallurgy and in the whole metallurgy as well (Hadjyiannis, 2006, p. 17). Figure 3.2 gives evidence of huge correlation between steel production and Panamax earnings (correlation coefficient total production/ Panamax earnings 0.87).

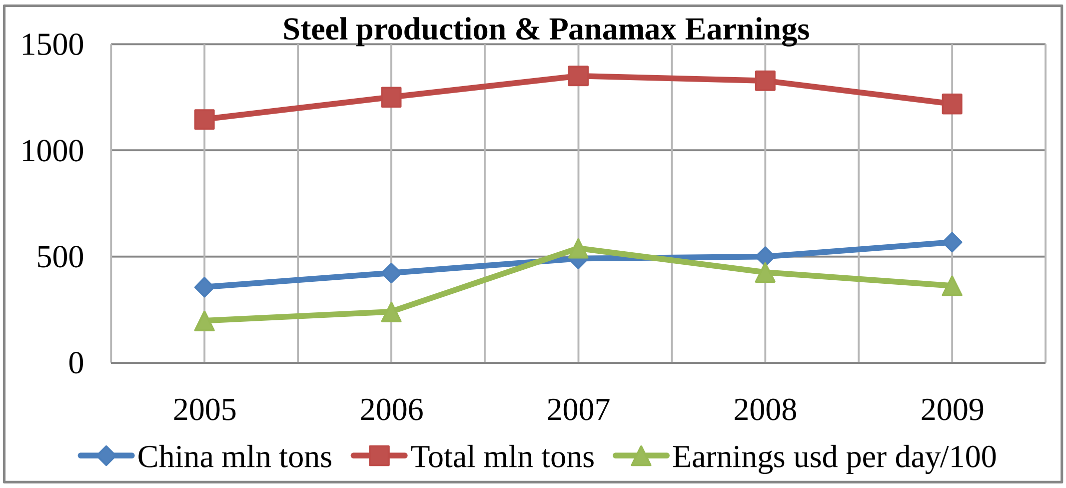

Figure.3.2 Earnings for Panamax ship ($/day) and production of Steel in China and in the world.
Source: author and Drewery Shipping Consultant, World Steel Organization.

At the same time the forecasting of price in metallurgy is a very difficult issue, thus it is almost impossible to make a forecast of freight earnings based on information about future prices for the steel for next 20 years due to very high uncertainty. Partially it can be explained that steel production itself depends on many other factors so a forecast should be focused on prices for the main commodities. The main commodities for steel production are iron ore and coal. However, the correlation with coal prices is not close enough to use it for a freight earnings forecast.

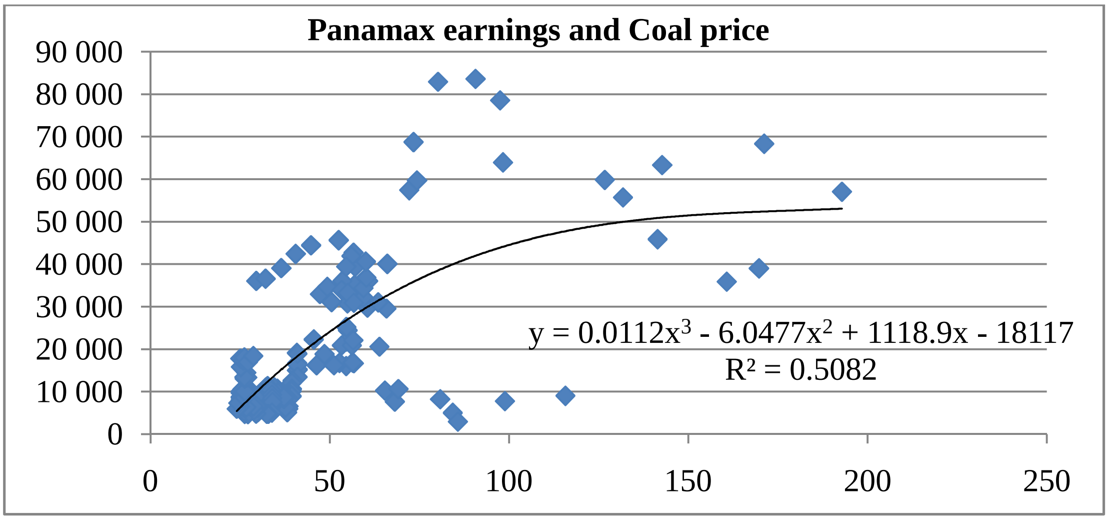

Figure 3.3 Earnings Panamax vs. Australian thermal coal, 12000- btu/pound, less than 1% sulfur, 14% ash, FOB Newcastle/Port Kembla, $ /mt; monthly average 06.1995 – 04.2009
Source: author and Index Mundi, Drewery Shipping Consultant

The same conclusion that iron ore prices are weak correlated with freight earnings can be done based on data presented in Figure 3.4.

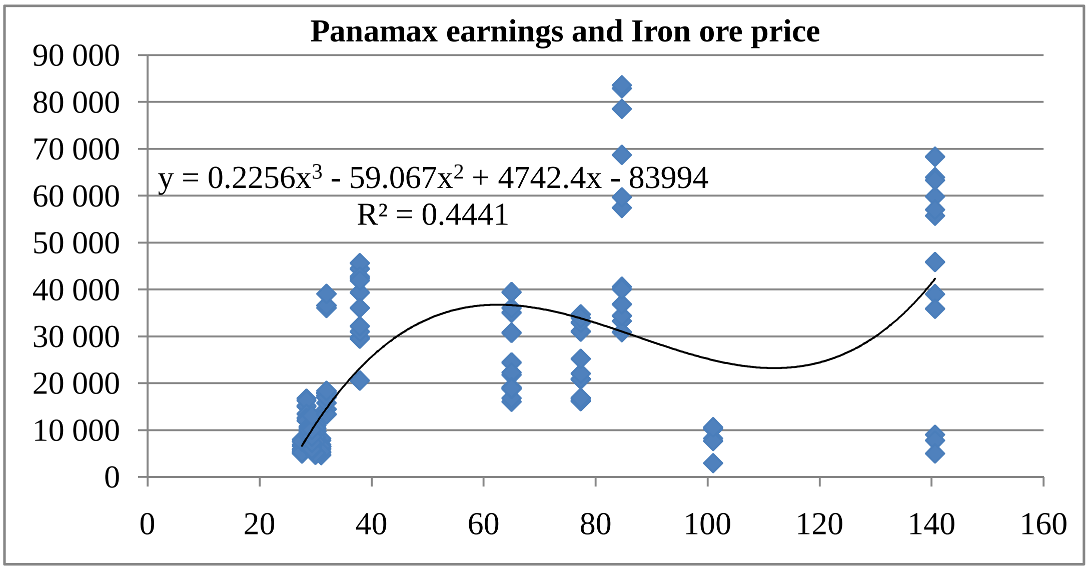

Figure 3.4 Earnings Panamax vs. Iron Ore, 67.55% iron content, fine, contract price to Europe, FOB Ponta da Madeira, US cents per dry metric ton unit; monthly average 06.1995 – 04.2009
Source: author and Index Mundi, Drewery Shipping Consultant

Finally, it is important to bear in mind that oil prices also have a huge impact on freight rates. Figure 3.5 shows the relationship between oil prices and Panamax earnings.

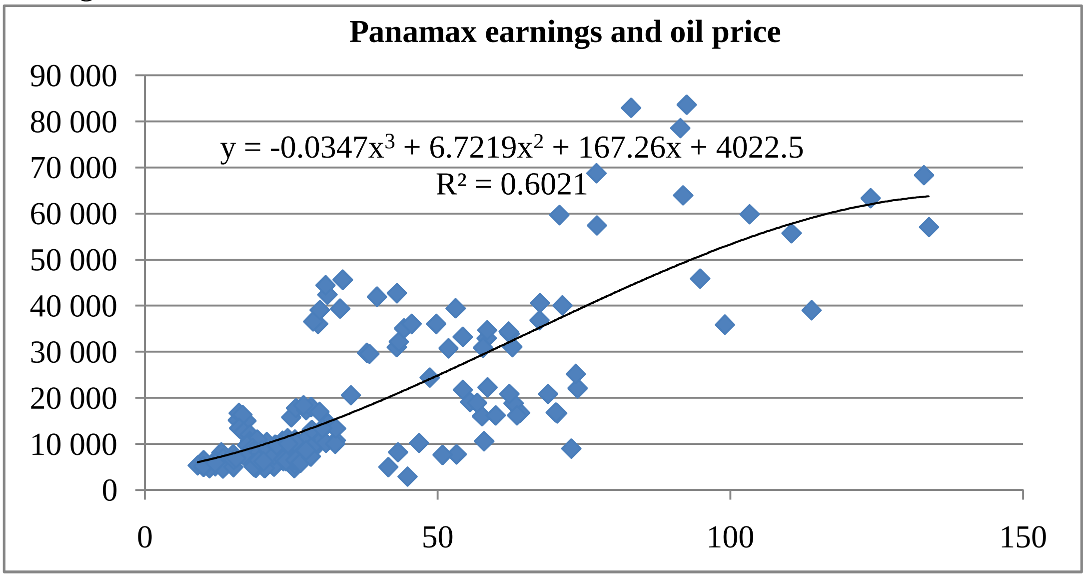

Figure 3.5 Earnings Panamax vs. Brent $/bbl; monthly average 06.1995 – 04.2009
Source: author and Index Mundi, Drewery Shipping Consultant

First of all it can be explained that oil prices are like a mirror of the whole economic situation in the world, since oil is the main source of energy and energy consumption is related with the growth of economy; or because transportation of any goods generally will be related with oil prices. Another important issue regarding shipping is that ships which do not transport oil still use fuel oil for steaming. Bunker prices and oil prices are related; this will be shown later in the forecast for bunker fuel. At the same time growth of the fuel cost increases the operation cost of the vessel. Consequently to compensate this extra cost for fuel oil, the freight rates are assumed to be increased.

After all correlations with main commodities are performed, it is possible to conclude that the highest correlation coefficient and R^2 for Panamax sector with main commodities is earnings of Panamax with oil prices. Consequently, oil prices will be taken like a guiding line for forecast of freight rates. Forecast of oil prices till 2030 is taken from the US Agency of Energy. Figure 3.6 shows Panamax earnings and oil prices till 2030.

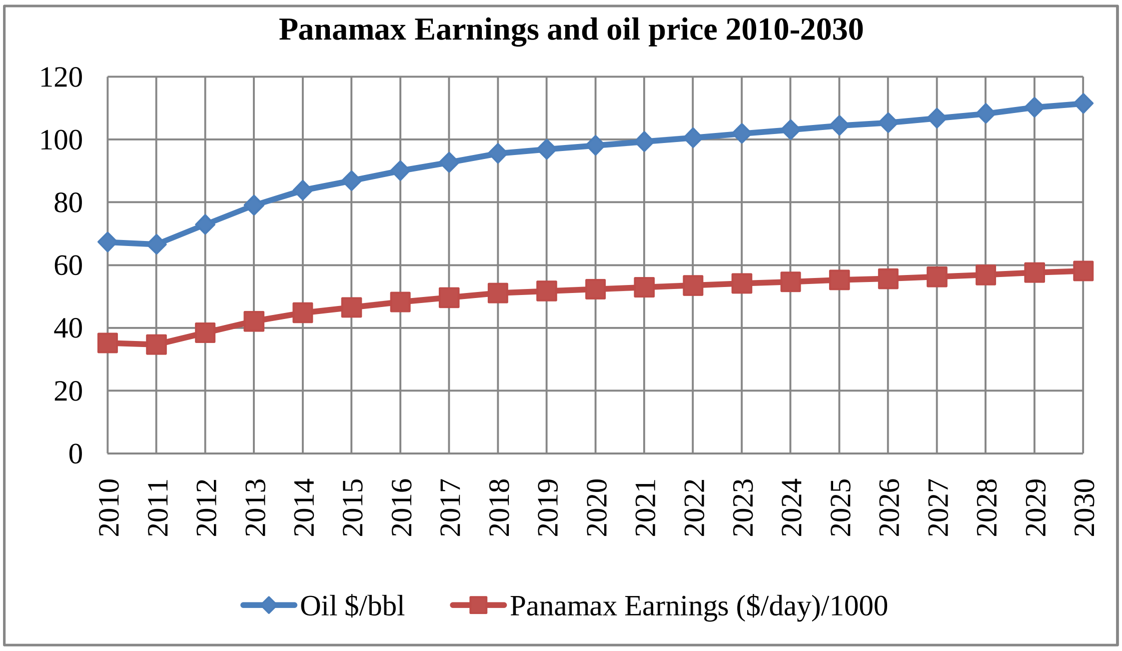

Figure 3.6 Earnings Panamax vs. Oil $/bbl; year average 2010 – 2030.
Source: author and US Energy Information Administration, Drewery Shipping Consultant

The same method is used for forecasting freight earnings for other types of ships. Freight rates are correlated with oil prices for Capesize, VLCC and Aframax ships; details are described in Appendix A. Figure 3.7 shows freight earnings and oil prices for these ships from 2010 to 2030.

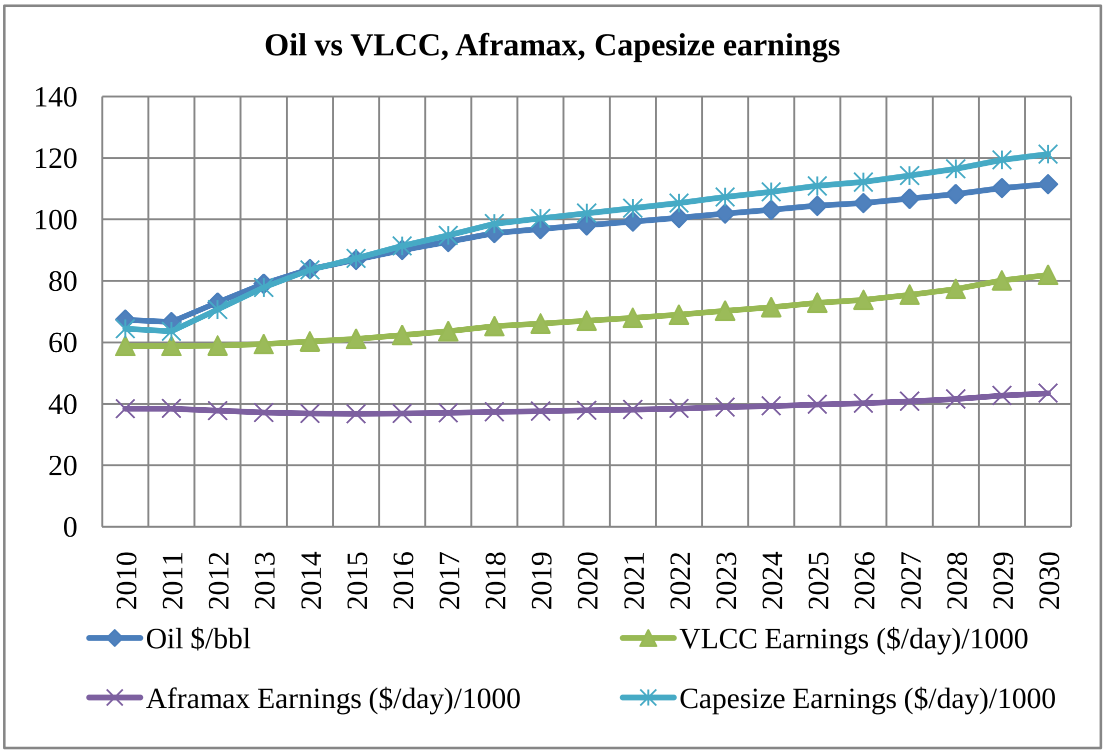

Figure 3.7 Earnings VLCC, Aframax, Capesize vs. Oil $/bbl; year average 2010 – 2030.
Source: author and US Energy Information Administration, Drewery Shipping Consultant

3.2. Fuel oil price forecast

This part of forecasting is based on the statistical data regarding prices of bunker fuel and crude oil. A forecast will be done for the period from 2010 to 2030 for main types of bunker fuel such as: High Sulfur Fuel (HFO 380) – heavy bunker fuel with a 3.5% - 4.5% of sulfur; Low Sulfur fuel (LSFO 380) – heavy bunker fuel with content of sulfur around 1%; Marine Diesel Oil (MDO) - distillate fuel with a sulfur content less than 0.5%; Marine Gasoline Oil (MGO) – distillate fuel with a sulfur content less than 0.1% (Bunker Index, 2010). A price forecast for fuel oil is extremely important for assessment of economical impact of SOx emission regulations because to fulfill these limitations ship owners have to change the fuel from HSFO to LSFO and then to distillates. Thus this forecast has crucial information regarding extra cost which will be imposed on shipping operations. At the same time price differences between different types of bunker fuel will be also used like earnings (fuel savings) regarding new technologies (e.g. scrubbers) which will be installed onboard to avoid consumption of low sulfur fuel.

A forecast of bunker fuel prices is done on statistic basis. A prediction of demand and supply for a particular type of fuel is a difficult issue, but at the same time a correlation coefficient between historical price for crude oil and different types of bunker fuel is reliable for forecasting (R^2 >0.95), so this approach seems to be the best alternative. Figure 3.8 presents the interrelationship between crude oil price brent \$/bbl and HFO 380 average in the 5 major bunker ports \$/mt; data were taken on a daily basis from March 2009 to April 2009.

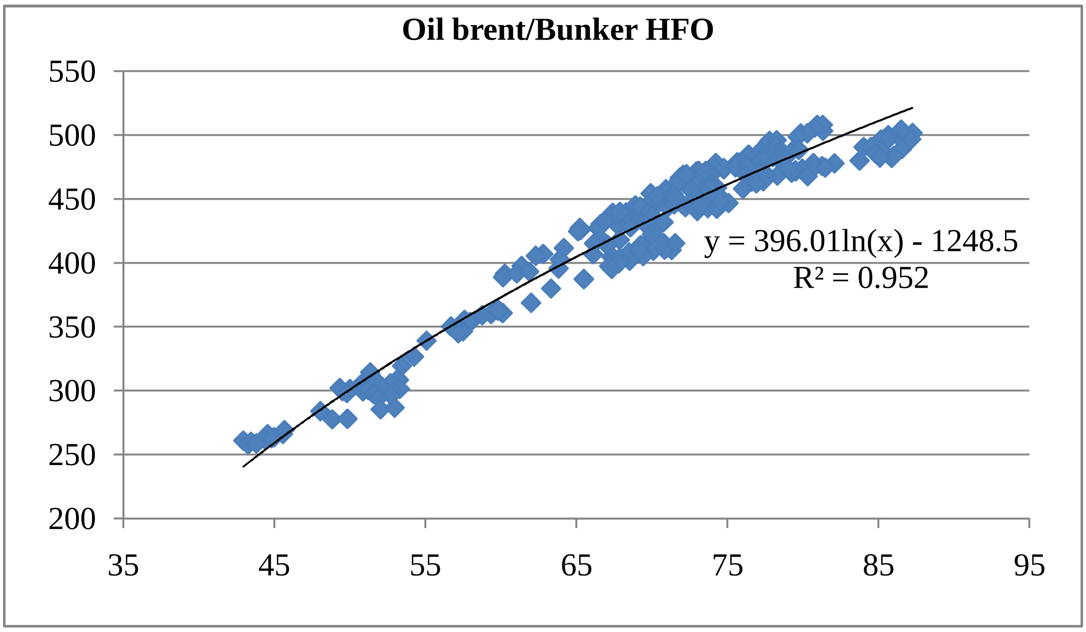

Figure 3.8 Oil price brent \$/bbl vs. HFO 380 \$/mt, March 01, 2009 – April 30, 2010
Source: author, Bunker Index

Using the same methodology in the next step the correlations between crude oil MGO and MDO prices are found with the help of the past data from a bunker index web site; details are presented in Appendix A. Prices for LSFO are calculated as the price of HFO multiplied by 110% (Roos, 2010). Finally, with the help of a forecast of fuel oil prices until 2030, like it has been done for the forecast of freight rates in the previous part, extrapolation of the oil prices with a bunker fuel prices can be done until 2030. Figure 3.9 shows fuel prices.

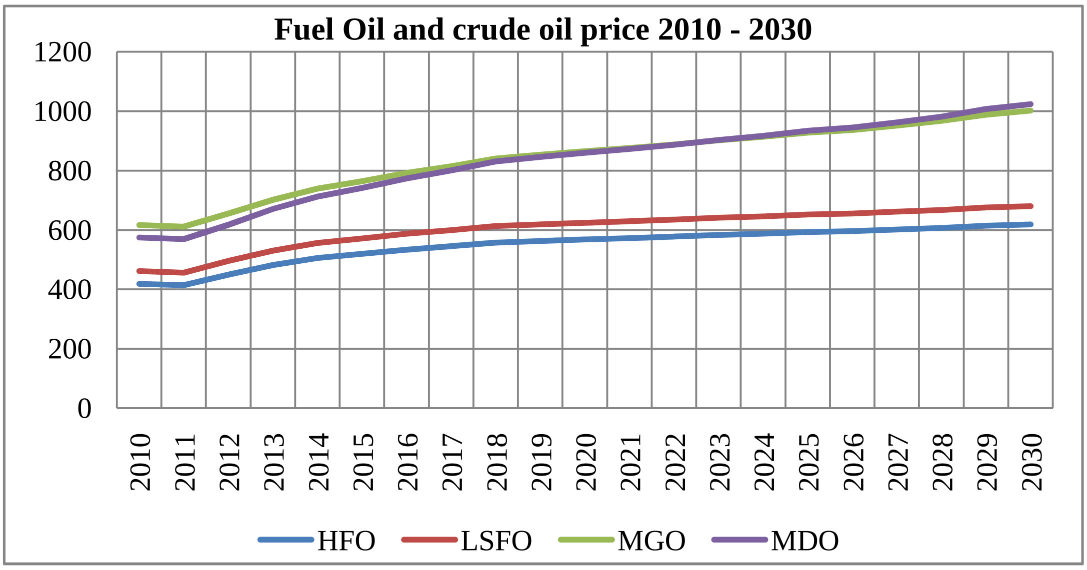

Figure 3.9 Oil price brent $/bbl vs.HFO 380 $/mt, LSFO $/mt, MGO $/mt, MDO $/mt, 2010 – 2030. Source: author and Bunker index

3.3. Fuel Oil consumption forecast

As far as all emissions from ships are generated due to the burning of the fuel, it is important to forecast oil consumption for assessment of the future level of emissions and impact on particular segments of shipping from the new environmental regime. Generally, this forecast takes into account the economic activity of the fleet and has a crucial meaning for appraisal of investment to fleet modernization.

3.3.1 Main engine workload and Average speed

The activity based model is used to forecast fuel oil consumption. First of all within this model it is important to determine the factors that have a direct impact on the amount of fuel consumed by ships. According to the study "Estimate of fuel consumption in 2007 by international shipping", which is a part of the Second IMO Green House Gas Study (Buhaug, 2009, p. 137), fuel consumption is determined by the 4 following factors: Installed power – Average operating days – Average load – specific fuel oil consumption (SFOC). At the same time, installed power and specific fuel oil consumption for a ship should be taken as constants. For example, for a Panamax dry bulk ship with 60,000 – 99,000 dwt, the average power of the main engine in 2007 was 9912 kW. Another constant – specific fuel oil consumption shows how many grams of fuel oil is consumed to generate 1 kW per hour. Table 1 describes the average ME power, SFOC for different types of ships and fuel oil consumption.

Table 3.1 Main engines data.

	Panamax	Capesize	VLCC	Aframax
DWT 1000 tons	60-99	100-199	200+	80-120
SFOC g/kW*h	170	170	170	170
ME power, kW	9912	15108	24610	12726
FOC = ME*SFOC tons/hour	1,68504	2,56836	4,1837	2,16342

Source: Second Greenhouse Gas Study, IMO, 2009
Calculation: author

The last line of the table has figures of fuel oil consumption when the engine works with full power. However, practically it is almost impossible, and most of the time the workload of the main engine in average per year is around 70% - 80%. The workload of the main engine is directly related with the average speed and time that the ship spends at sea, thus to determine fuel oil consumption days at sea, and main engine workload should be found. Table 3.2 shows typical engine and propeller loads corresponding to ship speed in clean-hull calm-sea conditions at the design draught (Buhaug, 2009, p. 142).

Table 3.2 − Typical engine and propeller loads corresponding to ship speed

ship speed	50%	75%	80%	90%	95%	100%
propeller load (% kW)	13%	42%	51%	73%	86%	100%
engine MCR (% MCR)	11%	38%	46%	66%	77%	90%

Source: Second Greenhouse Gas Study, IMO, 2009

Based on this data, it is possible to find a relationship between average speed and main engine workload. Figure 3.10 shows this function which can be determined by the following formula: ME workload = $0{,}904 \cdot x^{3.0339}$, where x is average speed.

Consequently, to calculate the average main engine workload it is important to find the average speed.

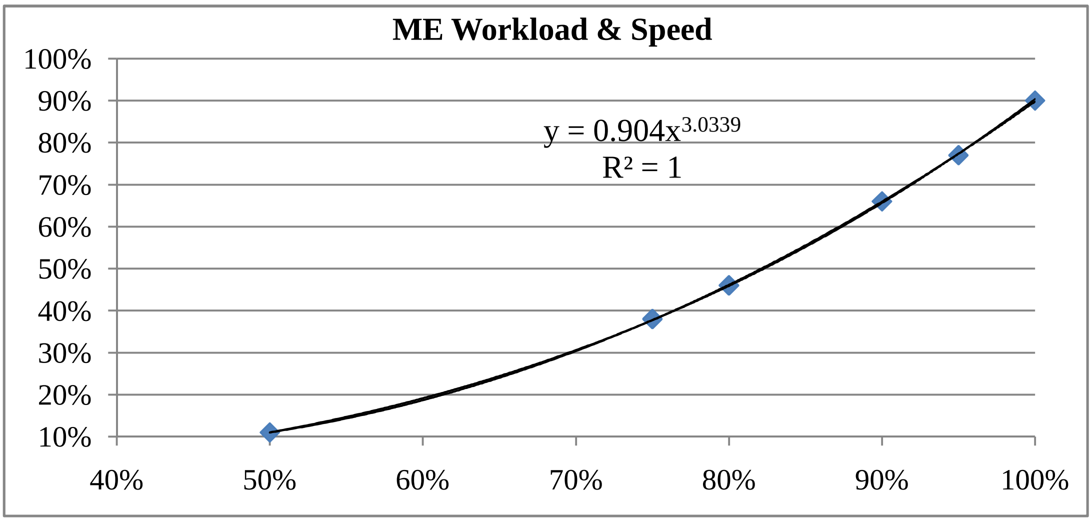

Figure 3.10 –Typical ME engine load corresponding to ship speed
Source: Second Greenhouse Gas Study, IMO, 2009

The average speed is calculated as number of miles per year divided to hours that the ship spends during the year not in the port. So to determine the average speed, first of all, data about time at port should be found.

3.3.2 Days at sea and in port

For this research, time in port means time when the ship is physically at port for loading or unloading, in dry dock for maintenance and repair, or anchored during a particular period of time due to lack of demand and unprofitability to be employed. Table 2 describes time in port of different ships during 2007. Days at sea in this case are calculated as 365 minus days at port.

Table 3.3 – Days at sea and at port in 2007

	Panamax	Capesize	VLCC	Aframax
Days at port	94	86	91	111
Days at sea	271	279	274	254

Source: Second Greenhouse Gas Study, IMO, 2009

To forecast how many days a ship will spend in port during the next 20 years number of days at port will be related with the economic activity of the ship with help of average freight earnings. To relate days at port with average freight earnings, the annual change of earnings will be taken as annual changes in freight earnings taking into account that market interest rate r = 2% for calculation of net present value of earnings. For example, average freight earnings for Panamax in 2007 was 53903$/day and in 2010 it was 35204$/day, consequently NPV2010 = 35204$*$(1.02)^{-3}$= 33173$. Thus, annual change in freight earnings can be found as NPV2010/Earnings 2007, for this case annual change = 33173$/53903$=0.6154. After the number of days in port in 2010 can be calculated as Days at Port 2007 divided (growth of the earnings reduces days at port) by annual changes in freight earnings, thus Dport2010 = 94/0.6154 =152.7 days, thus Dsea2010 = 365-152.7 = 212.3 days.

Figure 3.11 shows meaning of net present value of average earnings and time that Panamax ship will spend at sea and at port during the period 2010 – 2030.

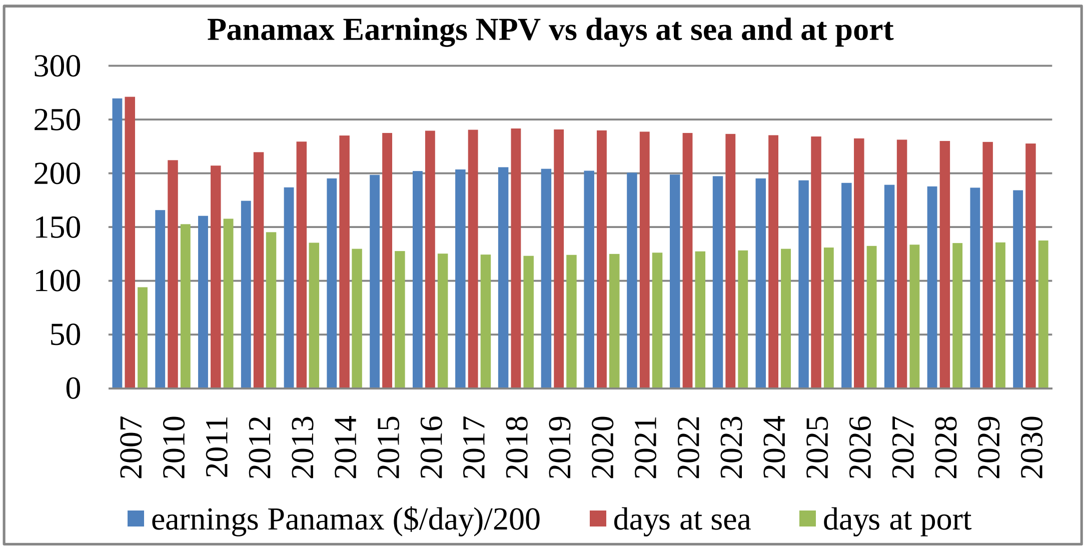

Figure 3.11 Panamax earnings vs. days at sea and at port in 2010 - 2030
Source: Author, Second Greenhouse Gas Study, IMO, 2009

3.3.3 Average distance

The distance a ship covers per year can be determined assuming that the number of miles per year is a variable of demand and related with freight earnings. As far as product of shipping is transportation service which can be expressed in ton*miles, demand on annual basis for shipping can be determined as ton*miles per year. For example, in a particular period of time t demand and supply are in equilibrium, and Demand = Supply, or [(ton*miles)/t], where ton this is amount of cargo to be transported, miles the distance which should be covered, and t – time which is taken to cover this distance. However, if this equilibrium is breaking and demand for example raises two times, to satisfy it, supply has several options: 2*Demand=2*(ton*miles)/t, this means that supply should double the size of the ship or to employ 1 more ship. Another option 2*Demand= (ton*miles)/0,5*t, this means that to satisfy demand time to cover the same distance with the same amount of cargo, the time of steaming should be cut by two. On the other hand, if the market goes down demand for ships and freight rates are decreasing, if a ship owner does not want to lay up his fleet to ensure the equilibrium between demand and supply time of steaming can be reduced. In case when demand is on the same level, but supply increases, for example D=2*(ton*mile)/*t, to reach equilibrium supply should take away half of the tonnage, or double the steaming time. Consequently, market conditions play a direct impact on the average distance covered by ship per year.

Table 3.4 shows ME workload and Average speed of vessels in 2007. Average speed is calculated as a function of ME workload, as Average speed = $1{,}0338*X^{0{,}3296}$, where X is average main engine workload.

Table 3.4 - ME workload and Average speed of vessels in 2007

	Panamax	Capesize	VLCC	Aframax
ME workload	70%	70%	73%	80%
Average speed	14.7	12.9	11.2	13.4
Days at sea	271	279	274	254

Source: Second Greenhouse Gas Study, IMO, 2009
Calculation: author

From this table the average distance for Panamax ship in 2007 can be calculated, it is: Average distance = days at sea * 24*Average speed = 271*24*14.7 = 95649.2 nm. The next step is related with freight earnings and average distance correlation. To forecast the average distance from 2010 to 2030, the annual changes of the freight earnings will be calculated (with net present value), as it has been done to determine days at port.

Then, assuming that the annual changes in freight are corresponding with the annual change in average distance the mean of average distance can be predicted, as average distance in 2007 multiplied by annual changes in freight earnings. Consequently, for average distance in 2010 it is: S av. = 95649.2 * 0.6154 = 60042 nm.

Figure 3.12 shows net present values of freight earnings and average distances for Panamax ship from 2010 to 2030.

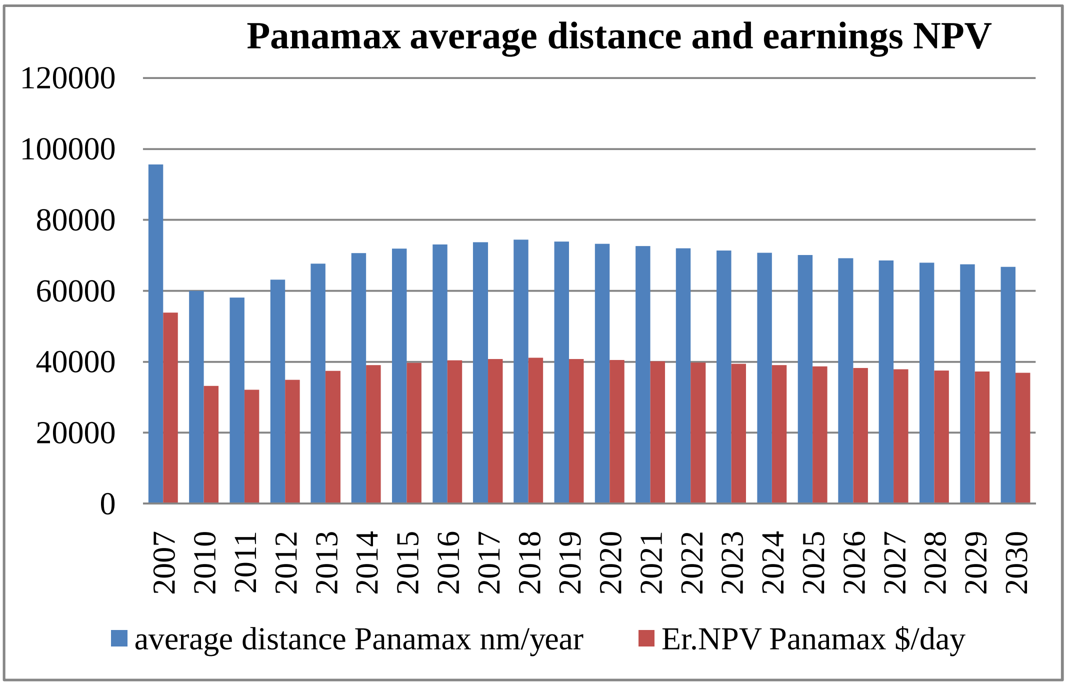

Figure 3.12 Earnings as NPV and average distances for Panamax ship 2010 – 2030
Source: Author and Second Greenhouse Gas Study, IMO, 2009

After the time at sea and the average distance during a year are found the average speed per year can be calculated with the following formula V average = S average/Time at sea. For example, for a Panamax ship the average speed in 2010 is 11.8 knots (60042 nm / 212.3 days = 11.8 knots). At the same time it was found that the average speed is correlated with the ME workload, thus using the data of the average speed, the ME workload can be calculated with the following formula:

ME workload = $0.904*x^{3.0339}$, where x is average speed. Figure 3.13 shows average speed and ME workload for Panamax ship during 2010 – 2030.

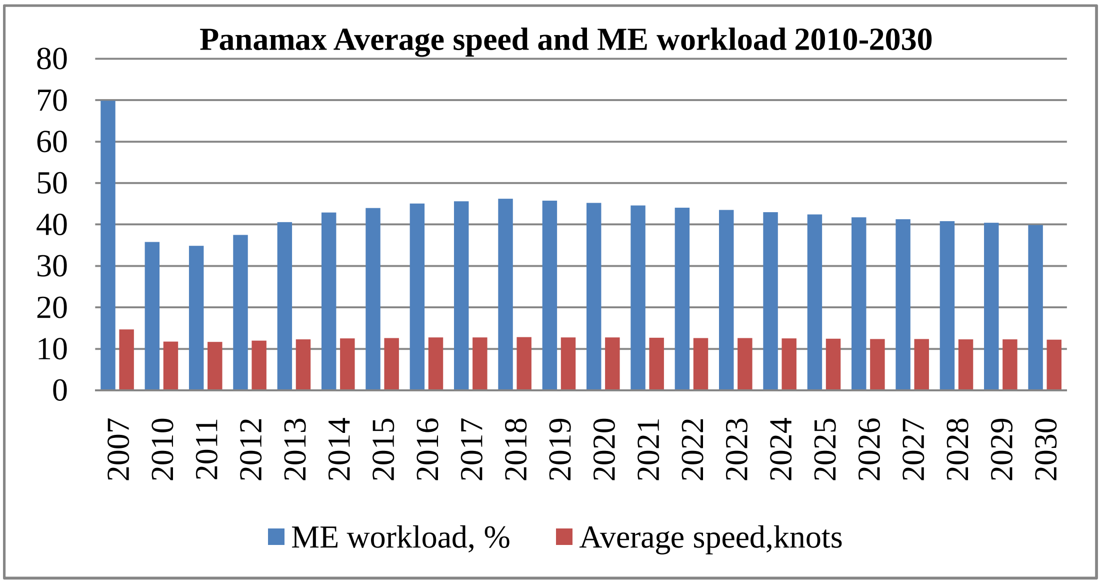

Figure 3.13 Average speed and ME workload for Panamax ship 2010 – 2030.
Source: Author and Second Greenhouse Gas Study, IMO, 2009

3.3.4. Days at sea at full and at economy speed. Calculations of fuel oil consumption

According to this study, days at sea represent total time at sea without exact division for time which a ship spends with full and economy speed; and it presents data based on the average speed. However, average speed is not linearly correlated with ME workload. Consequently, general information about Average speed and Average ME workload are not sufficient data to predict fuel oil consumption. For estimation of fuel oil consumption it is important to find the number of days at sea at a full speed, when ship will steam with ME workload about 90%, and days which ship will steam at slow speed with ME workload 11%. After that using SFOC it is possible to calculate correctly fuel consumption for different types of ships until 2030.

To calculate the time that a ship spends with full speed and with eco speed the system of equations should be solved. The first equation presents the formula of average speed, which could be determined as,

V average = (distance at full speed + distance at eco speed)/total days at sea, or

V av = (Vf*Tf + Ve*Te)/Ts. (1), where

Vf = full speed, for Panamax ship 16 knots,

Ve = economy speed, for Panamax ship 8 knots,

Tf = time at sea at full speed,

Te = time at sea at slow speed

Ts = total time at sea

Second equation presents number of days at sea, Ts = Tf + Te (2).

From the second equation Te = Ts – Tf.

Then we put this Te to the first equation, so V average:

Vav= (Vf*Tf + Ve*(Ts-Tf))/Ts, (3), from this equation we express Tf.

Tf = ((Vav-Ve)*Ts)/(Vf+Ve), (4). Then using the data of 2010 we can calculate

Tf = ((11.8-8)*212.3)/(16-8) = 100.5 days.

Finally deducting from total time at sea days at full speed time at economy speed can be found, e.g. for 2007 Te = 212.3-100.5 = 111.8 days.

After all data about economic activity of the ship are found the fuel oil consumption can be calculated by the following formula:

FOC = (Te*K2*P*SFOC) + (Tf*K1*P*SFOC) + (Tp*3), or

FOC = P*SFOC*(Te*K2+Tf*K1) + (Tp*3), where

FOC – fuel oil consumption tons per year,

Te – time at economy speed per year in hours,

Tf – time at full speed per year in hours, P – average ME Power in kW,

SFOC – Specific fuel oil consumption in tons/ kW per hour

K1 – ME Workload at full (100%) speed

K2 - ME Workload at slow (50%) speed

Tp – time at port in days, with a fixed fuel oil consumption 3 tons per day.

For example for Panamax ship in 2010 the expected fuel oil consumption will be:

9912*0.00017*(24*111.8*0.11 + 24*100.5*0.9) + (152.7*3) = 4,613 tons/year.

Figure 3.14 shows freight earnings and fuel oil consumption for a Panamax ship during the period 2010 – 2030.

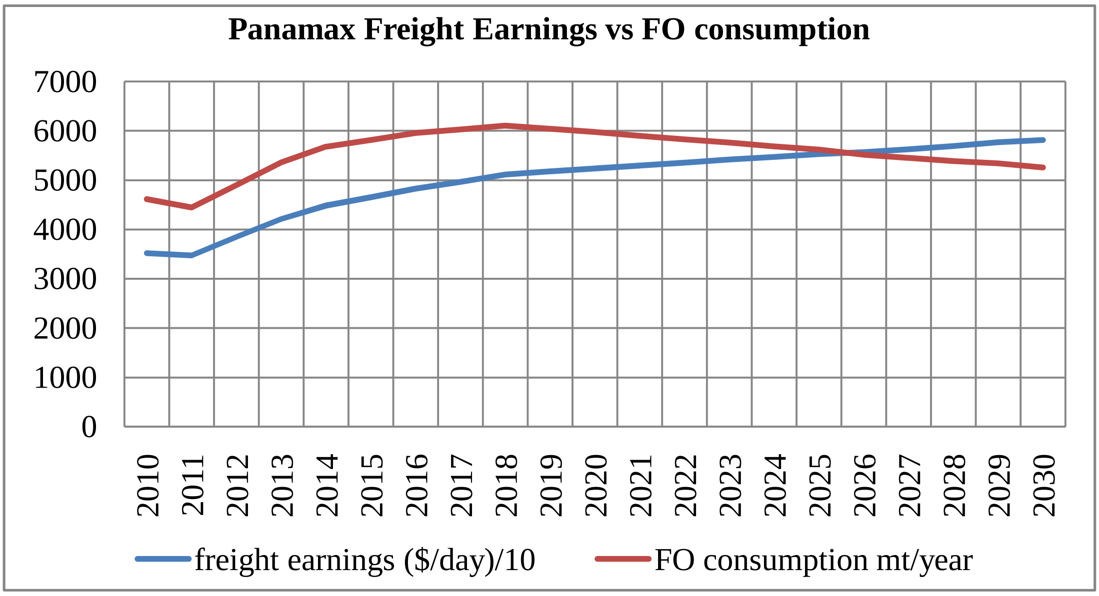

Figure 3.14 Freight Earnings vs FO consumption for Panamax ship 2010 – 2030.
Source: author

At the same time to analyze the economic impact of new regulations on different types of ships, it is very important to define the average time that a ship will spend in the SECA area. Thus on the next stage of fuel oil consumption forecasting time in SECA and consumption of HFO, LSFO, or MGO for different ships should be calculated.

3.4. Calculation of HFO, LSFO, MDO and MGO consumption

Calculation of the time that a ship will spend in SECA, and consequently will use low sulfur fuel till 2015 and MGO after 2015, is determined by main trading routes that are served by particular types of ships. The Baltic Exchange introduced special designed indexes for Panamax (BPI), Capesize (BCI) and Crude Oil carriers (BDTI) that shows average freight rates on the main routes, at the same time these routes are weighted according to their meaning for particular type of ships. For calculation of time that ships spend in SECA these routes will be evaluated from two main aspects: share of SECA area for these routes, weight of these routes in the market share for particular type of ship.

3.4.1. Panamax main trading routes time in SECA

A Panamax ship is a dry bulk cargo carrier with deadweight 60,000 – 80,000 tons, engaged in worldwide trading. The main cargos for Panamax ships are: iron ore, coal and grain. Also phosphate, bauxite and fertilizers are carried by Panamax ships. Dimensions are determined by the size of the lock in Panama Canal, for example a typical Panamax ship has the following characteristics: length 220m, beam 32 m, draft 13m (Institute of Chartered Shipbrokers, 2003, p. 157).

According to the Baltic Panamax Index (BPI), Panamax activity can be assessed taking into account four main routes with the same weight 25% each route.
P1A_03 Transatlantic RV; for this route example without SECA area is taken for instance from La Rochelle-Pallice to Hampton roads round voyage distance is 6600 nm.
P2A_03 SKAW-GIB/FAR EAST; for this route example with SECA area is concerned, so the distance from Rotterdam (SW bound) to the limit of SECA area is 370 nm, while the total distance from Rotterdam to Busan via Suez Canal 10700 nm.
P3A_03 Japan-SK/Pacific/RV; this route can not be in SECA area, total distance of Pacific round voyage from Busan to Los Angeles is 10500 nm.

P4_03 FAR EAST/NOPAC/SK-PASS; this route con not be in SECA, total distance from Busan to Vancover 4500 nm (Clarkson Securities, 2010).

For calculation of share of time that a ship spends in SECA, weighting coefficient of the route should be taken into consideration because routes can be not equally weighted. Thus share of time in SECA will be calculated by the following formula: SECA time (%) = Weight (%)*Route distance (nm)/SECA distance (nm).

Table 3.5 shows time that average Panamax ship spends in SECA area.

Table 3.5 Average time of Panamax in SECA

Route	Weight	Distance	SECA	SECA,%
P1A_03 Transatlantic RV	25	6600	0	0
P2A_03 SKAW-GIB/FAR EAST	25	10300	370	0.9
P3A_03 Japan-SK/Pacific/RV	25	10500	0	0
P4_03 FAR EAST/NOPAC/SK-PASS	25	4500	0	0
Total	100	31900	370	0.90%

Source: author and Clarkson Securities.
Calculation: author

Based on this information the amount of fuel in SECA area for Panamax ship per year can be found by the following formula:

FOCseca = FOCtotal*0.9%.

3.4.2. Capesize main trading routes and time in SECA

A Capesize ship is a dry bulk cargo carrier with deadweight 100,000 – 160,000 tons, engaged in worldwide trading. The main cargos for Capesize ships are: iron ore and coal. Typical dimensions of Capesize are: length 290m, beam 45m, draft 18m. According to (BCI) area of trading for Capesize ships is determined by 12 routes and every route has different weight (Clarkson Securities, 2010). Based on the same methodology that was earlier described regarding Panamax ship, the average time in SECA area for Capesize ship can be found.

Table 3.6 presents time that average Capesize ship spends in SECA area.

Table 3.6 Average time of Capesize in SECA

Route	Weight	Distance	SECA	SECA,%
C2; Tubarao –Rotterdam	10	4972	370	0.74%
C3; Tubarao - Beilun/Baoshan	15	10639	0	0.00%
C4; Richards Bay – Rotterdam	5	6979	370	0.27%
C5; W Australia (Dampier) – Beilu	15	3064	0	0.00%
C7; Bolivar – Rotterdam	5	4537	370	0.41%
C8_03; Hamburg trans Atlantic RV	10	7500	1360	1.81%
C9_03 Continent trip Far East	5	13600	370	0.14%
C10_03 Pacific RV (NSW – California)	20	23600	0	0.00%
C11_03China/Japan trip Mediterranean/Cont	5	13600	370	0.14%
C12 Gladstone – Rotterdam	10	13315	370	0.28%
Total	100	101769	3580	3.78%

Source: author and Clarkson Securities.
Calculation: author

Thus total amount of fuel that Capesize ship consumes in the SECA area can be calculated as: FOCseca = FOCtotal*3.78%.

3.4.3. VLCC main trading routes and time in SECA

VLCC is a tanker ship designed for carriage of crude oil. The typical deadweight of VLCC is 200,000 – 300,000 tons. Ships of this type are engaged in worldwide trading. Typical dimensions of VLCC are: length 350m, beam 55m, draft 24m. Special designed index for crude oil tankers (BDTI) describes 17 routes for different tankers that are engaged in transportation of crude oil. For determination of routes that are designed for VLCC and define their weighting factors the statistical data from McQuilling Services that were published in the review Tanker Demand and Trade Matrix are used. Based on the market share of every route the weighting factors are distributed (McQuilling Services, LLC, 2007). Table 3.7 presents data for calculation of time in SECA for average VLCC ship. Data in the line other

Table 3.7 Average time of VLCC in SECA

Routes	Weight	Distance	SECA	SECA,%
Middle East / Far East-SE Asia (Ras Tanura/ Chiba)	47%	6551	0	0%
Middle East / Carib-USG-USAC TD1 (Ras Tanura – Loop)	14%	12169	0	0%
West Africa / Far East-SE Asia (Offshore Bonny – Singapore)	7%	7949	0	0%
West Africa / Carib-USG-USAC TD4 (Offshore Bonny- Loop)	6%	5863	0	0%
Middle East / Europe (Ras Tanura – Rotterdam)	4%	11100	370	0.13%
Middle East / USWC (Ras Tanura – Long Beach)	2%	15146	0	0%
Carib-S America / Far East-SE Asia (Jose Terminal - Singapore)	3%	11047	0	0%
E Med-N Africa / Far East (Ceyhan – Singapore)	1%	12642	0	0%
E Med-N Africa / USG-Caribs (Ceyhan – Loop)	2%	6500	0	0%
Other (Average of 9 routes)	14%	9885	41	0.06%
Total	100%			0.19%

Source: author and McQuilling Services
Calculation: Author

Total amount of fuel that VLCC consumes in the SECA area can be calculated as: FOCseca = FOCtotal*0.19%.

3.4.3. AFRAMAX main trading routes and time in SECA

An Aframax tanker is a tanker ship mostly used for carriage of crude oil. The deadweight of the Aframax tanker is between 80,000 – 120,000 tons. Ships of this type are engaged mostly in regional trading on short and medium long routes. Typical dimensions of the Aframax ship are: length 250m, beam 35m, draft 15m. For calculation of times in SECA the same methodology as for VLCC is used. Table 3.8 presents data for calculation of time in SECA for average Aframax ships.

Table 3.8 Average time of Aframax in SECA

Routes	Weight	Distance	SECA	SECA,%
Mediterranean /Europe (Lavera – Rotterdam)	17%	2046	370	3.07%
Carib-Samerica/Carib-USG-USAC TD9,Puerto la Cruz – Corpus Christi	14%	2130	0	0.00%
SE Asia / Far East-SE Asia Seria – Singapore	15%	664	0	0.00%
Middle East / Far East-SE Asia-ISC Mina al Ahmadi – Singapore	11%	3791	0	0.00%
North Sea / Europe, TD 7 Sullom Voe – Wilhelmshaven	7%	518	518	7.00%
Baltic / Europe Primorsk – Rotterdam TD17	5%	1021	1021	5.00%
Mediterranean / Carib-USG-USAC Lavera – Corpus Christ	3%	5497	0	0.00%
North Sea / Carib-USG-USAC Sullom Voe – Corpus Christ	3%	4774	95	0.06%
Other (Average of 8 routes)	26%	2555.125	250.5	2.55%
Total	100%	22996.125	2254.5	17.68%

Source: author and McQuilling Services
Calculation: Author

Total amount of fuel that Aframax consumes in the SECA area can be calculated as: FOCseca = FOCtotal*17.68%.

3.4.5 Total cost of fuel oil

Based on information about fuel oil consumption and time that different ships spends in the SECA, the total cost of the fuel oil can be calculated with the following formulas:

till 2015 Total Cost = $(P_{HFO} * FOC*(1-T_{SECA})) + (P_{LSFO} * FOC*T_{SECA})$,

from 2015 till 2020: Total Cost = $(P_{HFO} * FOC*(1-T_{SECA})) + (P_{MGO} * FOC*T_{SECA})$,

from 2020: Total Cost = $(P_{MDO} * FOC*(1-T_{SECA})) + (P_{MGO} * FOC*T_{SECA})$; where

P_{HFO}, P_{LSFO}, $P_{MDO,}$ P_{MGO} – price of HFO380, LSFO380, MDO and MGO based on the forecast described in part 3.2

FOC – is fuel oil consumption per year based on the forecast described in part 3.4.

Figure 3.15 shows total cost of the fuel for Panamax, Capesize, VLCC and Aframax ships during the period from 2010 till 2030.

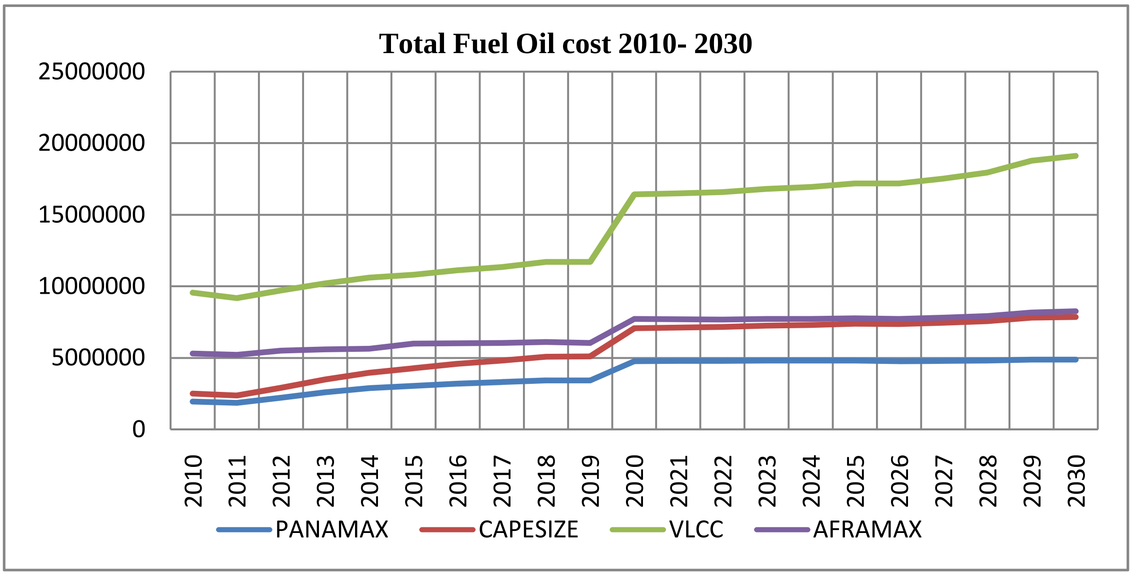

Figure 3.15 Total cost of fuel oil 2010 – 2030.
Source: author

3.5. Forecast CO_2 emissions price, amount of emissions and total cost for ships

The price of CO_2 is an important factor for assessment of investment for reduction of emissions of CO_2. Since there is still no adopted legislation scheme for limitation of CO_2 emissions from shipping, for calculation of CO_2 emission costs, the Emissions Trading Scheme option is used. With a high probability this scheme will be introduced in the nearest future. Based on the assumption that the shipping market is a part of the global market of CO_2, principles as those in the cape and trade system will also be implemented for shipping. In such situation ships that have level of CO_2 emissions higher than prescribed by the allowance, have to get extra quota in the open market. In such situation the ship that is more efficient regarding CO_2 emissions will produce savings of operational expenses. For forecasting of prices of CO_2 many different factors should be taken into account. One of the main drivers of the CO_2 emissions market is legislation that will limit greenhouse gas emissions. However, it is a very difficult task to analyze what kind of legislation regarding CO_2 emissions is going to be implemented in different countries or globally during next 20 years. Based on this assumption all forecast of CO_2 prices have several scenarios (Schlissel, 2008, p. 15). Figure 3.16 presents forecast of CO_2 prices form 2013 to 2030 based on 3 scenarios.

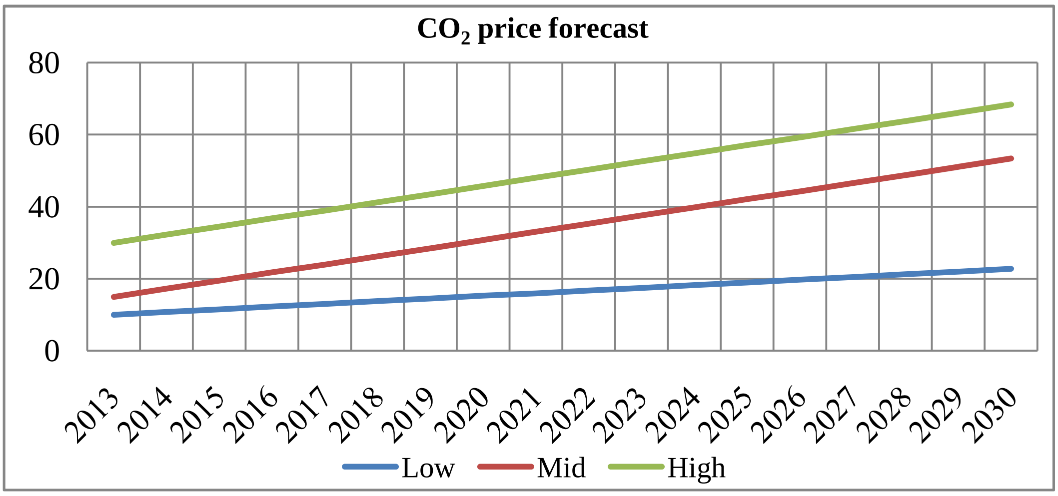

Figure 3.16 CO_2 price forecast $/ton, 2013 – 2030.
Source: Synapse Energy

A forecast with middle prices is taken for appraisal of investment in this research. The forecast is made from 2013 because there is no clear evidence that an emission trading scheme for shipping will be implemented earlier than in 2013.

After the price of CO_2 is determined, the amount of emissions and its total cost should be performed. Emissions of CO_2 are closely related with fuel oil consumption. According to the data presented in the IMO 'Guidelines for voluntary use of the ship Energy Efficiency Operational Indicator', in normal conditions 1 ton of HFO in process of combustion produces around 3.11 tons of CO_2, and 1 ton of MDO produces 3.21 kg of CO_2 (IMO, 2009). Taking into account this coefficient and forecast of fuel oil consumption amount of CO_2 emissions produced by ships during the period from 2010 to 2030 can be forecasted with the following formula: C = c1*FOC, where C total CO_2 emissions, c1=3.11, and FOC – fuel oil consumption for year i. Figure 3.17 presents the total cost of CO_2 and the amount of CO_2 emissions for the period from 2013 to 2030.

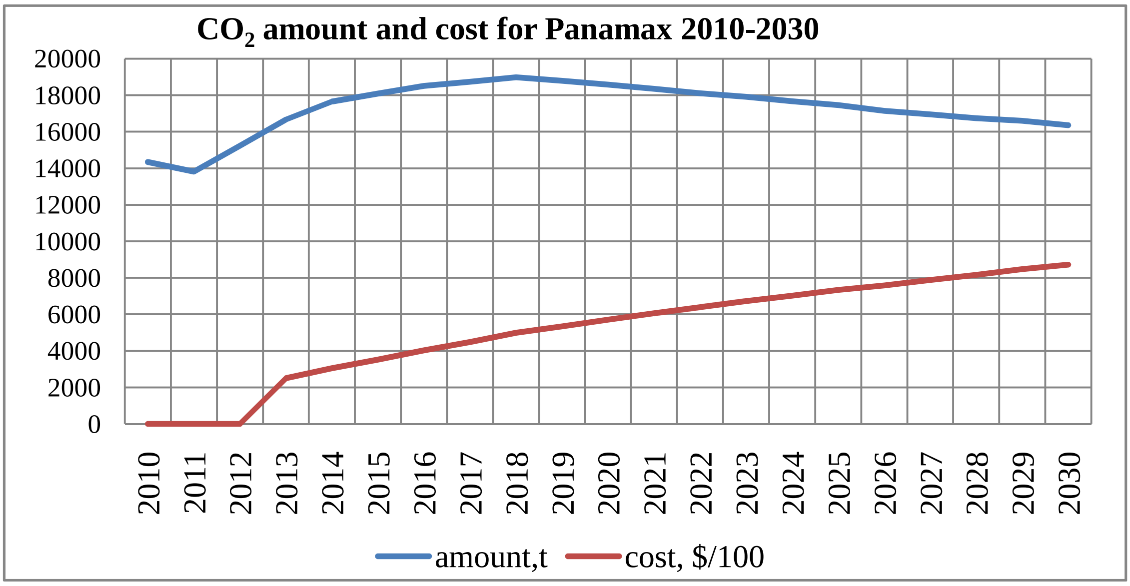

Figure 3.17 CO_2 amount and total cost for Panamax ship, 2010 – 2030.
Source: Synapse Energy, author.

However, it should be taken into consideration that the total cost of CO_2 emissions does not mean that a ship owner will have to pay for the full amount of CO_2 emitted. The ship owner will have to pay only for the emissions higher than a pre-established limit or quota. In this research it is assumed that after 2013 the maritime emission trading scheme will be introduced based on the cap and trade system. The baseline for this system is calculated on the EEDI basis. Taking into account that EEDI shows how many grams of CO_2 emitted per 1 ton*mile, the total amount of CO_2 baseline for emission in 2010 can be calculated by the following formula (International Maritime Organization, 2010):

Total CO_2 baseline = EEDI*DWT*Average distance,

where EEDI (baseline) = $a*(DWT)^{-c}$.

Table 3.9 presents results for possible baseline for CO_2 emissions for different ships.

Table 3.9 CO_2 emissions baseline for different ships.

	Panamax	Capesize	VLCC	Aframax
Coefficient a	1354	1354	1950.7	1950.7
Coefficient c	-0.5117	-0.5117	-0.5337	-0.5337
ME power, KW	9912	15108	24610	12726
DWT, tons	79000	149000	269000	115000
EEDI g CO_2/ton*miles	4.221851	3.051401	2.46792	3.88415
Baseline 2010, tons	20025.78	23070.43	49916	40164.98

Source: IMO 2010, author
Calculation: author.

Then based on the assumption that the baseline every year will be reduced by 2% of the previous year level to reach finally the goal of reduction of CO_2 emissions from the current level up to 30%, it is possible to calculate baselines for CO_2 emissions for the period from 2010 to 2030. Calculation of these baselines has a crucial meaning for the calculation of the discounted cost of CO_2 emissions. Discounted cost of CO_2 emissions can be calculated by the following formula:

Discounted cost CO_2 = CO_2 allowance – Total Cost CO_2, where

CO_2 allowance = Baseline amount CO_2 (tons)*average price CO_2 ($/t),

Total cost CO_2 = Actual amount CO_2 (tons)* average price CO_2 ($/t)

Thus Discounted cost CO_2 presents a real cost of CO_2 that the ship owner will have to pay or get in the open market based on the cap and trade principle. Figure 3.18 shows CO_2 allowance, total cost of CO_2, and discounted cost of CO_2 that the ship owner receives when CO_2 emissions from ship are below the cap or pay when CO_2 emissions are above the level.

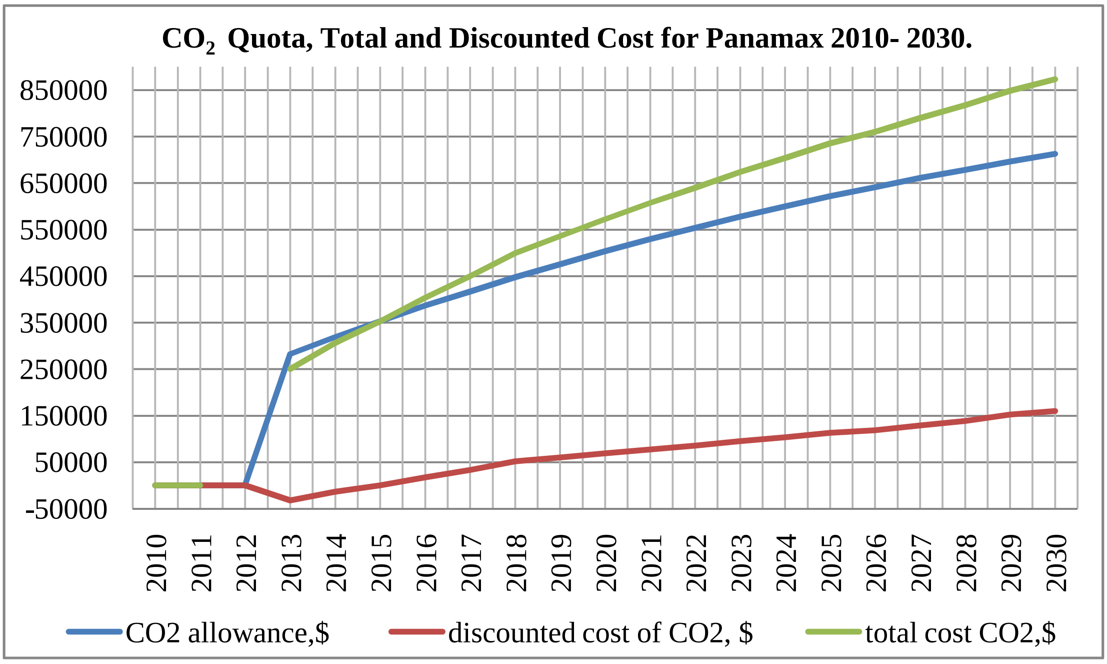

Figure 3.18 CO_2 amount and total cost for Panamax ship, 2010 – 2030.
Source: Synapse Energy, author.

3.6 Conclusion

The main goal of this chapter was the determination of the main market variables that will define the level of activity of ships from 2010 to 2030. To reach this goal a detailed methodology was presented for forecasting of the main economical variables for a Panamax ship. Also within this methodology, the relationship between different economic aspects, such as fuel oil prices, crude oil prices, fuel oil consumption, average speed and average distance per year, cost and amount of CO_2 emissions were investigated. Based on this data in Chapter 4 the detailed analysis of economical impact of new environmental regulations can be done.

Chapter 4. Analysis of economic impact of Annex VI on different types of ships

This chapter is dedicated to a comparative analysis of four business projects related with investment in purchasing new ships of different types. The main goal of this analysis is to show how new regulations regarding air emissions from ships will affect these projects. The results of this analysis are based on the comparison of projects before air emissions regulations entered into force and the present time. This comparison helps assessing the impact of new environmental regulations for different types of ships. Another goal of this chapter is to assess the various measures that will be implemented for different ships to comply with new regulations.

4.1. General provision

This part contains important features for investment appraisal and description of scenarios that will be used for analysis of the economic impact of Annex VI. Also this part provides all important data and information about the ships that will be used for assessment.

Analysis of the economic impact of Annex VI is done with help of Investment Appraisal for 4 different ships: Panamax, Capesize, VLCC and Aframax. Table 4.1 presents ships' profiles and their prices in Japanese shipyards (Simpson, Spence & Young Shipbrokers, 2010). Prices for new buildings were taken for the third quarter 2009 based on the assumption that new ships start operation in the first quarter 2010.

Table 4.1 Ships' characteristics and price.

Ship	Panamax	Capesize	VLCC	Aframax
Type	Dry bulker	Dry bulker	Oil tanker	Oil tanker
Deadweight	79,000 tons	149,000 tons	269,000 tons	115,000 tons
Price	$38,000,000	$69,000,000	$115,000,000	$ 60,000,000

Source: Simpson Spence & Young Shipbrokers

4.1.1. Description of scenarios

Scenario 0 presents a hypothetical situation when there is no regulation regarding emissions. Thus in this scenario there is no investment for ship's modernization and the cost of fuel oil is calculated based on the assumption that a ship consumes only HFO380. This scenario is useful to identify the difference between the present situation and the situation that was in shipping before.

Scenario 1 is a basic scenario that presents the situation when all regulations enter into force. However, there are no investments for ship modernization. Thus, to comply with regulations, ships use low sulfur fuel according to SOx regulations and buy extra quota for CO_2.

Scenario 2 is an optional scenario that presents the situation when all regulations enter into force, but the ship owner invests in fleet modernization and can save money on price differences between high sulfur and low sulfur fuel and save quota for CO_2 emissions.

The attractiveness and profitability of the various projects are established using the payback time, earnings before interests, taxation and amortization (EBITA), and return on investment (ROI).

4.1.2 Limitations

The initial investment for project (Panamax, Capesize, VLCC, Aframax), or investments in modernization of ships are performed by ship owners as a lump sum without bank loans and interests. This assumption is done to avoid additional difficulties regarding time value of money and capital expenses.

The price of new buildings is the price without any modernization of a ship related to Annex VI regulations. Cost of modernization for different ships is calculated with reference to the green ship project that was mentioned in Chapter 2, as proportion per KW of main engine power. Table 4.1 presents cost of modernization for different type of ship with reference to the main engine power.

Table 4.2 Cost of modernization for different type of ship

Type of ship, dwt	ME power	Modernization cost	$/KW
Handysize, 35,000t	7410 KW	$ 4,310,000	$582
Panamax, 79,000t	9912KW	$ 5,765,280	$582
Capesize, 149,000t	15108 KW	$ 8,792,855	$582
VLCC, 269,000t	24610KW	$ 14,323,020	$582
Aframax, 115,000t	12726 KW	$ 7,406,532	$582

Source: author and Schnack 2009.
Calculation: author.

All data that presents future prices and other economic variables are taken from the forecast described earlier in Chapter 3.

4.2. Methods for Investments Appraisal of projects

Payback time is a period of time required for the return on investment to cover the amount of the initial investment. However, this method does not take into account financial risk and opportunity cost. Payback time can be calculated by the following formula:

$$\sum_{i=0}^{k-1} Ai \leq 0 \text{ , } and \sum_{i=0}^{k} Ai \geq 0.$$

Where A – Cash flow, i = year, k – payback time (Cariou, 2009, p. 13). Or by other words calculation of payback time is based on the calculation of cumulative cash flow (Acum), and determination of time when it turns from negative to positive. Cumulative cash flow is calculated as sum of net cash flows per years that project is active. Net cash flow is the amount of money that a project earns and can be calculated as follows:

Net Cash $Flow_{2011}$ = (Earnings ($/day) * days trading) – total cost per year, where total cost per year is total fuel cost, CO_2 emissions discounted cost, for 2010 price of the ship and for 2012 in case of scenario 2 price of modernization.

EBITDA (Earnings Before Interest, Taxes, Depreciation, and Amortization). This method shows cash earnings without tax-jurisdiction effects and does not take into account reduction of assets' price (Cariou, 2009, p. 15). For calculation of EBITDA for ships taken for assessment the following formula should be used:

EBITDA = $Acum_{2030}$ – $Price_{2010}$, or

EBITDA = Total earnings – Total cost – Depreciation of the ship, where

Total earnings - is the summation of all the earnings that a ship generates during the service, and also $1,000,000 in scrap value.

The total cost - is summation of the expenses that a ship spends for fuel oil and CO_2 during her service and also the initial price of the ship, e.g. for Panamax ship is $38,000,000. For Scenario 2 also the price of modernization, e.g. for Panamax ship is $5,765,280.

The price of the ship is the initial price of the ship, e.g. for Panamax ship is $38,000,000.

Thus the formula for calculation of EBITDA can be presented in the other way:

EBITDA = Total earnings + Scrap value – (Total operational cost + Price) – Price, or

EBITDA = Total earnings + Scrap value - Total operational cost – 2*Price.

Also for comparison of means between different scenarios, it can be useful to calculate means of the EBITDA per year. This mean can be calculated in formulas follows:

EBITDA p.a. = ($Acum_{2030}$ – $Price_{2010}$)/20, where:

$Acum_{2030}$ is meaning of cumulative Net cash flow in 2030. Time when project should be finished and ship should be sold for scrap for $1,000,000.

$Price_{2010}$ = is initial investment for purchase the new ship.

20 years – is life span of vessel, time of project.

Return on Investment (ROI) – is the ratio of the profit gained from the project on an investment relative to the amount of money invested. This ratio is expressed in percents and calculated by the following formula (Cariou, 2009, p. 15):

ROI = EBITDA p.a / initial capital, where

initial capital - is investment for purchasing the new ship.

From the description of tools that are used for investment appraisal, logically the first step of determination of these parameters is calculation of cumulative cash flow.

4.2.1 Payback time and cumulative cash flow calculation

Cash flow is calculated on the yearly basis by the following formula:

A = (earnings per day)*355 days – (total operational cost per year + price).

For example for a Panamax ship A_{2010} = \$-38,000,000; A_{2011} = \$10,565,000, A_{2012} = \$16,042,769. Figure 4.1 presents earnings and total operational cost, and net cash flow (A) on a yearly basis for a Panamax ship, for the Scenario 1.

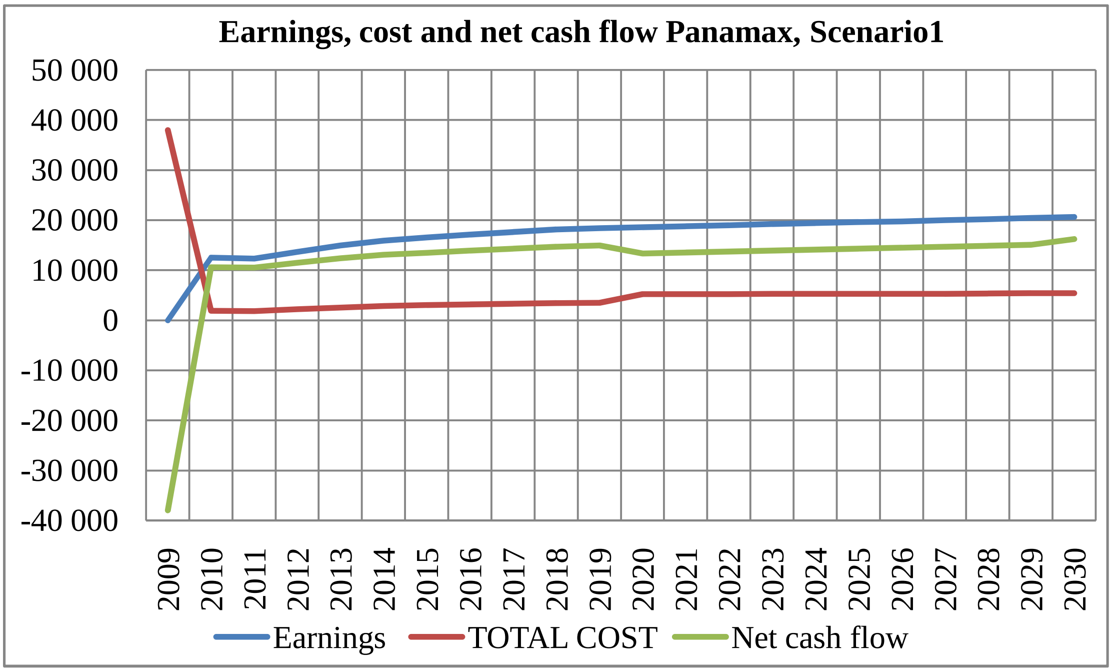

Figure 4.1 Earnings, cost and net cash flow for Panamax ship, 2010 – 2030, Scenario 1.
Source: author.

Results of net cash flow for Capesize, Aframax and VLCC based on the Scenario 1 are shown in Figure 4.2.

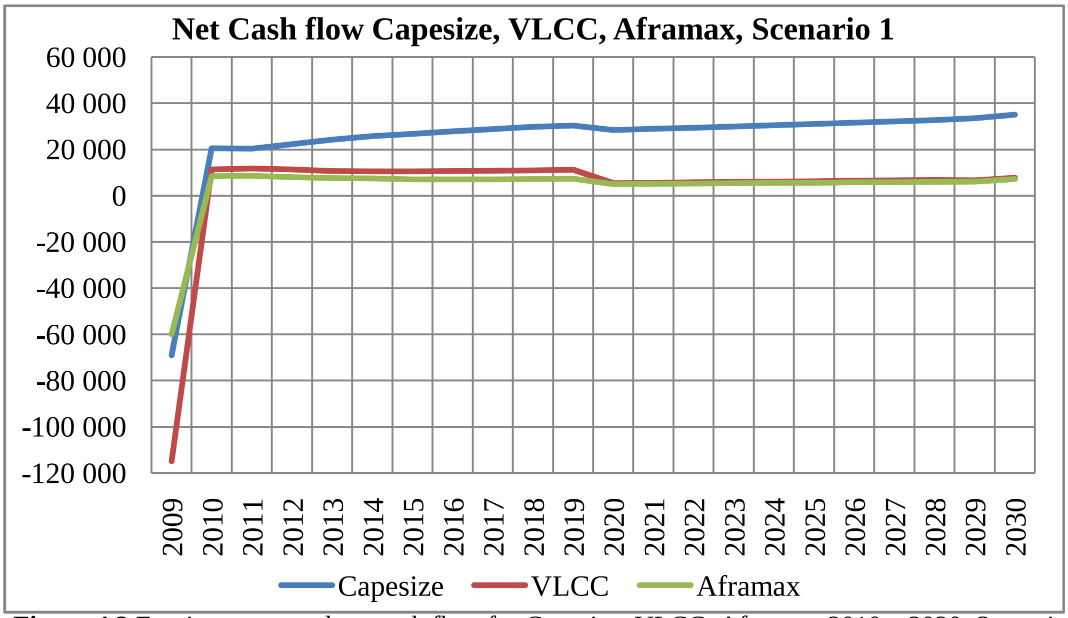

Figure 4.2 Earnings, cost and net cash flow for Capesize, VLCC, Aframax; 2010 – 2030, Scenario 1.
Source: author.

Figure 4.3 shows Cumulative cash flow (Acum) and net cash flows for a Panamax ship in the Scenario 1. Also from this chart Payback time can be found as the year when the graph of cumulative cash flow becomes positive, thus for a Panamax ship that was delivered in 2009 and started service in 2010, investments will be covered in 2013.

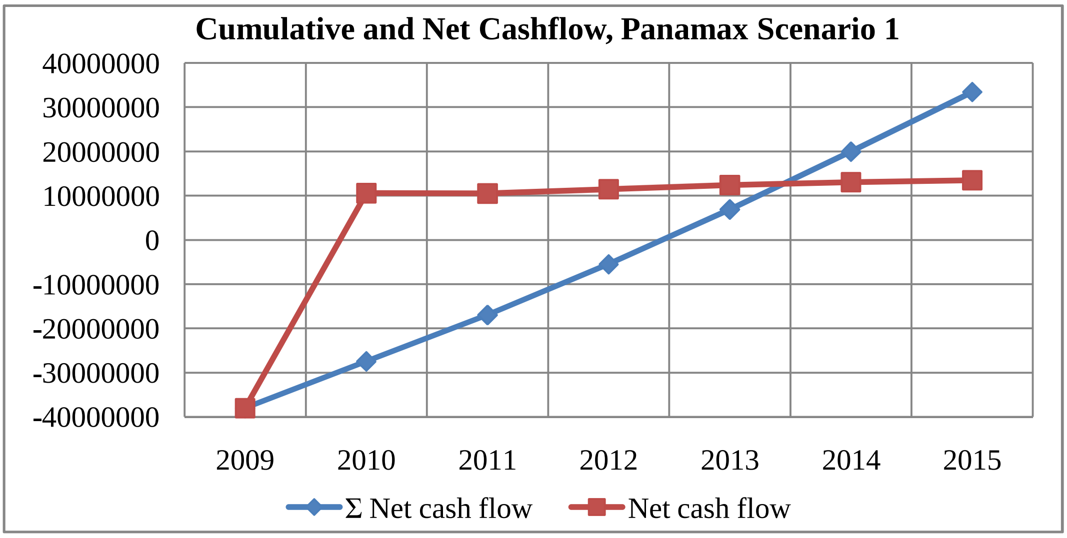

Figure 4.3 Cumulative and Net Cash Flow for Panamax ship
Source: author.

The same methodology for calculation of cumulative cash flow (A_{cum}) is used for other ships based on Scenario 0, Scenario 1 and Scenario 2; final results are presented in Figure 4.4.

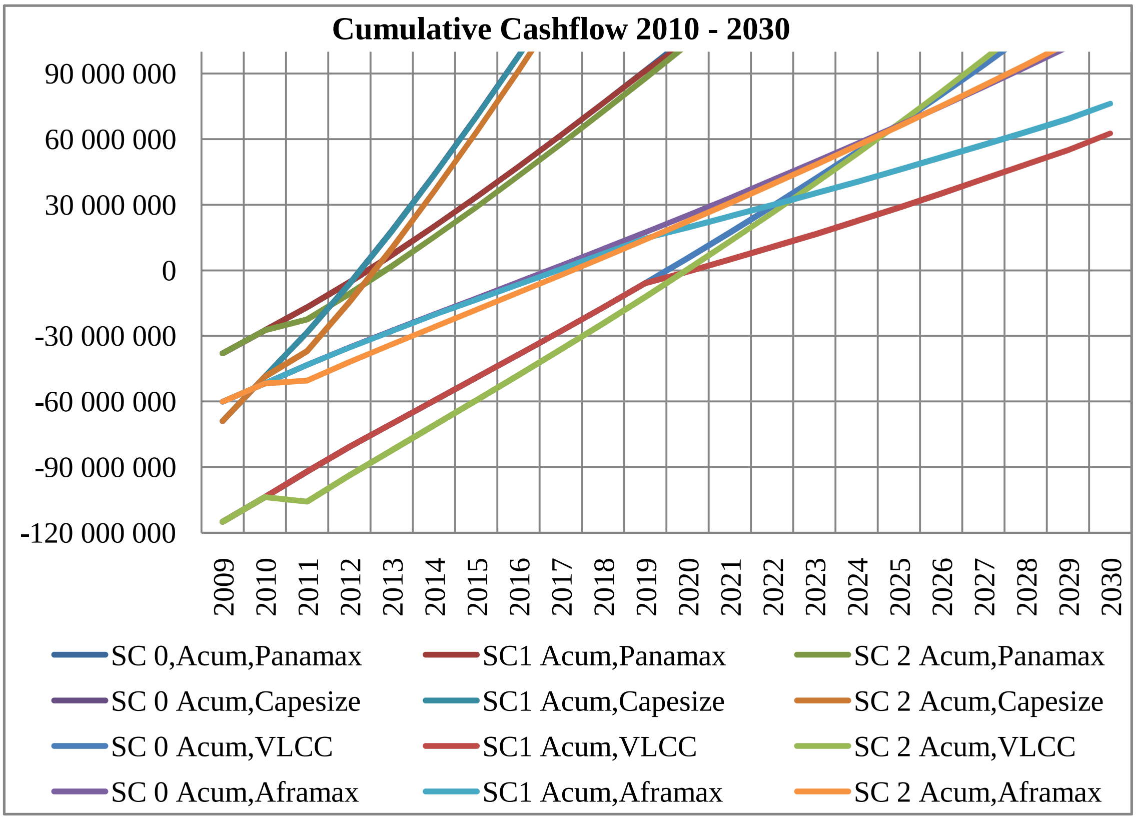

Figure 4.4 Cumulative cash flow, 2010 – 2030.
Source: author.

Graphs of Cumulative cash flow for Panamax and Capesize show that these ships will generate more profit and assume to be the best options for investment in the present market situation. This can be partially explained by the boom in 2007 and 2008 after which the dry bulk market fell down in 2009. The Collapse of markets made the price of new building and second hand vessels relatively low. However forecast based on statistical data shows that after 2012 the market will recover and in the long term perspective Panamax and Capesize ships will generate the same earnings as before the crisis. The situation with the tanker fleet is more complicated. The tanker market was not so overheated before the crisis, thus this market went through the crisis easier than the dry bulk market. Prices for new buildings did not drop in comparison with dry bulk ships; also statistical based forecast do not show that these ships will generate earnings as they were before the global economic crisis. Based on the Data from Figure 4.4 payback time, EBITDA and ROI for all ships can be found in accordance with formulas mentioned before. Table 4.1 shows results for payback time for scenario 0, scenario 1 and scenario 2.

Table 4.3 Payback time.

	Scenario 0	Scenario 1	Scenario 2
Panamax	2013	2013	2013
Capesize	2013	2013	2013
VLCC	2020	2021	2020
Aframax	2017	2017	2018

Source: author

From this table it can be concluded that payback time of the projects is not much affected by the new regulations. For Panamax and Capesize in all scenarios, payback has a constant mean. The difference between payback time for VLCC in Scenario 1 and in other Scenarios can be explained by high fuel oil consumption that affects operational cost; however the difference is also not so critical. Aframax has in scenario 2 a different mean of payback time because of high initial investment in modernization, but due to moderate FO consumption and money savings in the SECA only after 2015 will this modernization increase payback time for the whole project for 1 year.

Finally, regarding payback time it can be concluded that regulations that limits emissions from shipping do not have significant impact on payback time. Extra fuel cost or investment in modernization of fleet also does not affect pay back time.

4.2.2 EBITDA and ROI calculation

Calculation of EBITDA and ROI is based on the cumulative cash flow, thus all data for assessment with the help of this method are taken from Figure 4.4. As to initial investments (price of purchase of the ship), they are taken from part 4.1. Table 4.2 shows results for EBITDA for ships based on scenario 0, scenario 1 and scenario 2.

Table 4.4 EBITDA per annum.

	Panamax	Capesize	VLCC	Aframax
Scenario 0	11 684 336	24 877 838	1 905 628	2 830 050
Scenario 1	10 578 242	22 982 355	- 2 617 981	925 118
Scenario 2	11 602 349	24 571 227	1 411 946	2 845 529

Source: author

From this table it can be concluded that earnings for all ships based on scenario 1 are less than based on the two other scenarios. Scenario 1 is the actual situation and for VLCC and Aframax ships this scenario looks more than pessimistic and makes these projects even unprofitable. At the same time, modernization of ships (scenario 2) allows for VLCC, Capesize and Panamax vessels to generate almost the same EBITDA than they could earn, based on hypothetical scenario 0. For the Aframax ship EBITDA after modernization could be even higher than EBITDA based on scenario 0. Thus, it can be concluded that the economic impact of new environmental regulations is not significant in case of opting for the modernization of the fleet. Moreover, these regulations serve as extra motivation for investing in energy saving technologies that make services of the ship more profitable.

Return on investment is last method that is used for investment appraisal of four projects. Table 4.5 shows results of ROI for three scenarios.

Table 4.5 Return on investment.

ROI	Panamax	Capsize	VLCC	Aframax
Scenario 0	30.75%	36.05%	1.66%	4.72%
Scenario 1	27.84%	33.31%	-2.28%	1.54%
Scenario 2	30.53%	35.61%	1.23%	4.74%

Source: author.

Conclusions that can be derived from this data are almost the same that were done based on the EBITDA method. Means of ROI shows one more time that investment in energy saving technology is the best option for all ships.

4.3 Analysis of results

Based on the results of the main parameters that were used for investment appraisal, it is possible to analyze the impact of new regulations on costs and earnings of different ships. This method describes change of cost or earnings that the ship owner will have to do to equalize EBIDTA and ROI based on Scenario 1 or Scenario 2 with Scenario 0. For example, for a Panamax ship EBIDTA based on the Scenario 0 is \$11,684,336 per year; however, EBITDA based on the Scenario 1 is \$10,578,242; in such situation this can be explained by the extra cost that shipowner will pay for the fuel with higher grade and price. To equalize EBITDA, based on Scenario 0 and Scenario 1 there are two options: to cut cost, or to increase earnings (freight rates); to calculate the means of this options is possible by the following formula:

$E0 - E1 = (Er0 - b \times Er1) - (C0 - a \times C1) - (P0 - P1)$, where

E0, E1 – EBITDA 2010 - 2030 based on Scenario 0 and Scenario 1,

Er0, Er1 – Total earnings 2010 - 2030 based on Scenario 0 and Scenario 1,

C0, C1 – Total cost 2010 – 2030 based on Scenario 0 and Scenario 1,

P0, P1 – Price of new building based on Scenario 0 and Scenario 1.

a - is coefficient that equal, C1/C0 and shows how cost should be changed to equalize EBITDA

b - is coefficient that equal Er1/Er0, and shows how earnings should be changed to equalize EBITDA.

Taken into account that E0 = E1, Er0 = Er1, b=1, P0 = P1 it is possible to find coefficient a, that shows how total cost based on Scenario 1 should be changed to equalize EBITDA based on Scenario 0 and Scenario 1; in case when Earnings are the same based on both Scenarios.

$$0 = 0 - (C0 - a \times C1) - 0,$$

$$a = \frac{C0}{C1}$$

Coefficient b can be found taken by the following formula:

$$0 = (Er0 - b \times Er1) - (C0 - C1) - 0,$$

$$b = \frac{C1 - C0 + Er0}{Er1}$$

Where Er1 = E1 + C1 + P.

Table 4.6 shows Total EBITDA, Total Cost and Total Earnings of Panamax ship for the period from 2010 to 2030.

Table 4.6 Total EBITDA, Total Cost and Total Earnings of Panamax ship.

	EBITDA	Cost	Earnings	Price
Scenario 0	233,686,722	102,238,785	373,925,507	38,000,000
Scenario 1	211,564,842	124,360,665	373 925,507	38,000,000

Source: author

Based on the data presented in this table to equalize EBITDA between Scenario 1 and Scenario 0, cost1 should be equalized with cost 0, by multiplication on coefficient a, where a = 102,238,785/124,360,665 = 0.82212, or in other words this coefficient shows that Cost1 should be reduced by (1-a), % to equalize EBITDA based on scenario1 with EBITDA based on Scenario 0.

In case when there is no possibility to cut the cost, earnings should be increased by Earnings* b, where

$$b = \frac{C1 - C0 + Er0}{E1 + C1 + P} = 1.059161$$

This coefficient b shows that to equalize EBITDA based on Scenario1 with EBITDA based on Scenario 0, earnings based on Scenario 1 should be increased by 1.059161, or by the other words freight rates should be increased by 5.9%

Based on this method changes in costs and earnings for other ships can be found, with results presented in Table 4.7.

Table 4.7 Cost and Earnings equalizers for different Scenarios.

	Scenario 1/Scenario 0		Scenario 2/Scenario 0	
	Cost	Earnings	Cost	Earnings
Panamax	-17.778%	5.91612%	-1.579%	0.43852%
Capesize	-18.791%	5.19035%	-3.608%	0.83958%
VLCC	-20.4%	17.87504%	-2.721%	1.95079%
Aframax	-17.952%	13.10455%	0.178%	-0.10648%

Source: author.

From this table it is possible to conclude that for all four types of ships Scenario 1 brings almost the same cost increase of around 18% in comparison with Scenario 0. This finding also allows to conclude that the economical impact from new regulations from the point of view of extra cost will be the same for all types of ships. However, for customers of different types of ships, the impact of new environmental regulations is different, thus dry cargo freight rates are less affected than tanker freight rates. In total dry bulk market freight rates increase around 5%, while for the tanker market by 13% for Aframax and even for 20% for VLCC. Based on this data, it can be concluded that tanker markets will be more affected than other markets by the new environmental regulations.

However, data presented in Table 4.7 show freight rates change based on the assumption that ships that are described in the model as it was described in Chapter 3.4 spend limited time at SECA. To analyze better the economical impact from the new regulations, it is necessary to compare results from the standard model that was presented above with cases when ships spend different time in SECA.

4.3.1 Analysis of total cost change due to change of time in SECA

A comparison between scenario 1 and scenario 0 identified that the economic impact from new regulations can be assessed via calculation of total operational costs that will increase due to low sulfur fuel or CO_2 regulations. At the same time, for scenario 1 for all types of ships time in SECA was determined as a constant in Chapter 3.4. In this part time in SECA based on Scenario 1 is changed to identify changes in total cost. Figure 4.5 presents results for change of the fuel oil cost for a Panamax ship due to change of the time that ship spends in SECA.

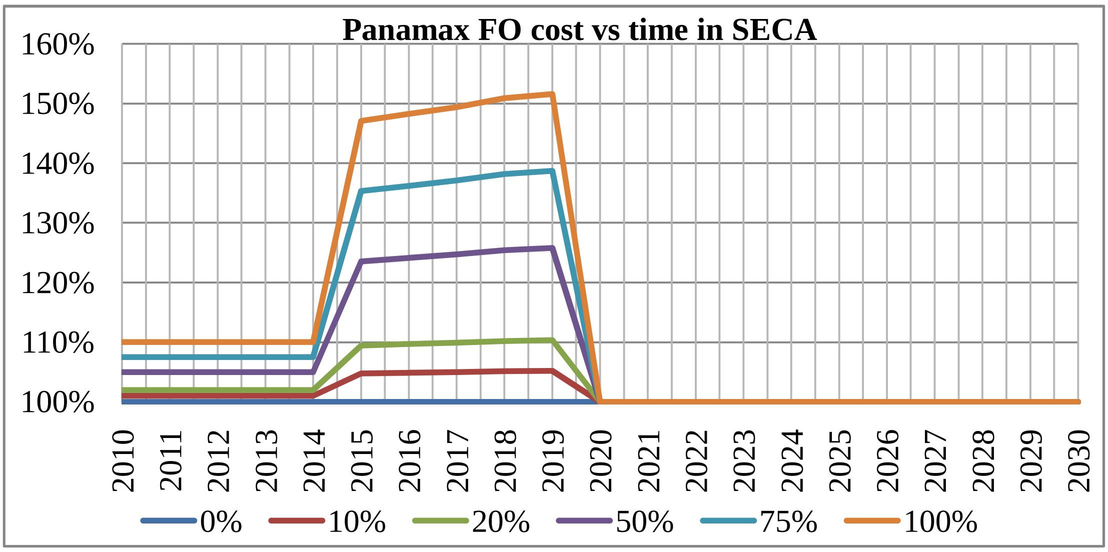

Figure 4.5 Fuel oil cost and time in SECA for Panamax ship, 2010 – 2030.
Source: author.

From this figure it is possible to conclude that fuel oil cost can increase by more than 50% if a ship spends 100% of sailing time in the SECA. This data shows that during the period from 2015 – 2020 when outside SECA area a ship will use HFO and in within SECA MGO additional time in SECA will have a crucial impact on the operational cost. After 2020 even outside SECA ships will have to use MDO, thus it would not be any difference between fuel oil cost inside and outside SECA because MDO and MGO prices are assumed to be the same. However, the cost presented in this figure reports only the cost of fuel that is only one part of the total cost that also include the cost of CO2 and the initial price of the ship. Thus to define the increase in costs due to different time in SECA the following formula should be used:

$$DCost\ SECA_{0\%-100\%} = \frac{Total\ FOCost_{seca100\%} + dCO2Cost + Price}{Total\ FOCost_{seca0\%} + dCO2Cost + Price}\ , \%$$

Where, Total $FOCost_{seca0\%}$ and Total $FOCost_{seca100\%}$ - is the total cost of fuel for the period from 2010 to 2030 based on the different time that ship will spend in SECA.

dCO_2Cost – is the total cost of CO_2 that should be purchased on the open market in the cap and trade basis during the period from 2013 to 2030.

Price – is the initial price of the ship.

Then with the help of this formula, it is possible to calculate the change of the total cost for different types of ships from 2010 to 2030, if they spend different share of time in SECA. Results of these calculations are presented on the Figure 4.6.

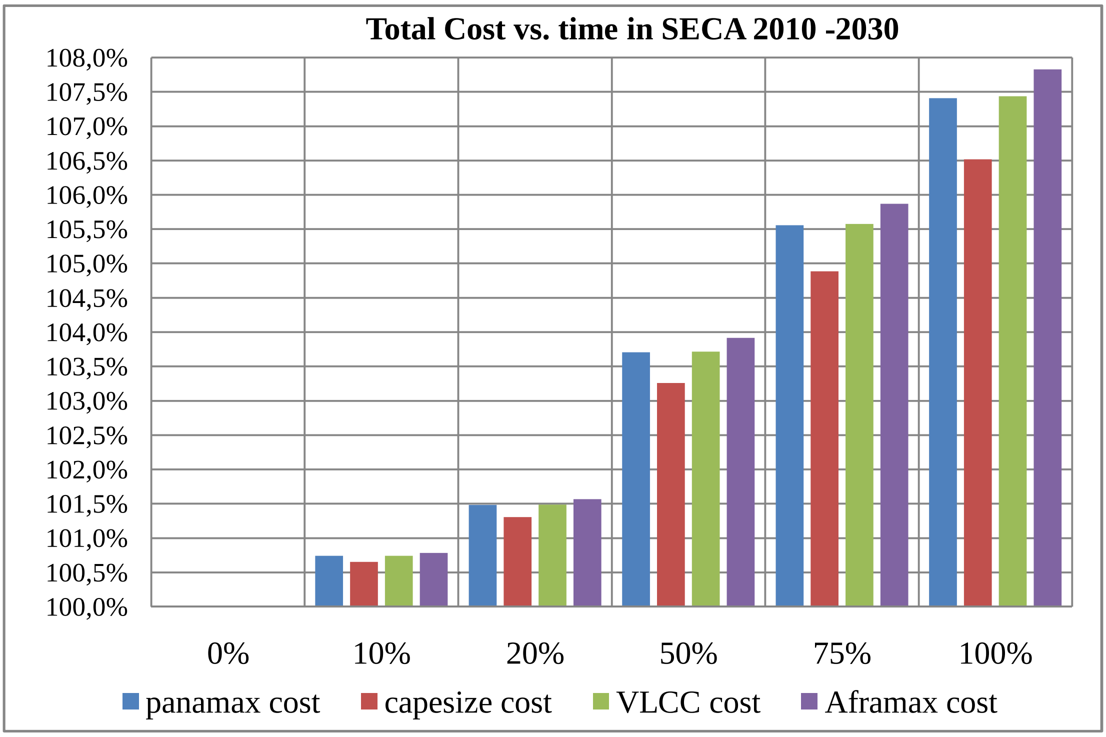

Figure 4.6 Total cost and time in SECA 2010 - 2030.
Source: author.

The results, which are presented in Figure 4.6, have a crucial meaning for determination of the percentage on which cost or earnings should be changed in case of comparison between Scenario 0 and Scenario 1. Or in other words $DCost_{seca}$ shows the amount of price that should be cut to equalize total cost based on scenario 1 with standard constant means of time in SECA described in Chapter 3.4, and the total cost based on Scenario 1 with flexible means of time in SECA. Furthermore, based on the above mentioned methodology that was described for making Table 4.7, $DCost_{seca}$ allows comparing the total cost based on Scenario 0 and the total cost based on scenario 1 with flexible time in the SECA. The final results of this comparison are presented in Table 4.8.

Table 4.8 Cost and Earnings equalizers for Scenarios with flex time in SECA.

	Panamax	**Capesize**	**VLCC**	**Aframax**
Cost Sc0/Sc1 – SECA0%	-17.734%	-18.590%	-20.388%	-16.816%
Cost Sc0/Sc1 – SECA10%	-18.339%	-19.117%	-20.975%	-17.462%
Cost Sc0/Sc1 – SECA20%	-18.935%	-19.638%	-21.554%	-18.099%
Cost Sc0/Sc1 – SECA50%	-20.672%	-21.159%	-23.241%	-19.950%
Cost Sc0/Sc1 – SECA75%	-22.064%	-22.384%	-24.593%	-21.429%
Cost Sc0/Sc1 – SECA100%	-23.408%	-23.571%	-25.897%	-22.855%
Earnings Sc0/Sc1 – SECA0%	5.89396%	5.12212%	17.86201%	12.10802%
Earnings Sc0/Sc1 – SECA10%	6.14018%	5.30167%	18.51339%	12.67167%
Earnings Sc0/Sc1 – SECA20%	6.38640%	5.48122%	19.16476%	13.23532%
Earnings Sc0/Sc1 – SECA50%	7.12507%	6.01987%	21.11889%	14.92627%
Earnings Sc0/Sc1 – SECA75%	7.74063%	6.46875%	22.74733%	16.33540%
Earnings Sc0/Sc1 – SECA100%	8.35618%	6.91763%	24.37577%	17.74452%

Source: author.

Results from this table should be referred to results of Table 4.7. The conclusion that was drawn before regarding the results of Table 4.7 can be applicable for the results of this table. Thus the level of cost decrease for equalizing with scenario 0 for different types of ships in every level of time in SECA is almost the same. However, the effect on the earnings increase is different. Consequently, customers of tankers will be more affected by the new environmental regulations regardless the time that different ships will spend in SECA during their service.

At the same time, for all types of ships the percentage of cost reduction has almost the same means; this difference can be a real motivation for modernization for investors who are going to invest in any of these projects. For all types of ships modernization that reduces fuel oil consumption and CO_2 emissions and allows for ships to use HFO even in the SECA area, seems to be the best alternative that cuts the cost and equalizes the total cost in scenario 0 and scenario 1; thus canceling any economic impact from new regulations and not increasing freight rates.

4.3.2 Determination of level of investment to modernization

As it was stated in the previous part, modernization of vessels can be assumed as a tool that allows keeping freight rates at the forecasted level, by decreasing the operational cost of ships, after all regulations regarding air emissions from ships will enter into force. Energy saving technologies decrease fuel oil consumption and the total operational cost. However, the cost of these technologies can be too high in comparison with their efficiency, thus the determination of cost and efficiency of modernization is a crucial part of the analysis of the economic impact of new environmental regulations.

Based on the results presented in Table 4.7, an assessment of investments for modernization can be done. For dry bulk ships, modernization, under the conditions that were specified above, brings extra cost and requires increasing freight rates in average of 1%; however, the trend for the whole sector is the same. At the same time, modernization of VLCC and Aframax has opposite trends regarding extra cost. Aframax after modernization can be even more profitable than a ship that was used before regulations entered into force, and the ship owner, who invests in modernization, can decrease freight rates by 0.1% from the level of scenario 0; while VLCC even after modernization to achieve the level based on scenario 0 has to increase freight rates almost with 2%.

The difference between trends that show change of extra cost for different ships in case of modernization can be explained by different levels of efficiency of modernization for a particular type of ship. Means that show change of cost based on scenario 2 in comparison with scenario 0 at the same time show the initial amount of investments for modernization to equalize cost based on scenario 0 and scenario 2. The difference between total cost based on scenario 2 and scenario 0 can be calculated by the following formula:

$dCost_{0-2} = C_0 - C_0 \times a_{0-2}$, where Co – cost for scenario 0,

a_{0-2} – coefficient that show cost difference between Scenario 0 and Scenario 2.

For example, for a Panamax ship $dCost_{0-2}$ = $-1,639,747. This mean shows that to equalize costs between Scenario 0 and Scenario 2, the cost of Scenario 2 should be reduced for $dCost_{0-2}$. From this it is possible to conclude that to equalize costs between Scenario 0 and Scenario 2 the cost of modernization should be reduced for $dCost_{0-2}$. For a Panamax ship the cost of modernization should be $4,125,532 instead of $5,765,280. At the same time costs based on scenario 2 directly depend on the effectiveness of modernization. The more savings that modernization brings will result in a decrease of the total cost. Table 4.9 presents means of initial investments and percentage of reduction of fuel oil consumption.

Table 4.9 Investments to modernization and their efficiency.

	Panamax	Capesize	VLCC	Aframax
Cost (for 7.7%)	4,152,532	2,660,648	4,449,370	7,716,110
Effectiveness current	7.70%	7.70%	7.70%	7.70%
Cost current	5,765,280	8,792,856	14,323,020	7,406,532
Effectiveness for current cost	9.8%	13.3%	11.5%	7 %

Source: author.

Based on the data from Table 4.9 it is possible to find functions that describe the level of investment and effectiveness of modernization to equalize costs between scenario 0 and scenario 2, thus to cancel the impact from the new environmental regulations. These functions have a crucial meaning for the assessment of strategies related with investments to ships modernization. These functions for different ships are presented in Figure 4.7.

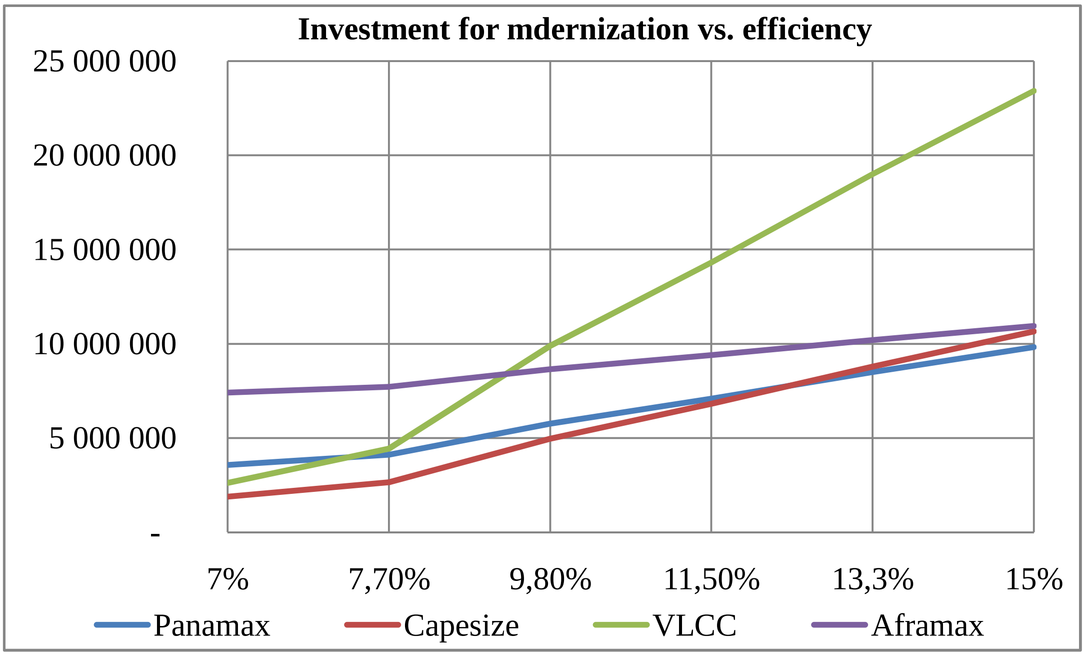

Figure 4.7 Investment for modernization vs. efficiency of modernization.
Source: author.

At the same time this function shows the amount of money that can be saved in case of reduction of fuel oil consumption for different percentages, provided that ship is totally equipped with technologies that allow using HFO even in SECA until 2020 or worldwide after 2020. For example, in the low level of reduction, the highest savings will be generated by Aframax ships and even if 7% of economy brings same amount of savings as for Panamax or Capesize 13% of fuel economy. At the high level of fuel consumption reduction the highest savings will be generated by VLCC ships, for example 15% of fuel economy saves in case of VLCC $23,417,172, this is more than for an Aframax ship $10,944,568 and also more than for a Panamax ship $9,825,606 or a Capesize ship $10,654,419. These figures show that tanker ships are more eligible for energy saving technologies and can also be evidence that proves that tankers are more affected by new regulations than dry cargo ships.

4.4 Conclusion

The first goal of this chapter was to identify the economic impact of new regulations for various shipping projects. With the help of tools that are used for investment appraisal, it appears that the payback time for all types of ships remains the same, while EBITDA and ROI vary. The main driver to explain such differences is the extra costs due to fuel prices or to the purchase of CO_2 emissions quota.

The second goal of this chapter was to compare different projects. For this purpose the EBITDA for different ships was analyzed, and it was found that the extra cost that all ships meet due to the regulations has almost the same relative level in percentage of the cost that ships had before the regulations. However, in regards to freight rates, the impact from the new regulations for dry cargo vessels and tankers is different, and customers of tankers are more affected by the new regulations than those from the dry cargo sector.

Finally, the goal of this chapter was to identify the effectiveness and costs of the measures for diminishing the impact from the environmental regulations. It was shown that modernization of ships can eliminate the impact of new regulations. The extra cost that arises due to new regulations can be deleted by energy saving technologies and other tools described in Chapter 2. At the same time, the relationship between the amount of investment in modernization and its effectiveness was found; this relationship can also be used as a tool for determination of fuel savings with a different level of energy efficiency of a particular ship. Finally, investment in tankers will generate more savings than in dry cargo ships.

Chapter 5. Results. Recommendation for decision making. Conclusion

This chapter, which is an overview of findings, is divided into three parts. The first part provides a general overview of results that were found based on the main objectives. The second part has several recommendations for decision making for ship owners who are going to invest in new buildings and are looking for the optimized solutions regarding the new environmental regime. The third part is a final conclusion.

5.1. Overview of results

According to main objectives of this paper in the process of the research the following results have been achieved.

From the legislation overview it has been shown that regarding SOx emissions all existing and new ships according to the tiers described in Marpol Annex VI should reduce their SOx emissions regardless when this ship was built. Reduction of SOx emissions is connected with fuel quality, thus all ships are obliged change fuel and pay extra operational costs. Regarding NOx emissions, it was shown that these regulations are mostly related to new buildings that are going to be built after 2011 and 2016, and taking into consideration these standards are extremely important for investors who are going to purchase a new ship. Finally, regarding CO_2 emissions, it was shown that IMO is still working out a new regime for CO_2 emissions reduction; however, in the nearest future these regulations will be implemented through command and control measures and market based instruments.

Market research and forecast of freight earnings, fuel oil cost and cost of CO_2 emissions have been performed to find income and cost of the particular type of ship. For estimation of income for different types of ships, forecast of freight earnings for Panamax, Capesize, VLCC and Aframax ships has been performed based on the statistical data for the last 15 years. As to the costs that ships will have to pay for operation during the period from 2010 to 2030, an activity based model forecast has been performed. Within this forecast, it was shown that fuel oil consumption depends on the economic activity of the ship. For estimation of fuel oil consumption, it has been found how many days ships will spend at port and at sea, and what the average speed and average distance will be on annual basis. Then based on the data about average speed and distance the main engine workload has been determined and finally annual fuel oil consumption has been forecasted. Furthermore, fuel oil consumption was specified by types of fuel that ships will have to use according to the SOx regulations of Marpol Annex VI. For this purpose an analysis of main trading routes for different ships has been done. Finally, based on the amount of fuel that will be consumed by the ships, the total cost of fuel oil has been determined. Forecast of CO_2 emissions and their costs has been done based on the data of fuel oil consumption.

Investment Appraisal has been used as an instrument for identification of the economic impact from new environmental regulations. Based on the calculation of payback time, EBITDA, and return on investment, it was shown that VLCC and Aframax ships will be more affected than Panamax and Capesize ships by the new regulations. With help of detailed analysis of structure of EBITDA, it was shown that to diminish the economic impact from Annex VI ships have to cut their costs or increase their earnings. According to the calculations, it was found that the share of cost that ships have to cut is almost the same for all types of ships; contrary to this is the situation with earnings (freight rates) in which tanker ships will have to increase more than dry bulk ships to delete the impact of Marpol Annex VI. Furthermore, to diminish economic impact from Marpol Annex VI, a reasonable level of investments for modernization based on its effectiveness has been found for different types of ships.

Finally, the forecast of economic activity that seems to be higher for tankers and appraisal of investment identified that the tanker fleet will be more affected by new environmental regulations than the dry cargo fleet, thus one of the main question of this paper was answered.

5.2 Recommendations for decision making

Investors who are looking for investing in shipping nowadays should pay attention to ship's modernization and energy saving options; regardless of the type of ship. There is clear evidence that with help of energy saving technologies, the impact from new environmental regulations can be decreased to a minimum level. At the same time, due to different market conditions, different types of ships have different impact. Shipowners that operate tanker fleets should diversify their profiles by operation of dry cargo ships, which are less subject to the economic impact of new environmental regulations.

For ships that are going to spend most of the time in a Sulfur Emission Control Area modernization is almost the only one solution for the problem of extra fuel cost. Ships that are not engaged in trading within SECA in case of entering this area should use slow steaming, avoid wasting time and use the weather routing system as much as possible; in such case, the economic impact of the new regulations will be eliminated.

New buildings should be equipped with systems that allow complying with NOx regulations; at the same time, options that are going to make ships compliant with NOx regulations should be balanced with energy saving options.

Energy saving options become very important not only because of SOx regulations, but also because of coming regulations regarding CO_2 emissions. Thus, reduction of fuel oil consumption will allow saving money for fuel and also for CO_2 quotas; furthermore, savings that bring modernization become extremely profitable in case of a growing market and high economic activity of the fleet that corresponds with high ME workload.

Investment in energy saving options should be done with a proper understanding of current market trends and future market perspectives because their payback is connected with the economic activity of the ship and fuel oil consumption.

Investors who are going to invest in tankers should be more concerned about energy saving technologies, than investors who are going to invest in dry cargo ships.

Shipping companies that operates tankers should pay extreme attention to energy savings through slow steaming, proper scheduling and other possible operational options.

5.3 Conclusion

This research was dedicated to the analysis of the economic impact of Marpol Annex VI on different types of ships. With the help of different tools, the economic impact was defined; at the same time it was shown that there are measures that can help to eliminate this economic impact. For many years, shipping remained an area without standards and regulations regarding air emissions; however, many other industries had been faced before with such kind of regulations, and shipping surely will also pass through this stage to be more ecologically friendly.

Currently, in a world economy there is still global economic crisis. Crisis is an ancient Greek word which can be translated like a justice; regarding the shipping industry this is a justice for an economic model which resulted in a lack of attention to environmental issues that are urgent for the well being of everybody. In such situation, there is a good hope that shipping companies with help of the International Maritime Organization will recognize that such situation should be changed as soon as possible and in some years shipping will be the green and ecologically friendly industry that will still offer like now cheap and reliable transportation services for customers.

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Appendix A: Forecasting of freight earnings and total cost for VLCC, Aframax and Capesize ships

This Appendix presents results of forecasting of freight earnings and the total operational cost for Capesize, VLCC and Aframax ships based on the same methodology that was used for Panamax ship in Chapter 3.

Figures A1.1 – A1.3 show correlation between Capesize earnings and Coal, Iron Ore and Oil prices on monthly basis from June 1995 to June 2009. Figures A1.4 and A1.5 present correlation between Oil prices and Aframax and VLCC earnings.

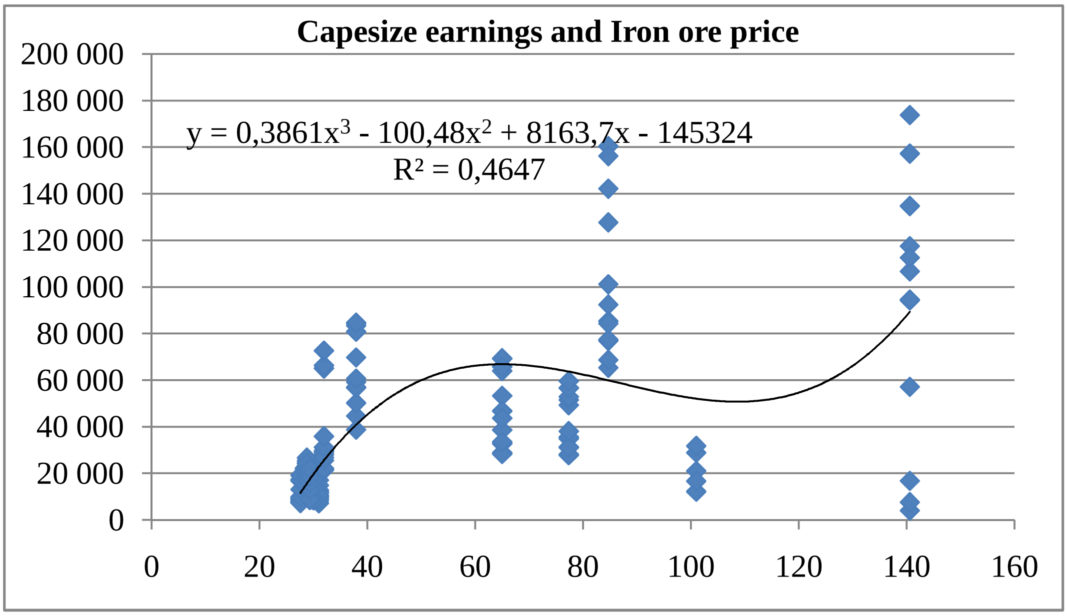

Figure A1.1 Earnings Panamax vs. Iron Ore, 67.55% iron content, fine, contract price to Europe, FOB Ponta da Madeira, US cents per dry metric ton unit; monthly average 06.1995 – 04.2009
Source: author and Index Mundi , Drewery Shipping Consultant

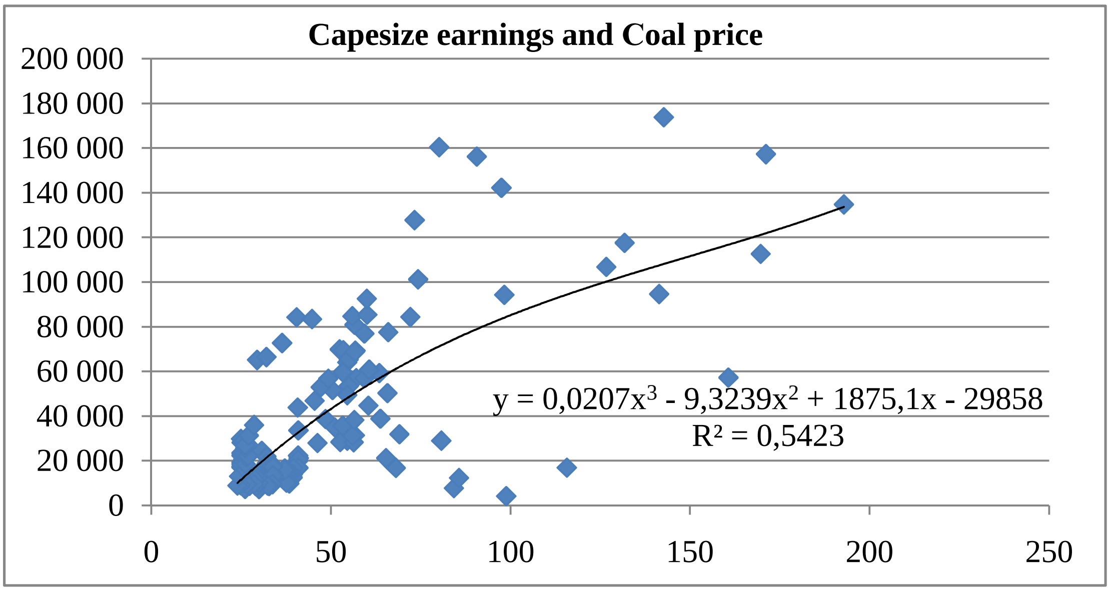

Figure A1.2 Earnings Capesize vs. Australian thermal coal, 12000- btu/pound, less than 1% sulfur, 14% ash, FOB Newcastle/Port Kembla, $ /mt; monthly average 06.1995 – 04.2009
Source: author and Index Mundi , Drewery Shipping Consultant

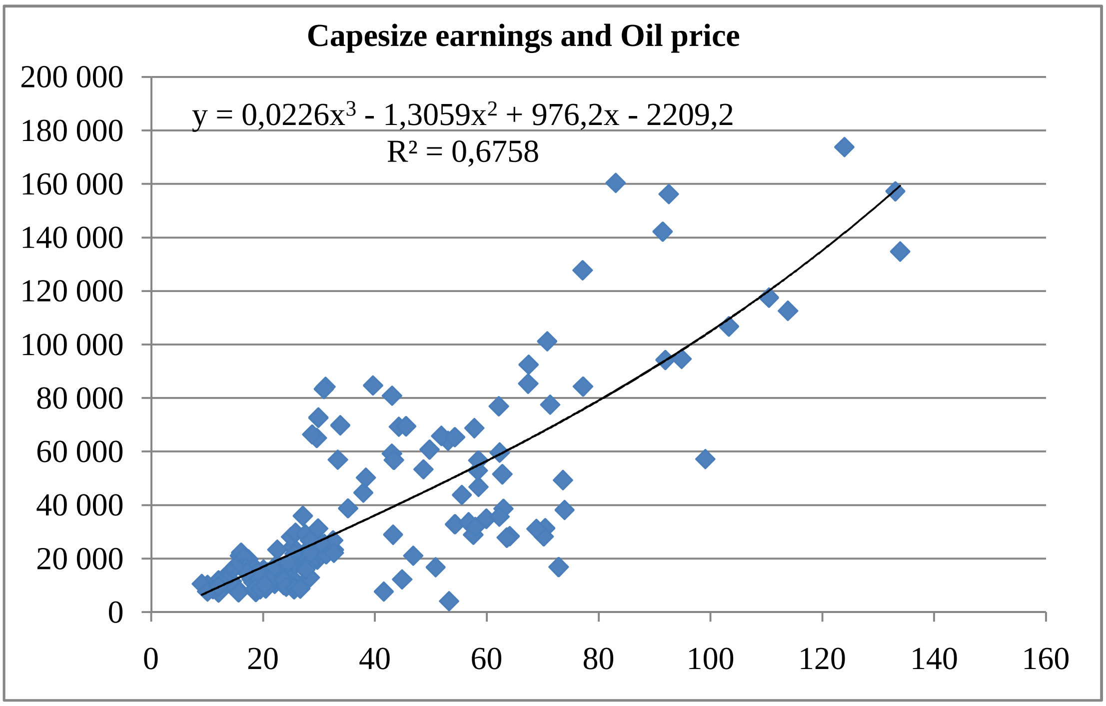

Figure A1.3 Earnings Capesize vs. Brent $/bbl; monthly average 06.1995 – 04.2009
Source: author and Index Mundi , Drewery Shipping Consultant

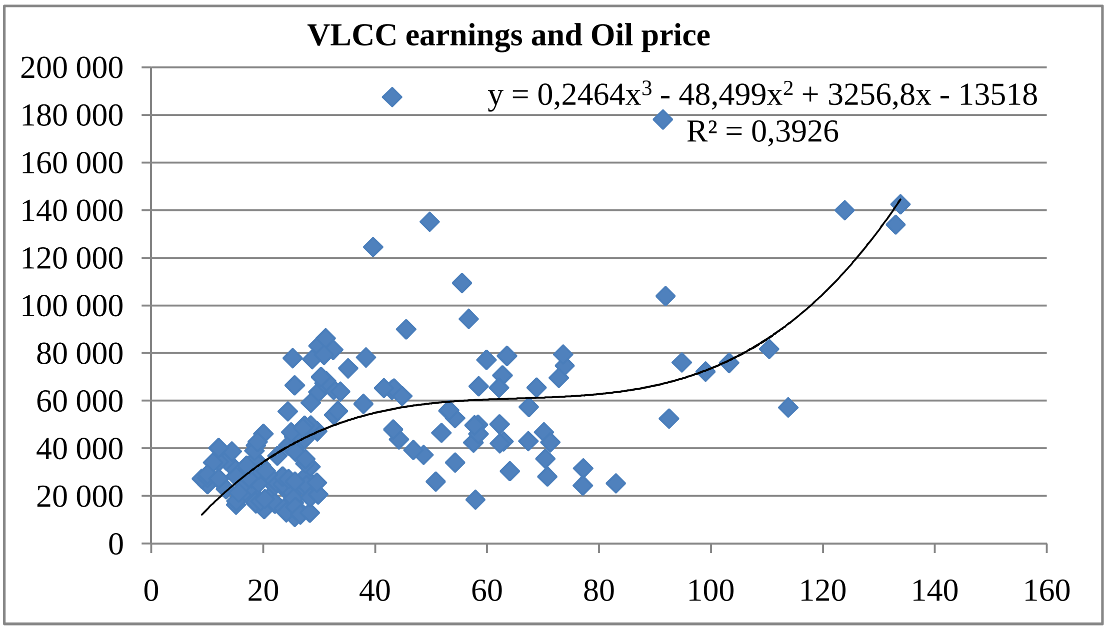

Figure A1.4 Earnings VLCC vs. Brent $/bbl; monthly average 06.1995 – 04.2009
Source: author and Index Mundi , Drewery Shipping Consultant

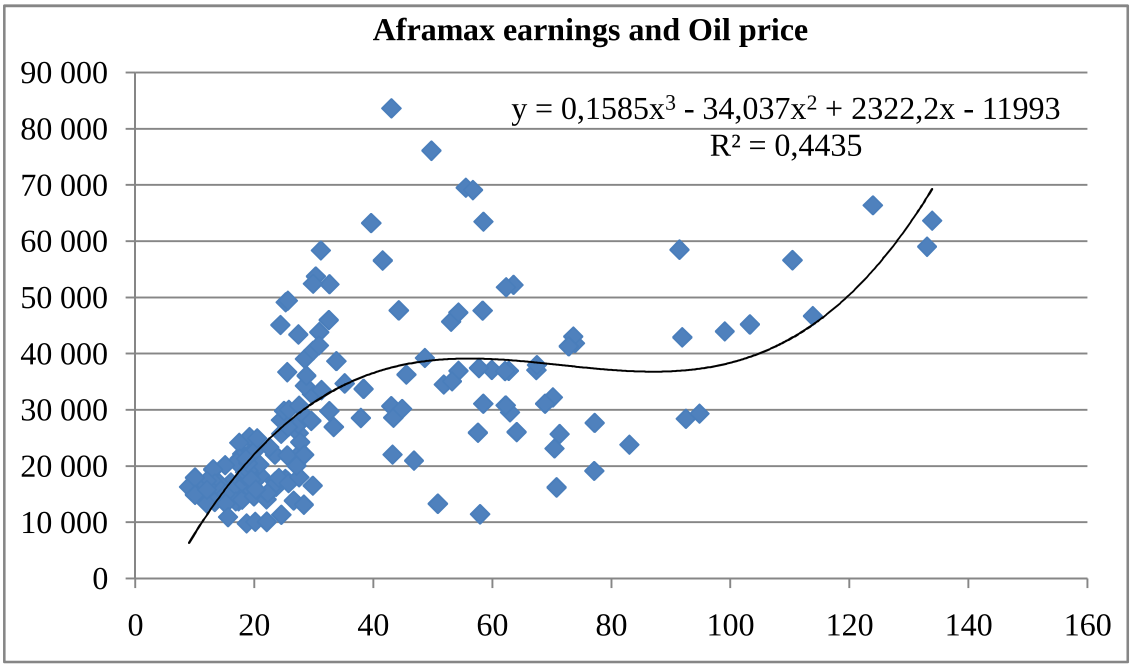

Figure A1.5 Earnings VLCC vs. Brent $/bbl; monthly average 06.1995 – 04.2009
Source: author and Index Mundi , Drewery Shipping Consultant

Figures A1.6 - A1.7 shows correlation between Crude oil prices and MDO and MGO, this data are used to find relationships between prices of different types of fuel with prices of crude oil.

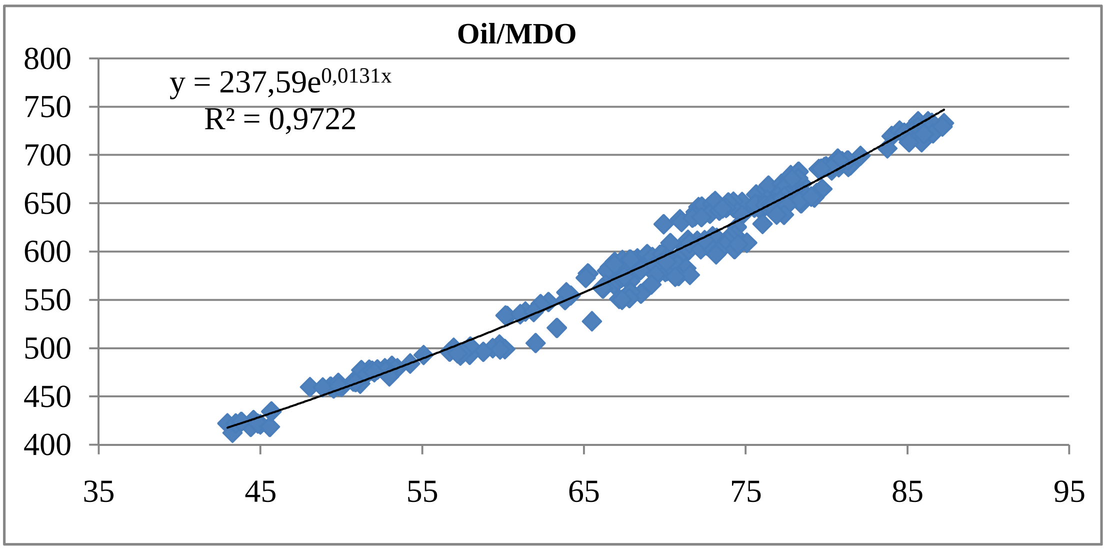

Figure A1.6 Oil price brent $/bbl vs. MDO $/mt, on daily basis March 01, 2009 – April 30, 2010
Source: author, Bunker Index

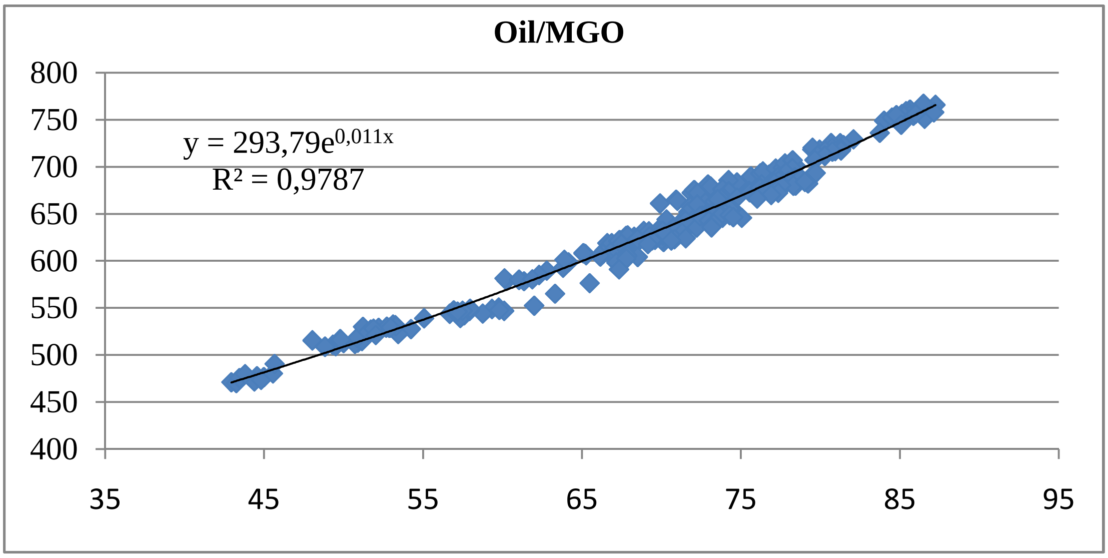

Figure A1.7 Oil price brent $/bbl vs. MGO $/mt, on daily basis March 01, 2009 – April 30, 2010
Source: author, Bunker Index

Figures A1.8 – A.11 present information about days at sea and at port that Capesize, Aframax and VLCC ships will spend during the period 2010 – 2030. Days at sea and at port are found according to the methodology described in chapter 3, and related with economic activity of the ship, i.e. freight earnings.

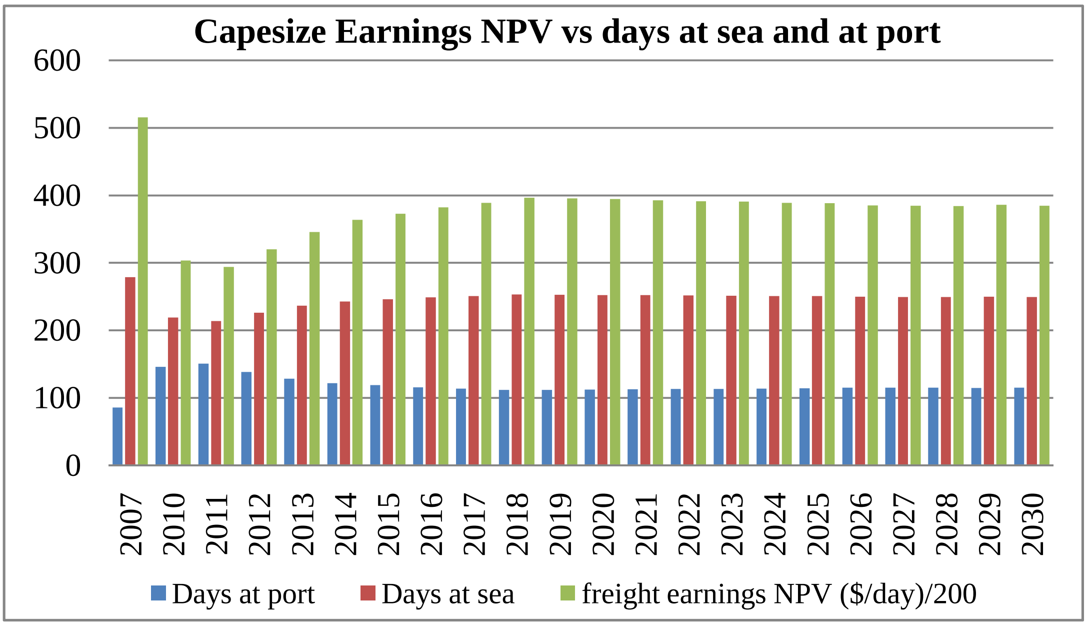

Figure A1.8 Capesize earnings NPV vs. days at sea and at port in 2010 - 2030
Source: Author, Second Greenhouse Gas Study, IMO, 2009

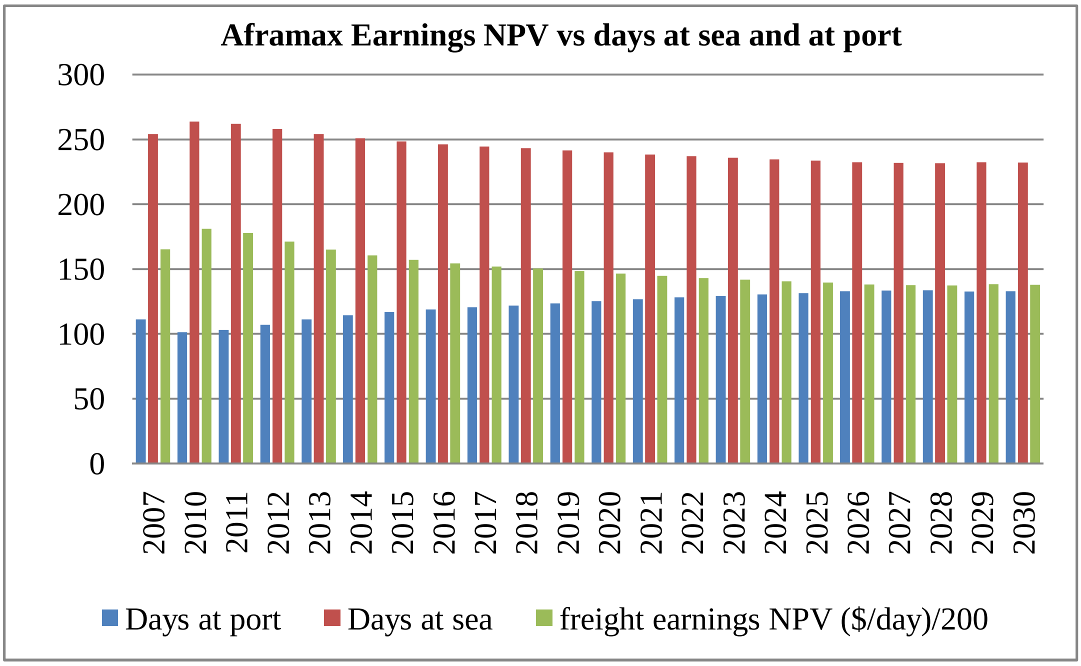

Figure A1.9 Aframax earnings NPV vs. days at sea and at port in 2010 - 2030
Source: Author, Second Greenhouse Gas Study, IMO, 2009

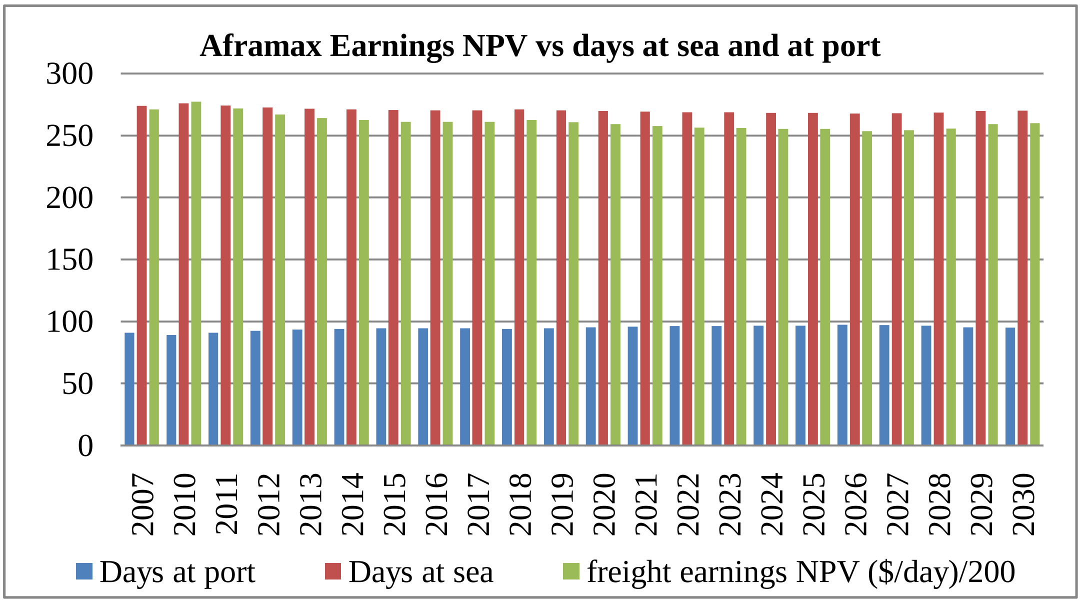

Figure A1.10 VLCC earnings NPV vs. days at sea and at port in 2010 - 2030
Source: Author, Second Greenhouse Gas Study, IMO, 2009

Figures A1.11 – A.13 present information about average distance per year that Capesize, Aframax and VLCC ships will cover during the period 2010 – 2030.

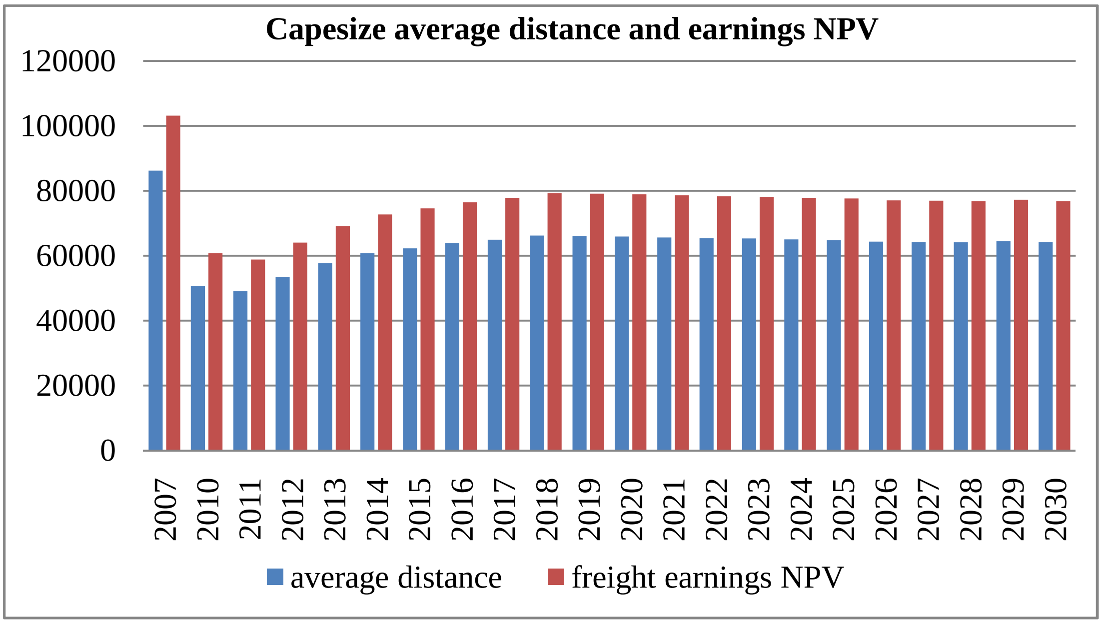

Figure A1.11 Earnings NPV and average distances for Capesize ship 2010 – 2030
Source: Author and Second Greenhouse Gas Study, IMO, 2009

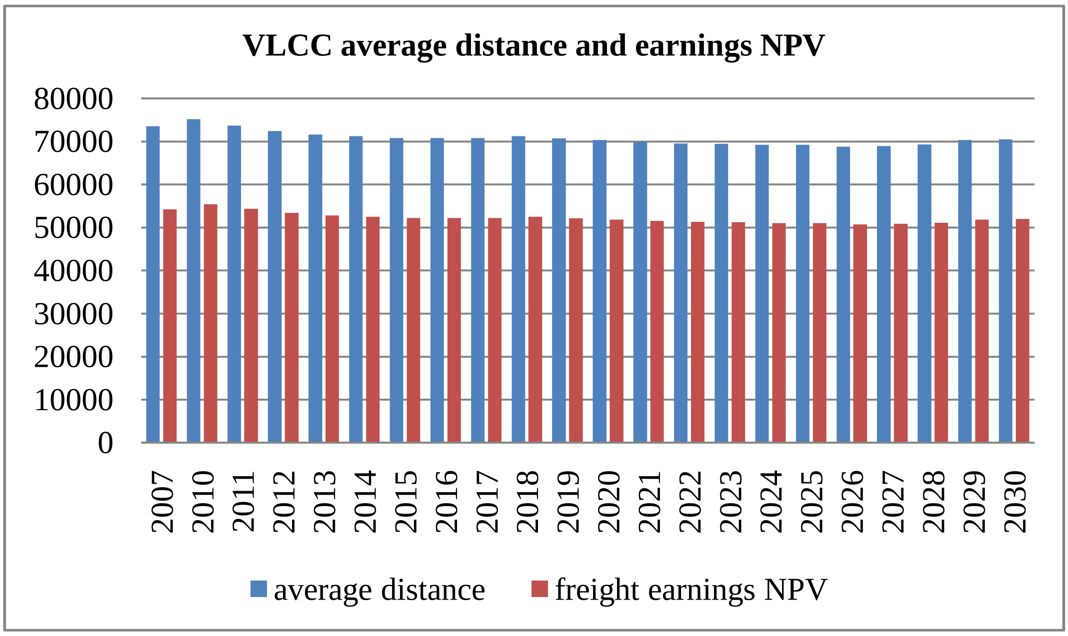

Figure A1.12 Earnings NPV and average distances for VLCC ship 2010 – 2030
Source: Author and Second Greenhouse Gas Study, IMO, 2009

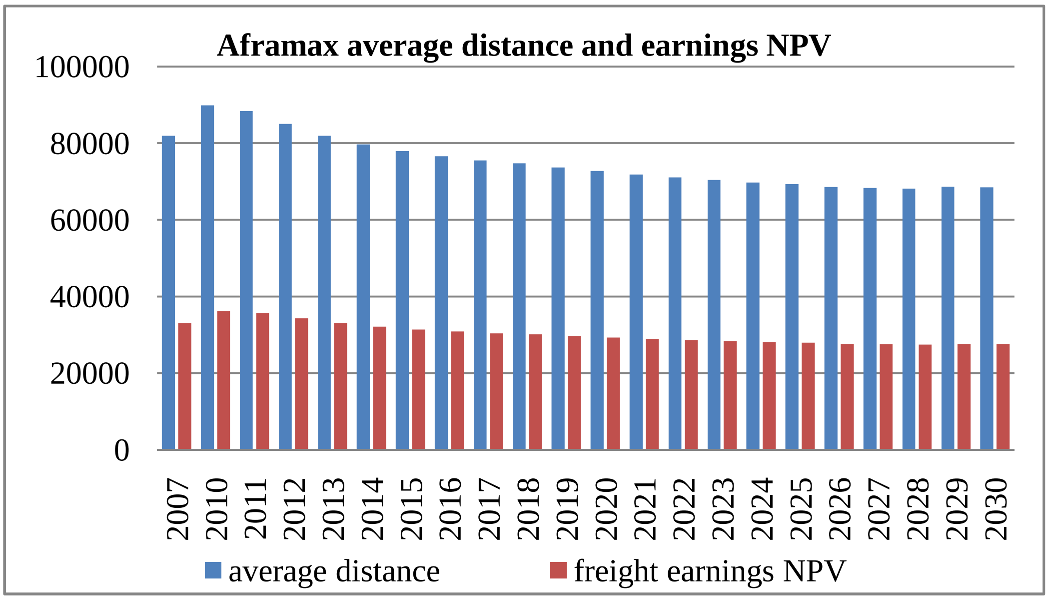

Figure A1.13 Earnings NPV and average distances for Aframax ship 2010 – 2030
Source: Author and Second Greenhouse Gas Study, IMO, 2009

Figures A1.14 – A.16 present information about average speed and average main engine Workload for Capesize, Aframax and VLCC ships during the period 2010 – 2030.

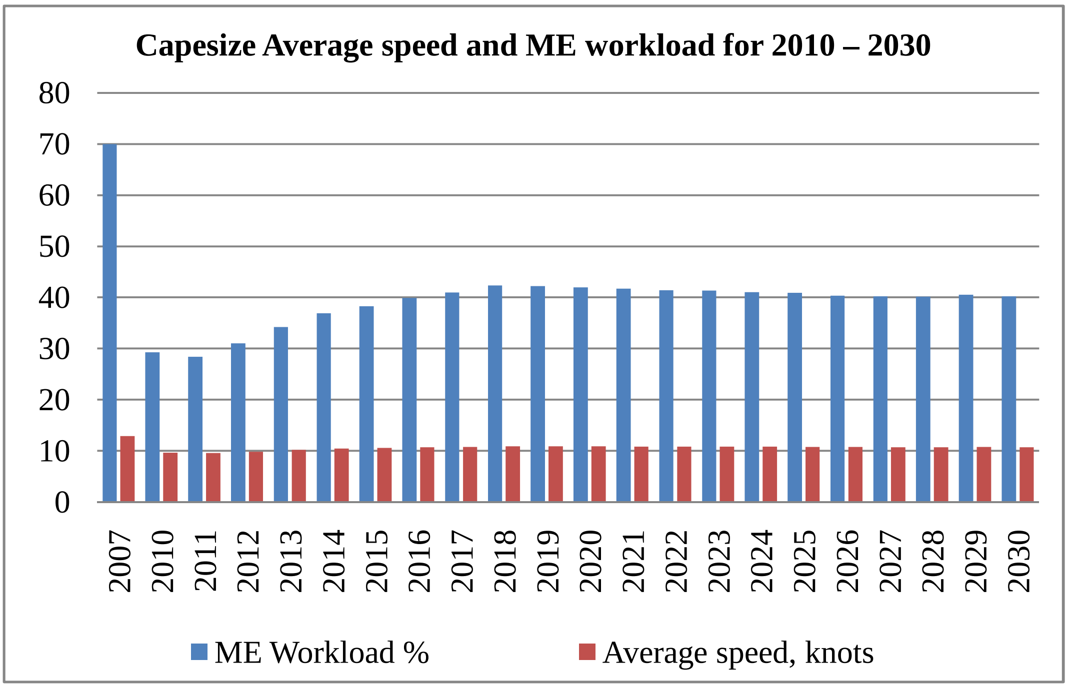

Figure A1.14 Average speed and ME workload for Capesize ship 2010 – 2030.
Source: Author and Second Greenhouse Gas Study, IMO, 2009

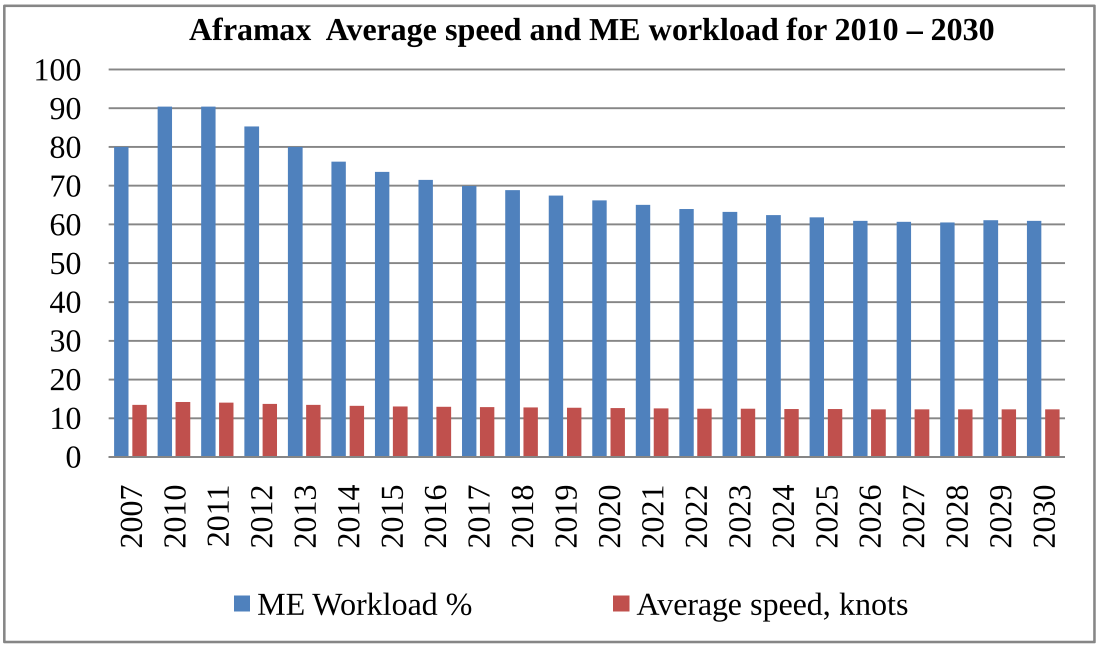

Figure A1.15 Average speed and ME workload for Aframax ship 2010 – 2030.
Source: Author and Second Greenhouse Gas Study, IMO, 2009

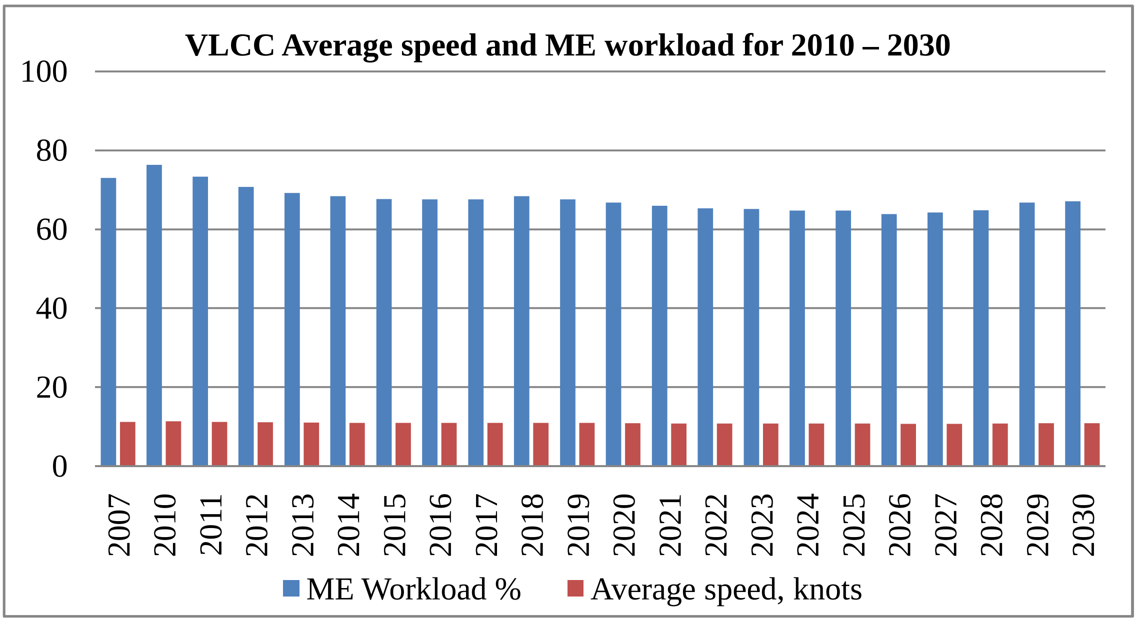

Figure A1.16 Average speed and ME workload for VLCC ship 2010 – 2030.
Source: Author and Second Greenhouse Gas Study, IMO, 2009

Figures A1.14 – A.16 shows Freight earnings and fuel oil consumption for Capesize, Aframax and VLCC ships during the period 2010 – 2030.

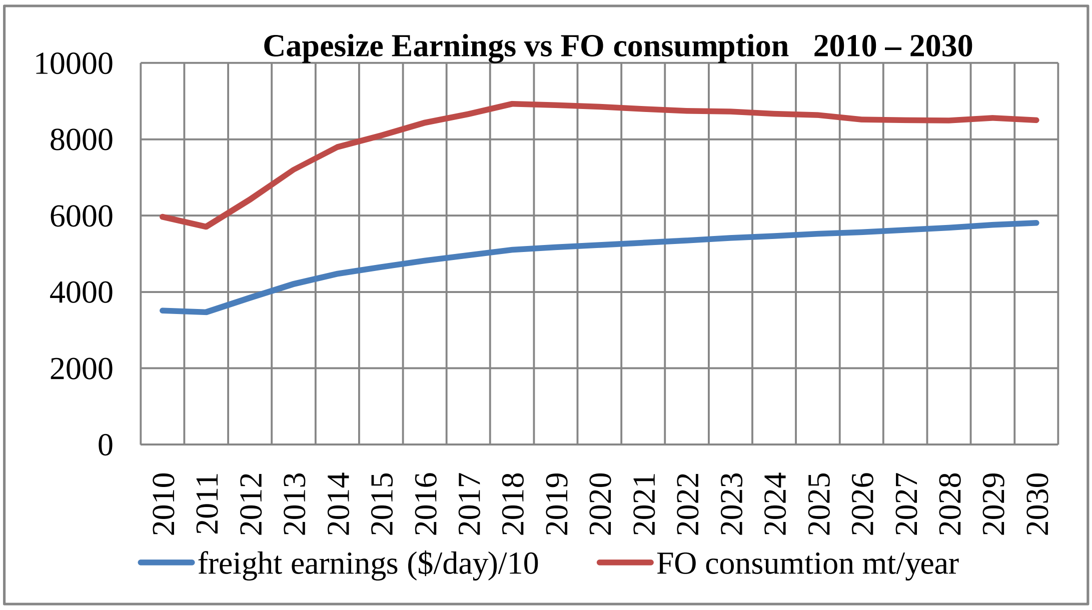

Figure A1.17 Freight Earnings vs FO consumption for Capesize ship 2010 – 2030.
Source: author

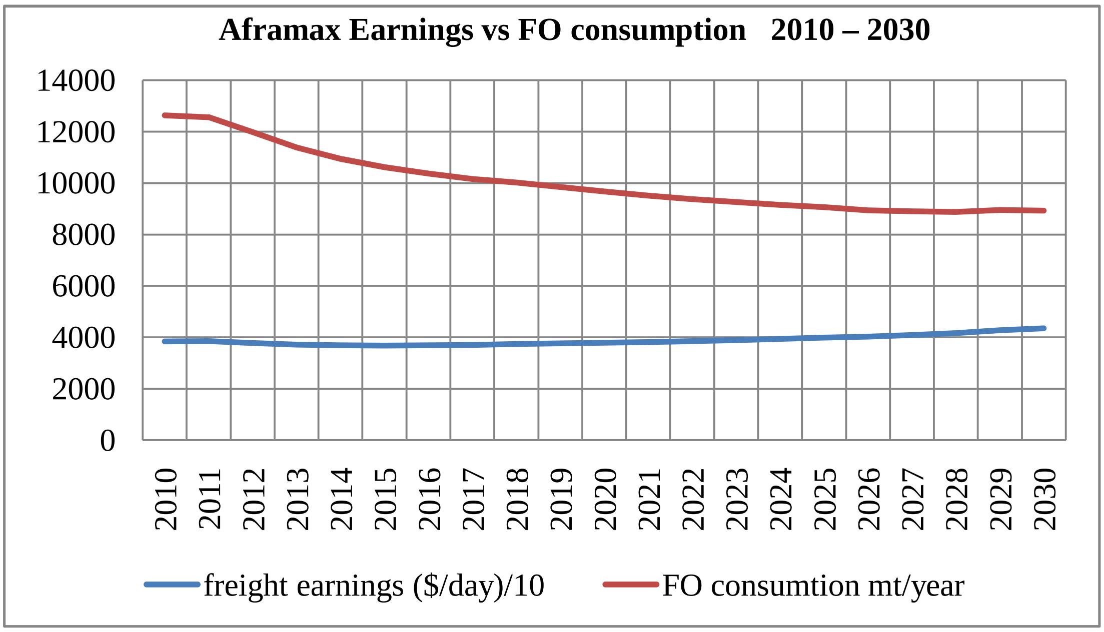

Figure A1.18 Freight Earnings vs FO consumption for Aframax ship 2010 – 2030.
Source: author

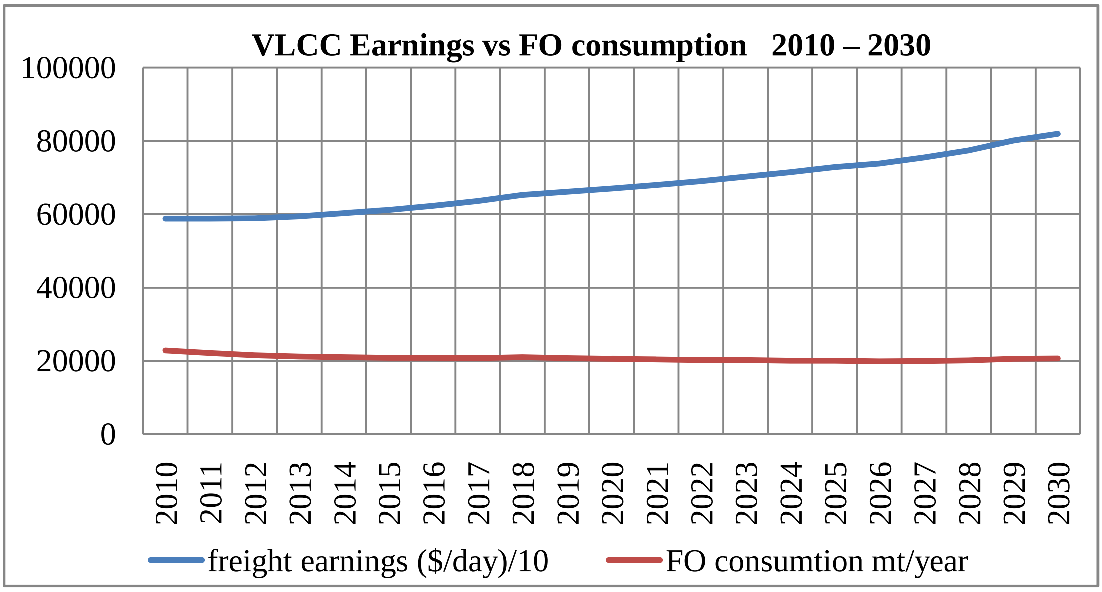

Figure A1.19 Freight Earnings vs FO consumption for VLCC ship 2010 – 2030.
Source: author

Figures A1.20 – A1.22 shows total amount and total cost for CO_2 emissions for Capesize, Aframax and VLCC ships during the period 2010 – 2030.

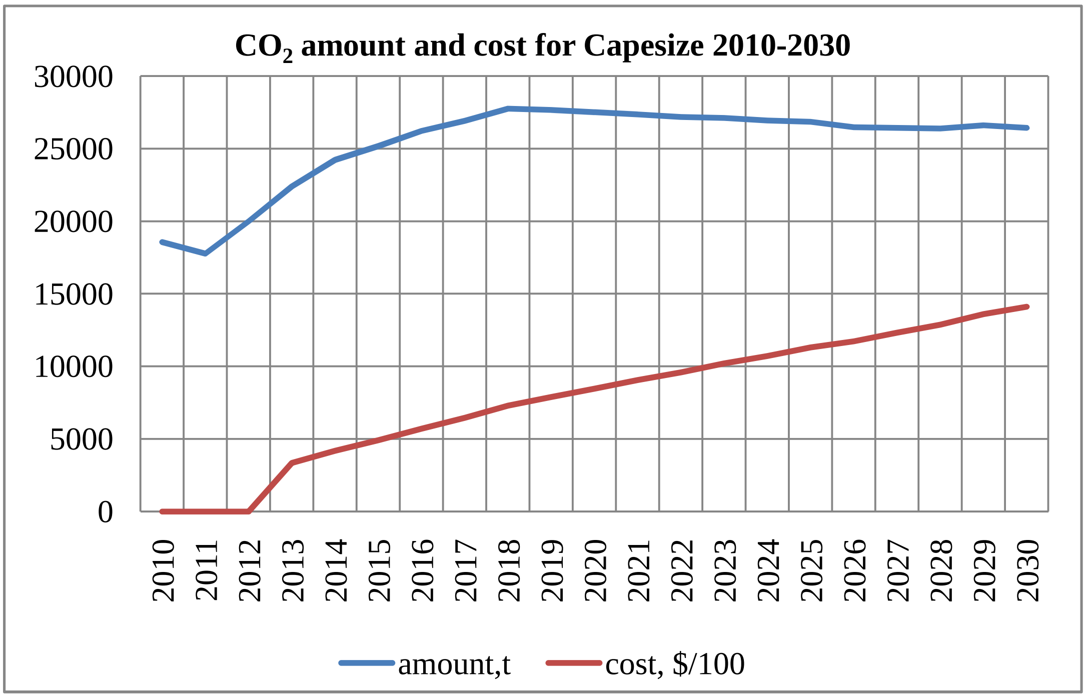

Figure A1.20 CO_2 amount and total cost for Capesize ship, 2010 – 2030.
Source: Synapse Energy, author

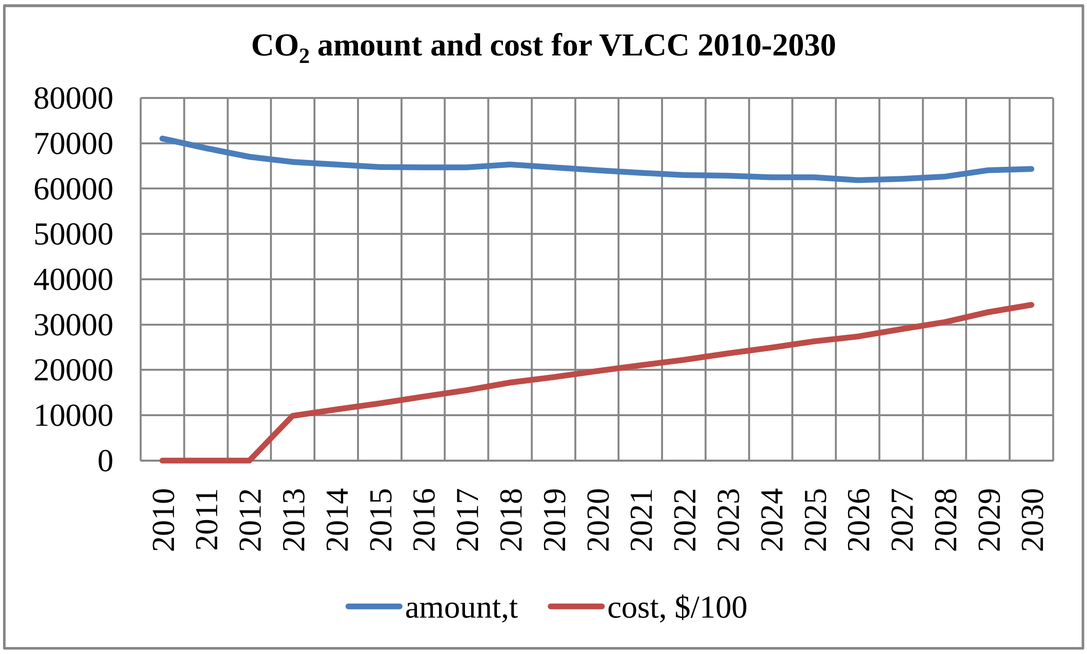

Figure A1.21 CO_2 amount and total cost for VLCC ship, 2010 – 2030.
Source: Synapse Energy, author

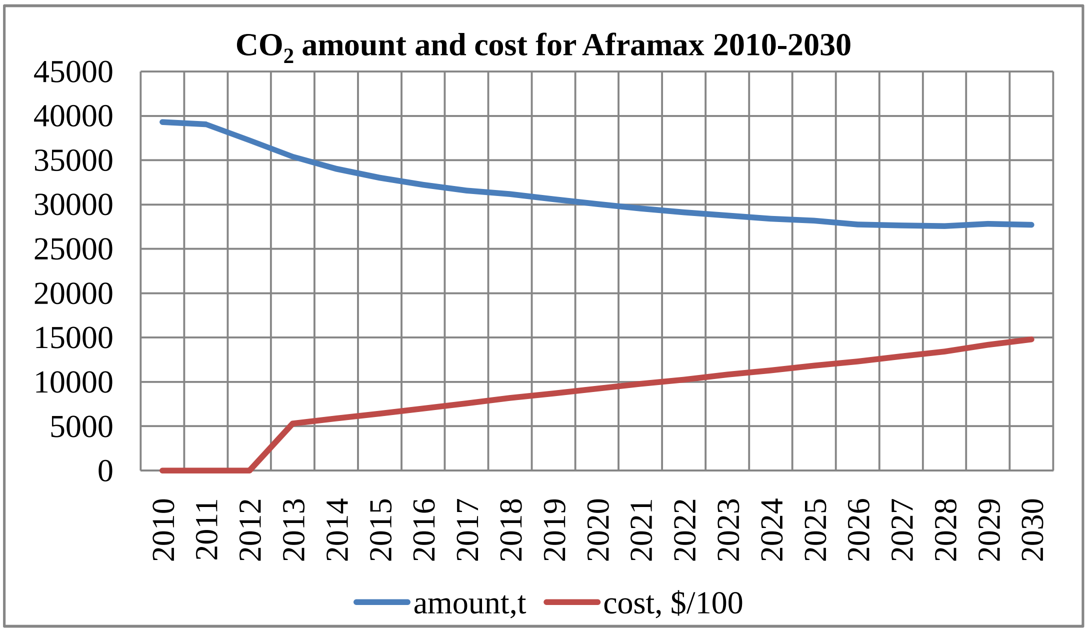

Figure A1.22 CO_2 amount and total cost for Aframax ship, 2010 – 2030.
Source: Synapse Energy, author.

Figures A1.22 – A1.24 shows CO_2 Quota, Total and Discounted Cost of CO_2 for Capesize, Aframax and VLCC ships during the period 2010 – 2030.

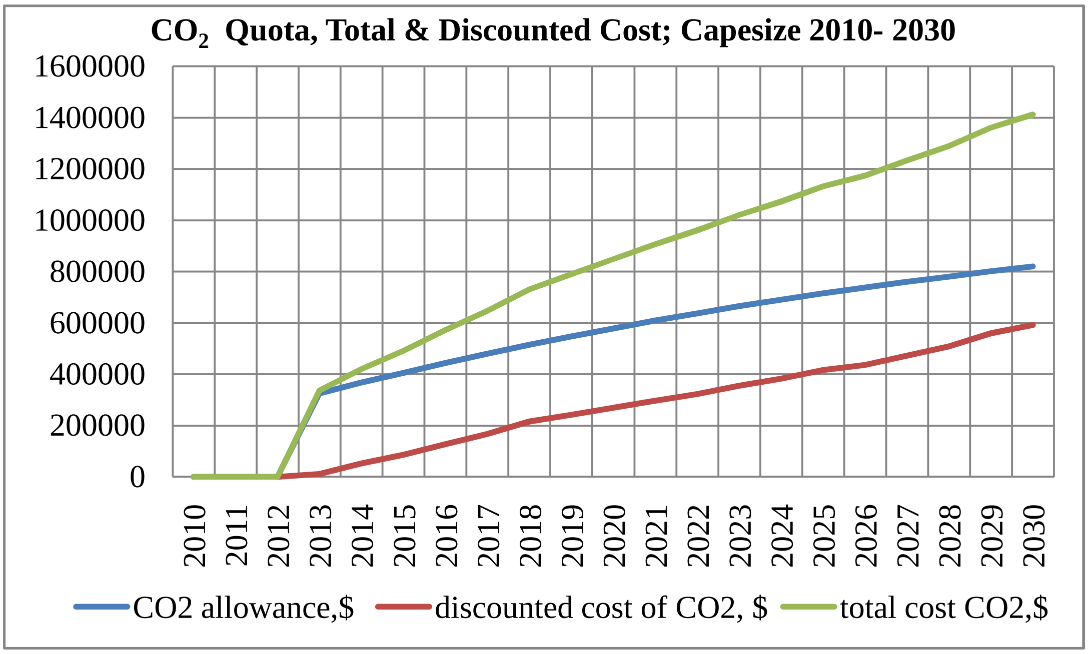

Figure A1.23 CO_2 amount and total cost for Capesize ship, 2010 – 2030.
Source: Synapse Energy, author

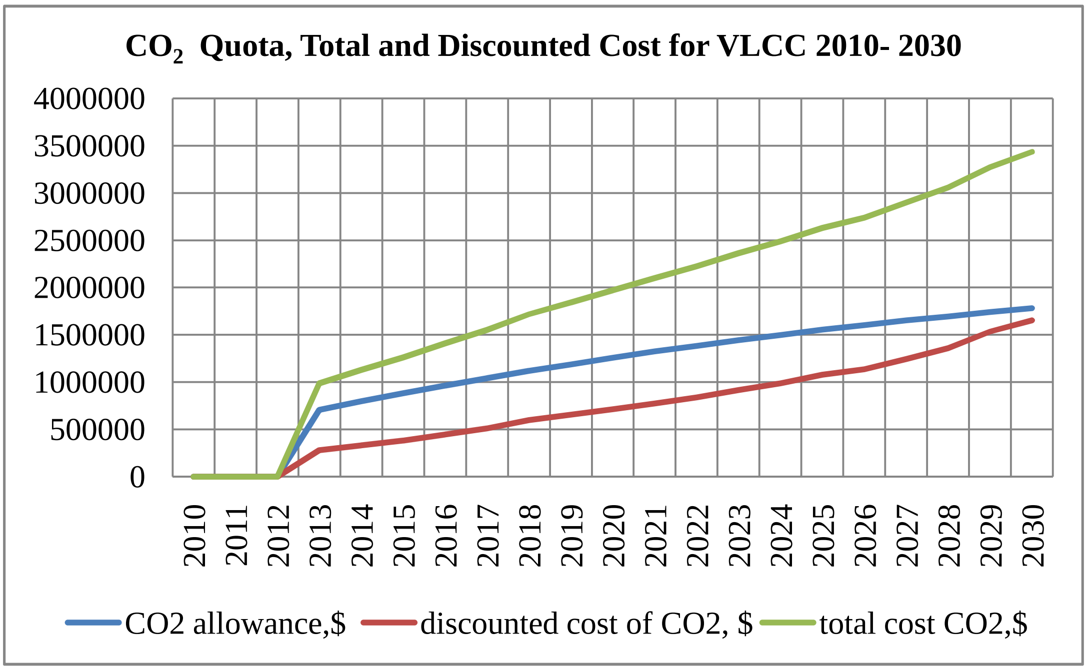

Figure A1.24 CO_2 amount and total cost for VLCC ship, 2010 – 2030.
Source: Synapse Energy, author

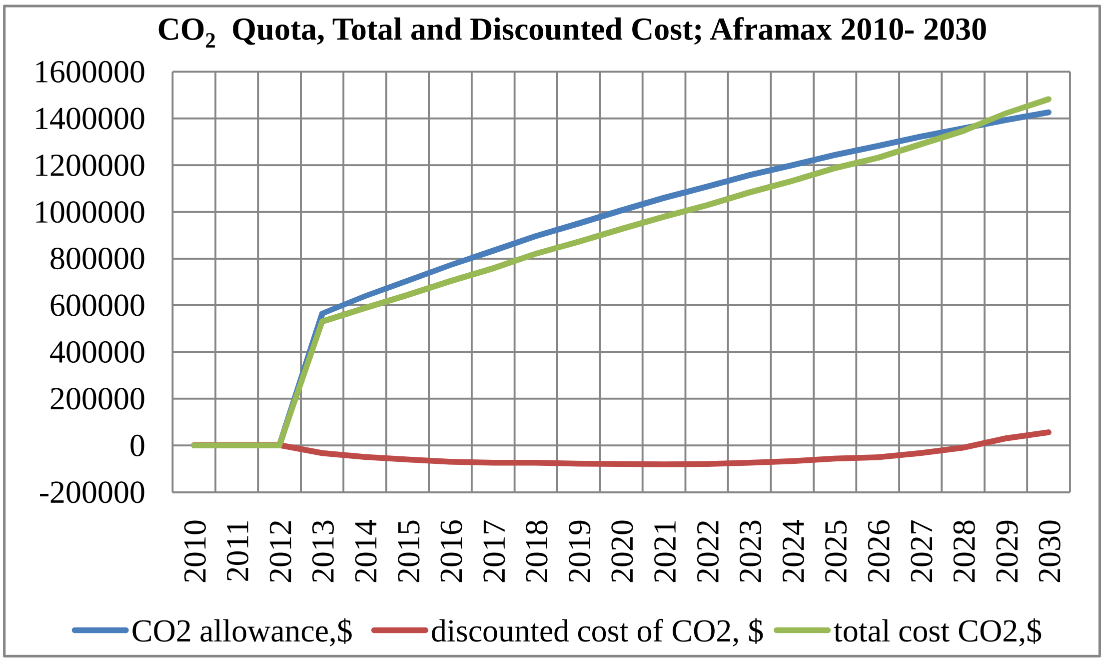

Figure A1.25 CO_2 amount and total cost for Aframax ship, 2010 – 2030.
Source: Synapse Energy, author