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Compliant strategy for shipowners towards sustainable maritime transport: a decision framework for air emission reduction measures

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COMPLIANT STRATEGY FOR SHIPOWNERS TOWARDS SUSTAINABLE MARITIME TRANSPORT

A decision framework for air emission reduction measures

By

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SHIPPING MANAGEMENT AND LOGISTICS

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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: **COMPLIANT STRATEGY FOR SHIPOWNERS TOWARDS SUSTAINABLE MARITIME TRANSPORT-A decision framework for air emission reduction measures**

Degree: **MSc**

IMO uses three pillar strategy for air emission reduction including, technical, operational and market-based measures (MBM). The dissertation briefly describes the maritime regulatory framework for reduction of emissions. An overview on air emissions caused by the shipping sector is analysed. A brief look is taken on the need and methodology for inventory management of air emissions. A comparison between the market-based measures, operational measures, carbon tax and abatement measures for averting air emissions of carbon equivalent is made.

The author has examined the abatement measures available to shipowners. This section also investigates the response of shipowners to different possible measures. There is a social cost which a company shall bear for the sustainability or go for abatement measures or MBM. By choosing correct abatement measures, shipowners can avoid carbon tax and avoid externality which ultimately will add to their financial gains.

Emission scenarios are collated and evaluated to know how much shipping contribute to future climate change. The purpose of these scenarios is not for future predictions but to explore the scientific and real-time implications. Methanol has emerged as a strong alternative fuel option because of stringent air emissions regulations.

A case study on a compliance cost for M.V. Stena Germanica demonstrated to show the applicability of the framework. The environmental and economic benefit is calculated to see the feasibility of the project, and then the result is compared with the different measures available to shipowners.

The conclusion gives a holistic view of the decision framework for the shipowners to decide whether to comply with the abatement measures or not. The case study proves that in the long term by complying with abatement measures shipowners will avoid carbon tax and will have social benefits and financial benefit.

Keywords: Technical measures, Operational measures, Carbon tax, Market-based measures, External cost, Health cost, Air emissions, Methanol, Emission projections

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List of Abbreviations

AIS-	Automatic Identification System
AMVER-	Automated Mutual-Assistance Vessel Rescue System
AMVER-	Automated Mutual-assistance Vessel Rescue system
BC-	Black carbon
BDN-	Bunker delivery note
CBDR-	Common but differentiated responsibility
CCS-	Carbon capture and storage
CFC-	Chlorofluorocarbons
CH_4-	Methane
CLRTAP-	Convention on Long-range Transboundary Air Pollution
CLRTAP-	Convention on Long-Range Transport of Air Pollution
CO-	Carbon monoxide
CO_2-	Carbon dioxide
DEHM-	Danish Eulerian Hemispheric Model
DOAS-	Differential Optical Absorption Spectrometry
EC-	European Commission
EEA-	European Environment Agency
EEA-32-	32 member countries of the European Environment Agency
EEDI-	Energy Efficiency Design Index
EEOI-	Energy Efficiency Operational Indicator
EGR-	Exhaust gas recirculation. Method to reduce NOx emissions
EIA-	Energy Information Administration
EMEP-	Emission Monitoring and Evaluation Programme
EMSA-	European Maritime Safety Agency
E-PRTR-	European Pollutant Release and Transfer Register
EU-	European Union
EU-27-	Belgium, Bulgaria, Czech Republic, Denmark, Germany, Estonia, Ireland, Greece, Spain, France, Italy, Cyprus, Latvia, Lithuania, Luxembourg, Hungary, Malta, Netherlands, Austria, Poland, Portugal, Romania, Slovenia, Slovakia, Finland, Sweden, United Kingdom

EVA-	Economic Valuation of Air pollution
GHG(s)-	Greenhouse gas(es)
GIS-	Geographical Information system
GT-	Gross tonnage. The expression of a ship's overall internal volume
GWP-	Global Warming Potential. Sums up all greenhouse gases regarding carbon dioxide equivalents
GWP 100-	Global warming potential with a 100-year time the horizon
GWP 20-	Global warming potential with a 20-year time the horizon
GWP 500-	Global warming potential with a 500-year time the horizon
HCFC-	Hydrochlorofluorocarbons
HFC-	Hydrofluorocarbons
HFO-	Heavy fuel oil
ICE-	Internal Combustion Engines
ICOADS-	International Comprehensive Atmosphere Data Set
IEA-	International Energy Agency
IMO-	International Maritime Organization
IPCC-	Intergovernmental Panel on Climate Change
ISO-	International Organisation for Standardisation
IRR-	Internal Rate of Return
LCA-	Life Cycles Assessment
LDC-	Least Developed Countries
LIDAR-	Light Detection And Ranging
LNG-	Liquefied Natural Gas
LPG-	Liquefied Petroleum Gas
LRIT-	Long-Range Identification Tracking
LRTAP-	Long-Range Transboundary Air Pollution
MARPOL-	International Convention for the Prevention of Pollution from Ships, administered by the IMO. MARPOL
MDO-	Marine diesel oil
MeOH-	Methanol
MeOHng-	Methanol produced from natural gas (one of the fuels investigated in the LCAs)

MeOHw-	Methanol produced from willow (one of the fuels investigated in the LCAs)
MMBTU-	One Million British Thermal Units
MGO-	Marine Gas Oil
NECA-	NOX Emissions Control Area
NGGIP-	National Greenhouse Gas Inventories Programme
NH_3-	Ammonia
NMFT-	No More Favorable Treatment
NMVOC-	Non-Methane Volatile Organic Compound
NO-	Nitrogen monoxide
NO_2-	Nitrogen dioxide
NO_x-	Nitrogen Oxides
NPV-	Net Present Value
ODP-	Ozone Depletion Potential
PM-	Particulate Matters
PM_{10}-	Particulate Matter with a diameter of 10 micrometres or less
$PM_{2.5}$-	Particulate Matter with a diameter of 2.5 micrometres or less
ROI-	Return On Investment
RO-PAX-	Roll-on/roll-off car and passenger ferry
SCR-	Selective Catalytic Reduction. The catalyst for NOx reduction, using urea as a reagent.
SECA-	Sulphur Emission Control Area
SEEMP-	Ship Energy Efficiency Management Plan
SIDS-	Small Island Developing States
SO_2-	Sulphur Dioxide
SO_x-	Sulfur Oxides
UAVs-	Unmanned Aerial Vehicles
UN-	United Nations
UNEP-	United Nations Environment Programme
UNFCCC-	United Nations Framework Convention on Climate Change
VOC-	Volatile Organic Compound

1. Introduction

1.1. Background

The maritime transport which carries around 90% of the global trade is a complex and dynamic sector. It involves many operations, processes, and maintenance. The logistics system provide benefits to the customer but causes an adverse impact on the environment. Environmental impact is caused by air pollution which affects human health, climate, flora fauna, and oceans (Endresen et al., 2003). These effects are not reflected in transport prices. Hence, a comprehensive based approach is needed to achieve environmental, health and climate benefit while making the continuous positive growth of the maritime sector and profitability to shipowner (OECD Council Working Party On Shipbuilding, 2010).

In reality, not all the solutions are viable for every ship. Hence, shipowners should identify the best possible solution for a specific ship. The maritime regulatory measures are minimum standards, requiring shareholders and authorities to implement. Shipowners are obliged to not only comply with these standards but also go for the co-benefits for the long term. One of the criteria for achieving the long-term benefits is to abide by the abatement measures (Kwon, 2013).

IMO uses a three pillar strategy for air emission reduction consisting of technical, operational and market-based measures (MBM). Technical and operational measures have been adopted by all the member states parties to MARPOL (International Convention for the Prevention of Pollution from Ships) Annex VI in MEPC 62nd session on 15 July 2011 whereas the MBM is still not applicable globally in the maritime transport.

To address the air pollution reduction IMO and EU has adopted various international regulations. MARPOL Annex VI sets the limits for the sulphur content of fuel (not exceeding 0.1%) used in the Emission Control Areas (ECA) which came into force in 2015. Ship Energy Efficiency Management Plan (SEEMP) provides guidelines for shipowners to comply with energy efficiency measures.

Responsibility of IMO in reduction of air emissions

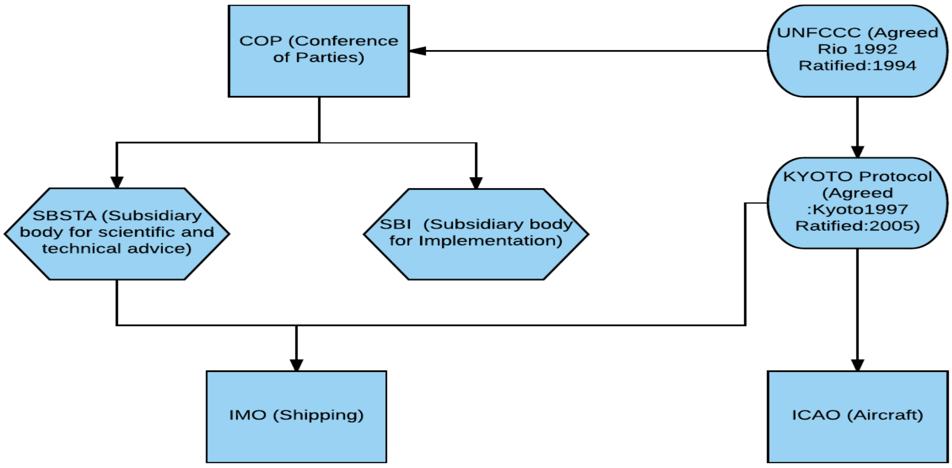


Figure 1.

Source: Adapted from Reynolds and Bazari,2005

In 2016, the SECA region also becomes a Nitrogen Oxide Emissions Control Area (NECA). As per the amended EU Council Directive 2005/33/EC,1 for Council Directive 1999/32/EC, a ship at berth must use fuel with a sulphur content less than 0.1%. Figure 1 shows the responsibility of IMO within the international framework for control of GHG emissions. Figure 2 shows IMO energy efficiency regulatory timeline since 1997 till May 2015 for reduction of GHG emissions from ships.

When it comes to compliance with the regulations, decision makers are facing a finite number of technological solutions, which are overlapping (Han, 2010). Another mechanism under consideration is MBM. MBM are ways to internalise the externalities. The main idea of using MBM is to give incentives to the shipowners to take initiatives to reduce air emissions. The selection of the best MBM depends on the impact and types of emissions (Psaraftis, 2012). The challenge is to evaluate and select the cost-effective measure. Shipowners are suffering through a heavy economic burden owing to fluctuation in fuel prices and mandated air emission regulations. Shipowners should make compliant strategies to improve the cash flow by improving the energy efficiency of ships.

IMO energy efficiency regulatory developments

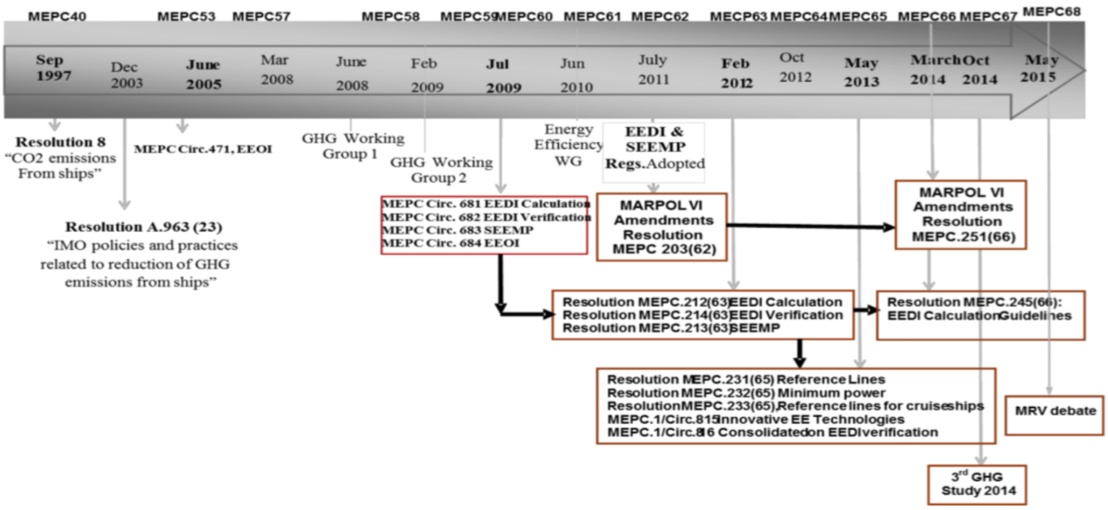


Figure 2.

Source: IMO, 2015

There are many studies regarding ecological and economic assessments of different abatement solutions with their cost-benefit analysis (Eide, Endresen, Skjong, Longva, & Alvik, 2009). It limits the approach for the shipowners to a single dimension. The economic impact of fluctuation of fuel costs and environmental pressure has forced shipowners to go for more clean, efficient energy technology (Notteboom, 2010). Shipowners should assess all air pollution reduction measures with regards to each attribute. These assessments can be environmental, economical and technological (Osés & Castells, 2009). However, there is no research for shipowners for making coherent decisions by comparing all the measures. The need for the cost effective socially accepted abatement measure is more than ever when the shipping industry is in under much pressure to comply with the stringent rules and regulations imposed by IMO and EU Directives.

1.2. Motivation

“Finding enough money to remain compliant with environmental regulation is going to be a challenge for shipowners and operators over the next few years.”

(Stephens Moore, MarEx, 2014)

The idea of developing a decision framework for shipowners on how to reach sustainable goals of IMO is the main driving force behind this dissertation. The profitability of shipowners in the long term depends on environment and health impacts, air pollution reduction, and sustainability, and they are connected with each other. In this regard, a comparison between the MBM, operational measures, carbon tax and compliance cost for averting carbon equivalent is made. The analysis will assist shipowners to go for one or numerous measures in a cost – effective manner while making their strategy.

1.3. Aim

The main aim of this dissertation is to make a decision-making framework for shipowners to go for appropriate measures for reducing air emissions while maintaining their profitability. The dissertation discusses the issues and reduction techniques related to emissions from the shipping sector. The study showed that the new rules like SO_x and NO_x emissions regulations would cause modal backshift and consequently will increase the costs of freight (Rozmarynowska, 2012). The main question addressed in this dissertation is what is the best option for a ship-owner whether to invest in technical measures or abatement technologies or chose a reliable market-based measure or to pay the carbon tax. However, there is no study comparing different measures. The ship-owner should make use of available technologies, calculation methods and emission reduction techniques to meet their objectives and ensure their profitability (Corbett & Fischbeck 1997). With the use of proper model and techniques, external effects can be quantified into monetary values and can be reduced. In this dissertation, a combination of both qualitative and quantitative approach is taken to fill the gaps in decision criteria for shipowners.

1.4. Research questions

The following questions will be discussed in the dissertation to fill the gap of compliance options faced by shipowners and decision makers.

- How do emissions affect the climate change and human health? How do shipowners anticipate future environmental constraints?

- What factors and technology improvements are responsible for a vessel in their overall environmental performance?
- What will be the effect of MBM if implemented? Is MBM compatible with IMO legal framework? Is Carbon tax necessary for reduction of air emission?
- What is the total cost of compliance due to new stringent environmental regulations? Do shipowners adjust their strategies for environmental liabilities?
- What are the factors missing in the decision framework for shipowners when making a compliant strategy for air emission reduction?

1.5. Methodology

The dissertation has used both quantitative and qualitative methodologies to design a decision framework for shipowners.

Qualitative methods used in this dissertation includes:

1. Study of different methods for development of the monitoring air emissions and inventory techniques.
2. Exposition of various factors affecting the adoption of air emission reduction measures.
3. Economy-wide impact analysis of MBM, Carbon tax, technical and operational measures for making a decision framework.

Quantitative methods used in this dissertation includes emission reduction calculation, cash flow analysis, and measurement of external cost.

4. The decision framework is exemplified with a real case study on the environmental and economic analysis of adopting Methanol as an alternative fuel onboard MV Stena Germanica. The result of the case study will be analysed and compared with the MBM, carbon tax to find out the impact on the polluter financially.
5. Estimation of externalities caused by air pollution.

1.6. Outline of the thesis

The dissertation is divided into following chapters.

Chapter 1 is about the background for air emissions measures and mentions motivation, aim and research questions for this dissertation. Then the methodology of the dissertation is discussed. Lastly outline of the dissertation is given.

Chapter 2 gives a background information about similar studies done.

Chapter 3 describes an overview emissions by maritime transport including the scope of emissions, air quality information around Europe and the world, Measurement and data compilation techniques is discussed in this chapter. This chapter also discusses the impact of air emissions to the ecosystem and human health.

Chapter 4 analyses all the options available to shipowners i.e. technical, operational and MBM to reduce air emissions.

Chapter 5 analyses Methanol as a future marine fuel. A financial analysis is done for the vessel MV Stena Germanica which has switched to Methanol from MGO to sail in the ECA area. This chapter includes a section about findings and discussion of the results. The results from the case study of compliance cost for fuel switching and other measures will be compared.

Chapter 6 discusses the decision framework for shipowners. Gaps in decision framework are identified. Emission projections and health cost analysis are done. Externality costs are calculated for the case study.

Chapter 7, the final chapter includes concluding remarks and will mention a summary of the main results and comparison between various measures available to shipowners.

At the end of the dissertation are references followed by Appendix A, B, C, D, E, F, G, H, I which consist of the calculations and other relevant data.

2. Literature Reviews

Magnus et al., (2009) assessed the cost-effectiveness of CO_2 reducing measures in shipping. Some technical and operational measures for reducing the CO_2 emissions were analysed for finding out the most cost effective measures.The study concluded by introducing a decision criterion of CATCH[1]<50$/t CO_2. Shipping may benefit significantly from the global emission reduction in a cost-effective manner. The advantage of using this approach was in favour of shipowners as it is easy to comply with the stringent regulations by investing less.

Ölcer et al., (2015) discussed a decision-making framework for evaluating the trade-off solutions of cleaner seaborne transportation for Copenhagen Port by using cold ironing technology. In this study, the economic perspective of the technology was taken into consideration. The paper uses the fuzzy logic technique for decision making for shipowners.

O balland et al., (2014) discussed the possible framework for concurrent optimisation of machinery system design and emission control installation onboard. This model did not debate the uncertainty in the future operation profile of the ship and prices of alternative fuel like LNG. Stott (2012) analysed the behaviour of the ship operators relating to the investment in the retrofitted equipment on new and existing vessel. The result indicated that the first owners present the best targets for selling the retrofitted equipment. The main reason is to get access to the extended payback period for their investment.

Banawan et al., (2009) proved that the conversion process of ship's main engine from the conventional fuel to an alternative fuel has both environmental and economic benefits. The emission reduction in NO_x, SO_X, CO_2, and PM was demonstrated. The annual costs for operation and maintenance were found to be less by 39%. The problem which the study did not cover was capital cost of the conversion process and bunkering infrastructure for LNG for the ships

[1] Cost of averting a tonne of CO_2 eq heating

Seddiek et al., (2014) analysed various methods which would reduce emissions. The results showed valuable percentage reduction by using Selective catalytic reduction (SCR) and scrubber systems. As per the study it was found that these measures were costly and would increase the operational cost of the ship. However, the study concluded that use of LNG as a fuel would give better results environmentally and economically.

Isensee and Bertram (2004) in their paper of quantifying external costs of emissions due to ship operation compiled the data for ship emissions. The study evaluated the use of alternative fuels for simulation and optimisation of transport costs involving ships. Bengtsson et al., (2011) compared the alternative fuels with Heavy Fuel Oil (HFO) and LNG for complying with SECA and Tier III regulations. Life cycle assessment of various fuels was done, and their acidification and eutrophication potential was evaluated. The study was useful in considering the environmental performance of the marine fuel and impact on the life cycle to choose the best alternative fuel. Zhou et al., (2003) analysed the eco-efficiency of biodiesel as a fuel in recreational boats in the United Kingdom. The property of biodiesel makes it suitable for inland waterways application and feasible when compared to other fuels.

Elgohary et al., (2013) compared alternative marine fuels for their environmental benefits the main emphasis was on LNG as future marine fuel. The work presented LNG could offer a reduction in SOX, NOX, CO2 and PM by 98%, 86%, 11% and 96%respectively. It was also concluded that the use of LNG would offset the use of conventional fuel. The limitation highlighted in this paper was due attention must be made regarding rules and regulations for ensuring safe storage, transport, and bunkering of LNG.

A study from the Danish companies for vessel emission was done in 2012. The work compared the various abatement technologies to meet emission levels for ECA's.The study concluded that it is possible to reduce SO_x by retrofitting the scrubber (Nielsen et al., 2012). The payback period found is quite long term. The study also revealed that the payback period is long if the LNG is used as a marine fuel within ECA area but when used outside the ECA area the payback period is almost one third. From the study, it is quite evident that complying with the LNG would bring financial benefit to the shipowners in the long term.

Psaraftis et al., (2010) discussed the balancing of the economic and environmental performance of the international shipping. The study provided some scenarios and framework to calculate the emissions. The work gave a framework for calculating the economic benefits in case of fuel switching considering the variability in the fuel prices.

Lazarowicz talks about a framework for reducing emissions by Global Carbon Trading mechanism in his paper (2009). The paper compares the two approaches sectoral and distributed auction approach. Lazarowicz concludes that the global emissions trading administered by IMO will bring the necessary environmental and economic benefit in the short run. The environmental outcome can be generated by setting a cap, and economic benefit will be favoured by trade.

Yubing shi (2016) analyses the MBM for reduction of GHG emissions from international shipping. The discussion proves that the MBMs are necessary for achieving absolute emissions reduction even though some of the MBMs are not justified at this particular time. The study reveals that the international community is looking forward to adopting global sectoral reductions target by levy scheme.

Liping Jiang et.al (2010) used the voyage based model to calculate the external cost for a ship. In the study, they did a cost-benefit analysis of saving in air pollution and climate change costs. In conclusion, environmental benefit is sufficient to increase the benefit-cost ratio. A similar methodology is used in the case study by the author.

In the maritime industry, premature deaths can be avoided by using alternative fuels to HFO and Diesel oil as it reduces the emissions of fine particles. The tropospheric ozone formation is because of photochemical reactions of GHG gases like NO_X, CO, CH_4 and VOCs (Ebi and McGregor, 2008). Reactions of GHG gases also increases the formation of the Ozone layer because of elevated temperature. (Hesterberg et al., 2009).

Chul-hwan Han (2010) gives different strategies to reduce air pollution from the maritime industry. He explains the technical, operational and market-based strategies available to shipowners and analyses the compliant strategy. The limitation of this study is there is no methodology for assessing the cost-effectiveness of this strategy.

Brandt et al., (2013) studied public health costs due to air emissions from international shipping in Europe for the year 2000, 2007, 2011, and projected for the year 2020. The study used the EVA modelling technique which maps the long range transport and physical and chemical changes. Data on the population who are exposed to the air pollutant concentration was evaluated, and health cost analysis was done to calculate the health externality.

3. Air emissions

This chapter provides an overview on air emissions caused by the shipping sector. It will help the reader to understand the know-how of air emissions and methods of reporting emissions data. This section also discusses the need and methodology for inventory management of air emissions as it will help shipowners to quantify their financial impacts.

3.1. Air emissions and Maritime Transport

The Greenhouse gas protocol in Kyoto has listed seven gases as the GHG gases under the 2011 amendments. They are Carbon dioxide (CO_2), Methane (CH_4), Nitrous oxide (N_2O), Hydrofluorocarbons (HFCs), Perfluorocarbons (PFCs), Sulphur hexafluoride (SF_6) and Nitrogen trifluoride (NF_3). The other indirect greenhouse gases mentioned are SO_2, NO_x, CO, and NMVOC[2] (UNFCCC,1992)(Kyoto Protocol, 1997). These gases are emitted from various sources.

World trade has led to the demand for seaborne transportation. As per the United Nations Conference on Trade and Development report (2015), shipping industry contributes about US$380 in transport prices globally which comes around 5% of total world trade. Over the last two decades, total seaborne trade has doubled. It is clearly visible in Figure 3 the demand for all kinds of products and raw materials have increased. It is projected that in 2060 the contribution from shipping will be 23 billion tonnes of cargo transportation (Rahm, 2015). The growth in demand might lead to the increase in the air emissions. Therefore, rules and policies are imposed at national and international levels.

The world's population is increasing, and hence the demand for manufactured products and raw materials. Since the maritime transport is the most fuel efficient form of transport compared to the other sectors, there will be an

[2] Non-Methane Volatile Organic Compounds

increase in global trade being carried out by sea. Hence, the increase in air pollution can be predicted (IEA Statistics, 2015).

World Seaborne Trade in last 20 years.

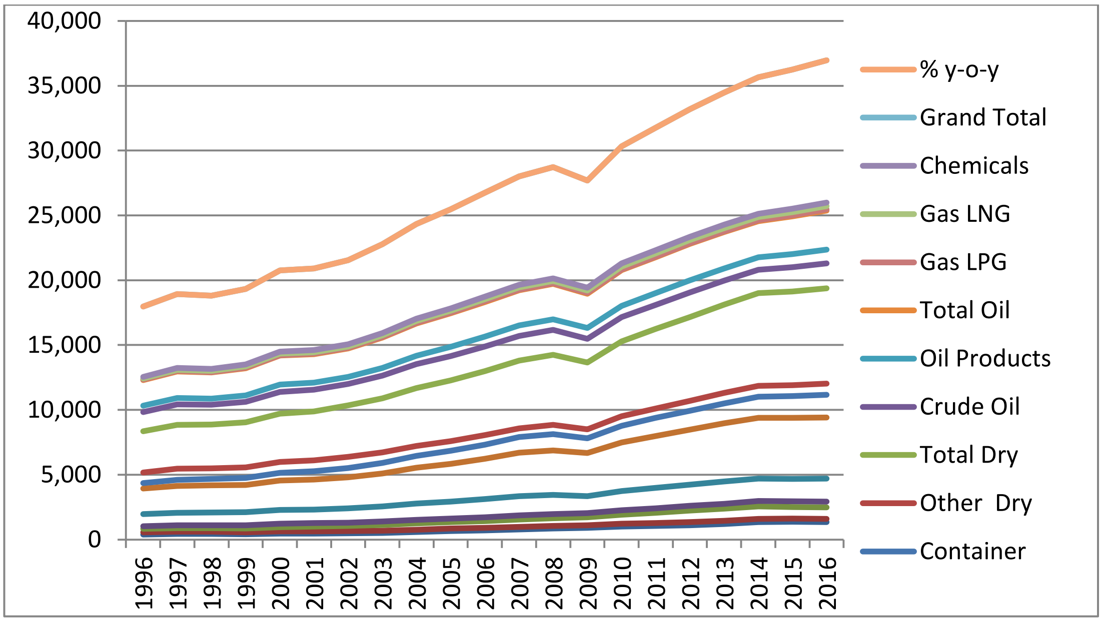


Figure 3.

Source: Clarkson Intelligence Network.

GHG emissions of OECD Countries

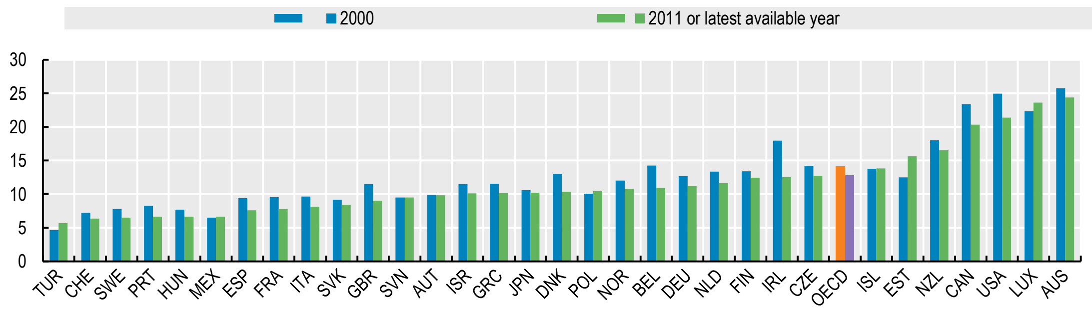


Figure 4 GHG emissions of OECD Countries in the year 2011 compared to the year 2000.

Source: OECD Factbook 2014: Economic, Environmental, and Social Statistics - © OECD 05-05-2014.

Figure 4 represents the GHG emissions from OECD countries contributed by the shipping sector. There has been a considerable decrease in the emission because of new policies and regulations for emissions. As also indicated in Figure 5 the CO_2 emissions from marine bunkers were increasing till the year 2010, but after EEDI regulation was approved, there has been a significant downfall in the emissions across different regions of the world.

CO_2 eq emissions from marine bunkers in million tonnes.

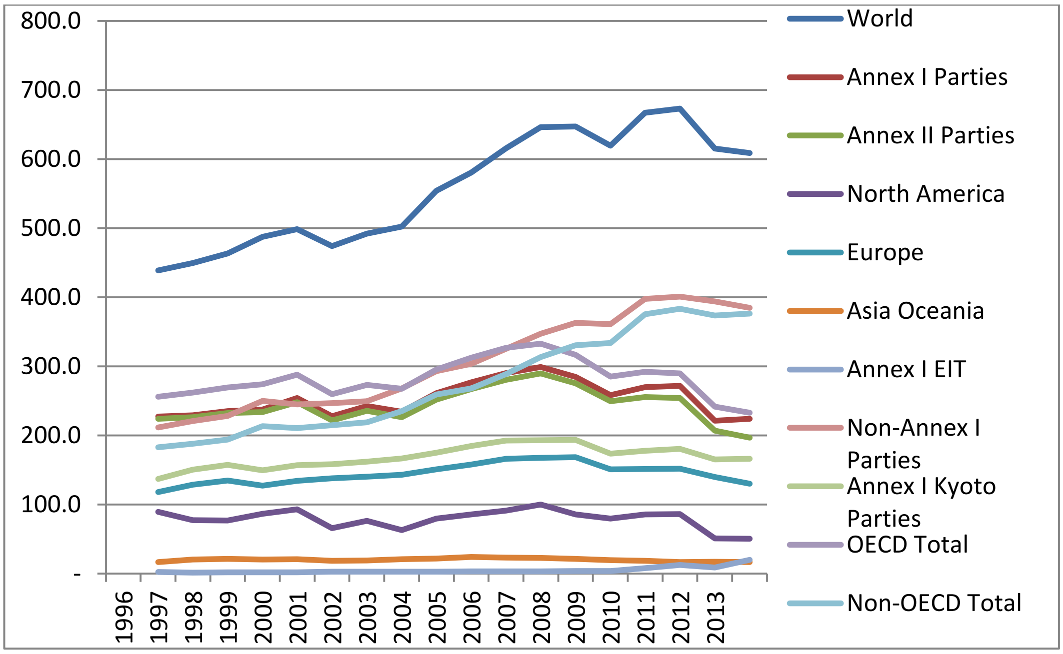


Figure 5. CO_2 eq emissions from marine bunkers in million tonnes.

Source: IEA CO_2 Emissions from Fuel Combustion, OECD/IEA, Paris, 2015.

Table 1 represents CO_2, GHG, CH_4, and NO2 from fossil fuel consumption and cement production, converted from Tg C per year to million tonnes. International shipping accounts for 0.24% and 5.60 % of CH_4 and N_2O compared to global emissions whereas total shipping including domestic shipping was calculated as 0.24% and 6.60% for CH_4 and N_2O respectively.

Table 1 Shipping emissions compared with global (values in million tonnes)

Year	Global	Total shipping	Percentage of global	International shipping	Percentage of global
Average global CO_2 in million tonnes	33,273	1,015	3.10%	846	2.60%
Average global CO_2e in million tonnes	36,745	1,036	2.80%	866	2.40%
Average global Ch_4 in thousand tonnes	96000	229	0.24%	227	0.24%
Average global N_20 in thousand tonnes	700	46	6.60%	39	5.60%

Sources: Boden et al., 2013, for years 2007-2010; Peters et al., 2013, for years 2011-2012, as referenced in IPCC (2013)

Emissions - EU28 (Convention) - Tg (million tonnes)

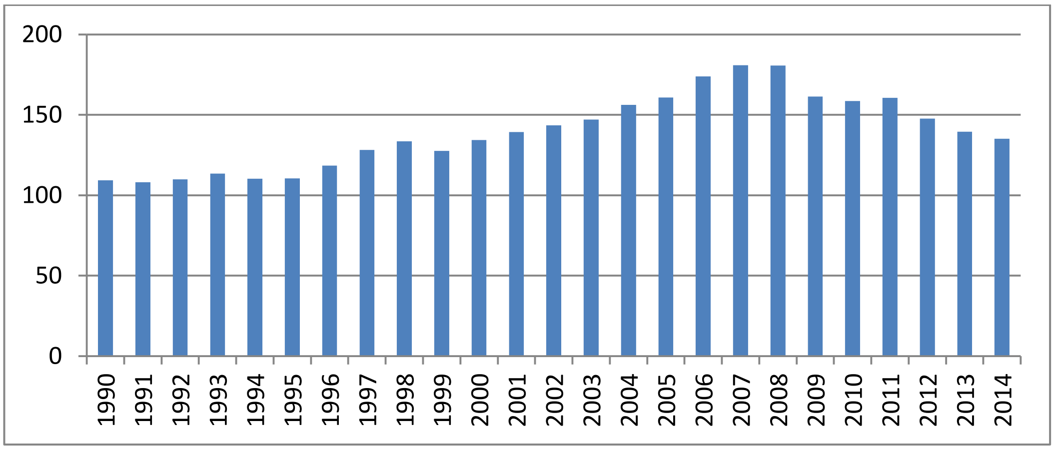


Figure 6. GHG gases equivalent to CO2 by international shipping in the European region

Source: Compiled by author by data given by EU Council

Emissions - EU28 (Convention) - Tg (million tonnes)

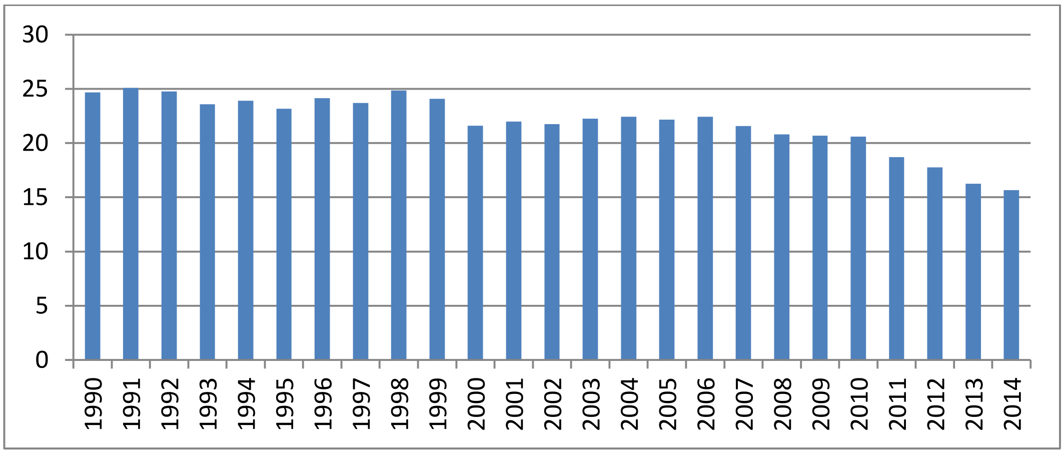


Figure 7. GHG gases equivalent to CO2 by domestic shipping and inland waterways in the European region.

Source: Compiled by author by data provided by EU Council

The emissions around Europe caused by the domestic and international shipping are shown in Figures 6 and 7. Figure 6 demonstrate the emissions of GHGs equivalent to CO_2 by international shipping in the European region. It is evident from the graph; there has been a decrease in the GHG emissions after 2008 because the global sulphur cap was reduced to 3.5% and 1% in ECA. Figure 7 shows the emissions of GHG gases equivalent to CO_2 by domestic shipping and inland waterways in the European region. There has been a considerable reduction because of the policies and regulations took by the EU directives as a proactive approach.

3.2. Impact of air emissions

Figure 8 explains the air pollutant concentrations and the effect of individual gases on the climate, ecosystem, and human health. Depositions of Nitrogen and Sulphur compounds have adverse effect on the ecosystem. The impact of air emissions on acidification and eutrophication of water is due to the deposition of air pollutants. According to Ng and Song (2010), the shipping industry possesses negative externalities to natural habitats and ecosystems. The illustration was shown by using EMEP[3] model (EMEP, 2015). The EMEP model gave the potential of emissions for acidification and eutrophication by using source-receptor matrices. According to EMEP receptor emissions around Europe has increased tremendously in the last five years.

Impact on health, ecosystem and climate.

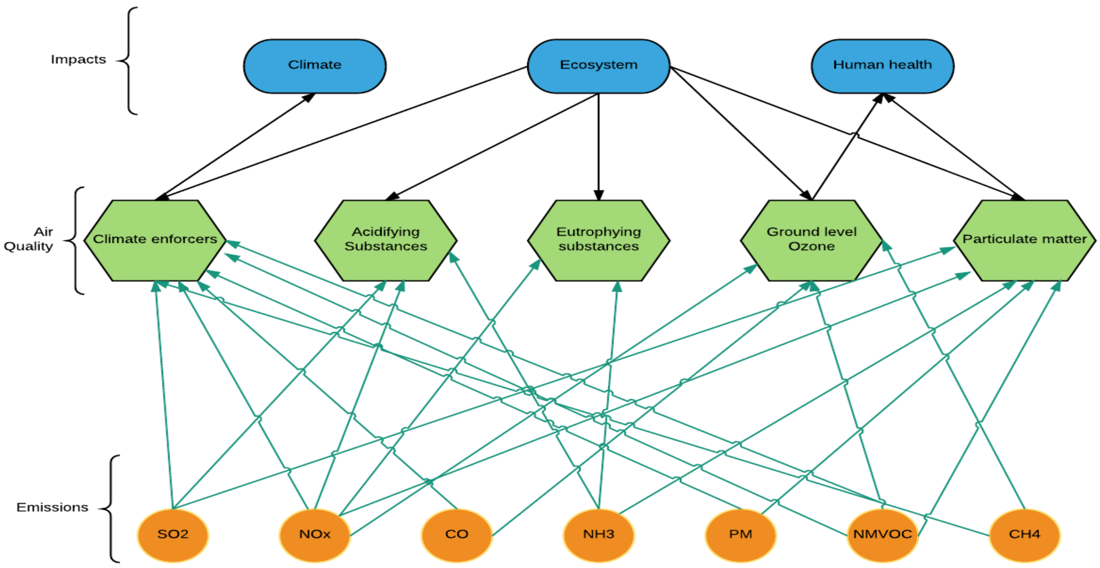


Figure 8. Major air pollutants in Europe clustered according to impact on health, ecosystem, and climate.

Source: Adapted from EEA (2012): Air quality in Europe 2012-report

[3] European Monitoring and Evaluation Program *(monitoring and evaluation of long range transmission of airpollution)*

GHG concentration is the main reason for global warming which is causing climate change. Global warming can be measured by an increase in global average temperature. The GHGs have different global warming potential (GWP). GWP is defined as

"The index is defined as the cumulative radiative forcing between the present and some chosen time horizon caused by a unit mass of gas emitted now, expressed relative to that for some reference gas (here CO_2 is used)."

(IPCC, 1995)

The GWP over a different period can be calculated by multiplying the GWP by the amount of gases emitted. The GWP varies a lot because different gases have a different lifespan in the atmosphere. Figure 9 shows that GWP of different GHG mentioned in the climate change report during the time horizon 20, 100 and 500 years. Different marine fuels emit different concentrations of pollutants and hence understanding the GWP of different gasses is necessary when choosing an alternative fuel.

GWP of GHGs

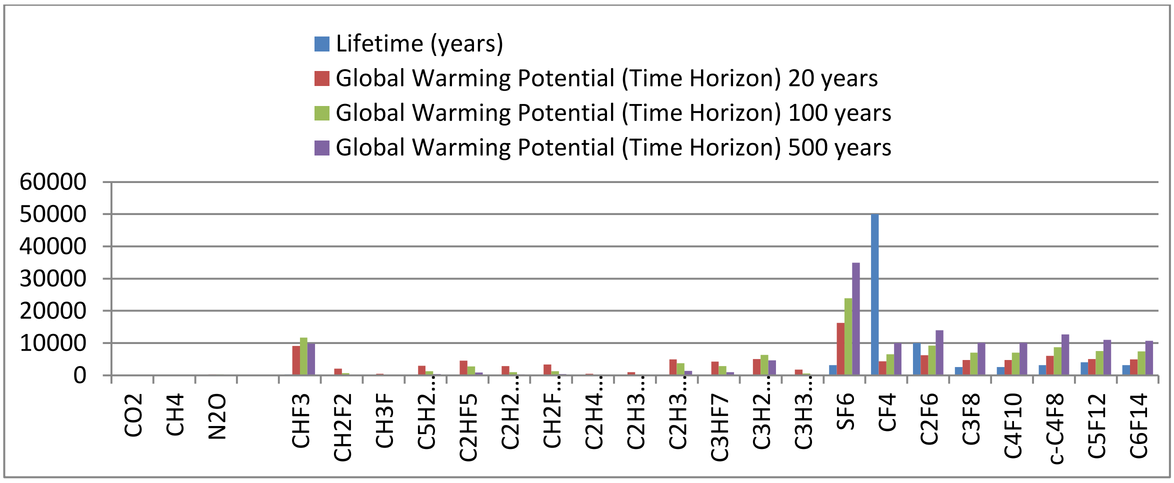


Figure 9 GWP of GHGs over different time span adapted from Bern carbon cycle model
Source: Climate Change 1995, The Science of Climate Change: Summary for Policymakers and Technical Summary of the Working Group I Report, page 22.

Brandt et al.,(2013) studied air emissions from the international shipping and evaluated that there were 50,000 premature deaths per year in Europe.Effects on the health are discussed in this section.

Table 2 Percentage of the urban population in the EU-27 Member States exposed to air pollutant concentrations above the EU and WHO reference levels (2009-2011).

Pollutant	EU reference value	Exposure estimate (%)	WHO reference level	Exposure estimate (%)
$PM_{2.5}$	Year (20)	20-31	Year (10)	91-96
PM_{10}	Day (50)	22-33	Year (20)	85-88
O_3	8-h (120)	14-18	8-h (100)	97-98
NO_2	Year (40)	5-13	Year (40)	5-13
BaP	Year(1ng/m^3)	22-31	Year(0.12ng/m^3)	76-94
SO_2	Day (125)	<1	Day (20)	46-54
CO	8-h (10 mg/m^3)	<2	8-h(10 mg/m^3)	<2
Pb	Year (0.5)	<1[a]	Year (0.5)	<1[a]
C_6H_6	Year (5)	<1	Year (1.7)	12-13

Source: Air quality status and trends in Europe (Cristina et .al, 2014).

Table 2 shows the comparison made for the most stringent EU limit or target values set for the protection of human health and illustrates the percentage of population exposed to different kind of air pollutants concentrations.Table 3 gives the overview of air quality as per the guidelines of WHO for various pollutant concentrations to the percentage of population exposed.

Table 3 WHO air quality guidelines (WHO, 2006, 2000)

Pollutants	Averaging time	AQG[4] values (µg/m3)
Particulate matter		
PM2.5	1 year	10
	24 h (99th percentile)	25
PM10	1 year	20
	24 h (99th percentile)	50
Ozone O3	8 h daily maximum	100
Nitrogen dioxide NO2	1 year	40
	1 h	100
Sulphur dioxide SO2	24 h	20
	10 min	500

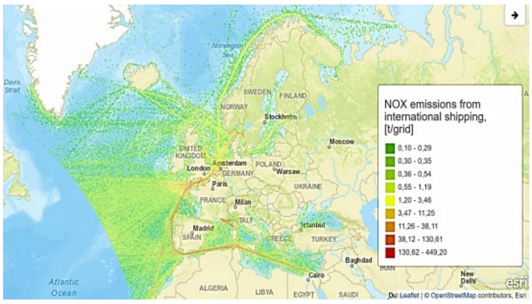
Source: Air quality status and trends in Europe Cristina B.B. Guerreiro et al.,2014.

[4] Air Quality Guidelines

3.3. Spatial effect on coastal areas of Europe

The grid shows the emissions of different pollutant concentrations. The concentrations are necessary to know the impact on various areas and population. To study air quality models emissions from a ship must be recorded. Local modelling techniques use high-resolution ship emission allocation in the range of 1-5 km whereas regional air quality modelling uses 10x10 km or 50X50 km grid resolution. In the case of unavailability of data, the activities by the ship are taken as a proxy. The movement of the ship can be aggregated by AIS[5], IOCADS[6] and AMVER[7] modelling. This dissertation has used the data of E PRTR[8] database sets to show the diffuse emissions caused by international and domestic shipping. (Figures 10 to Figure 17 show the diffuse emissions of SO_2, NO_x, PM, CO and CO_2 from international shipping and domestic shipping of the EU28 and EFTA4 countries per 5x5 km^2 grid cells for the reference year 2008.

Diffuse Emissions of Pollutants around coastal Europe



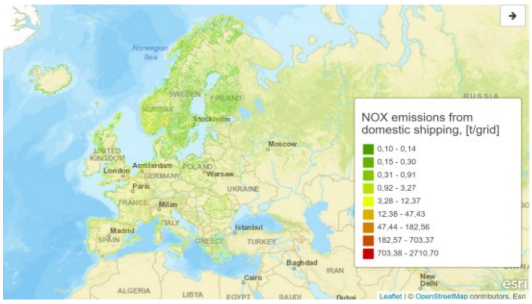
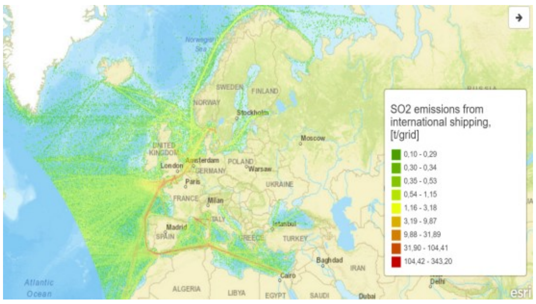


Figure 10 NOx Emissions from International Shipping and Figure 11NO_X emissions from domestic Shipping



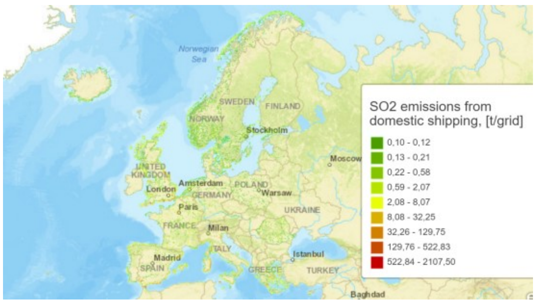


Figure 12 SO_2 Emissions from International Shipping and Figure 13 SO_2 emissions from domestic Shipping

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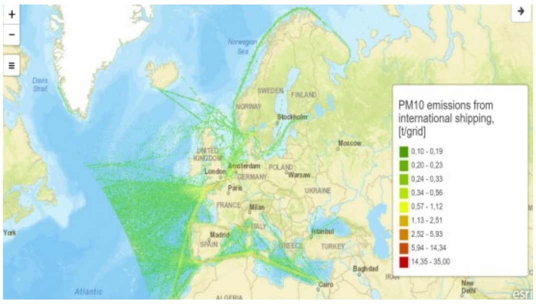
[5] Automatic Identification System
[6] International Comprehensive Ocean-Atmosphere Data Set
[7] Automated Mutual-Assistance Vessel Rescue System

[8] The European Pollutant Release and Transfer Register (E-PRTR) is the Europe-wide register that provides easily accessible key environmental data from industrial facilities in European Union Member States and in Iceland,



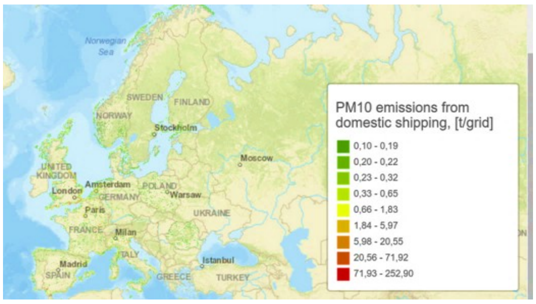
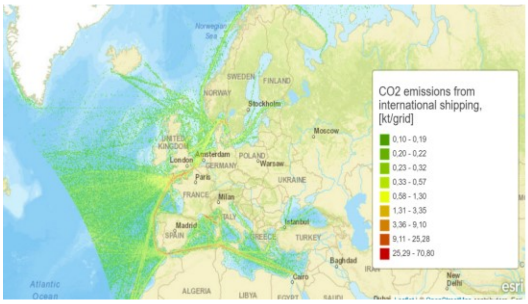


Figure 14 PM_{10} emissions from International Shipping and Figure 15 PM_{10m}emissions from Domestic Shipping



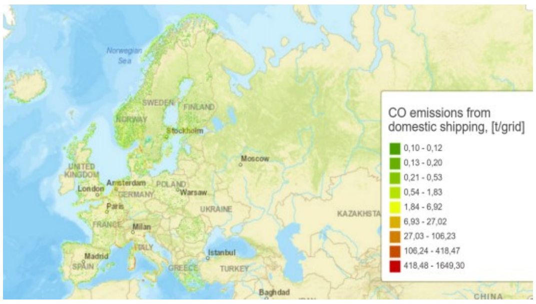


Figure 16 CO_2 Emissions from International Shipping and Figure 17 CO emissions from domestic Shipping

Source: E PRTR9 database, 2016

The diffuse emissions of pollutants are expressed in tonnes per grid cell. Emissions to air from international and domestic shipping are distributed according to the data reported to Convention on Long-Range Transport of Air Pollution (CLRTAP). The emissions are allocated using GIS[10] overlay techniques for distribution into grid cells with a spatial resolution of $5x5km^2$. There is considerable variation because emissions are dependent on the navigational route of ships and vessels traffic.

3.4. Monitoring emissions

As per the new legislation in EU states of MRV (Monitoring review and Verification directive), it is mandatory to record CO_2 emissions so that shipowners know the activities of the ship and its emissions. The scope of GHG emissions is defined for the measurement and finding out the impact of GHG on the environment.

[9] The European Pollutant Release and Transfer Register (E-PRTR) is the Europe-wide register that provides easily accessible key environmental data from industrial facilities in European Union Member States and in Iceland, Liechtenstein, Norway, Serbia and Switzerland

[10] Geographical Information system.

It is necessary to set the extent of GHG emissions to improve transparency and avoid duplicity of information when reporting. Moreover, reporting will help the ship operators and owners for inventory management and accounting of emissions. Therefore, all GHG Emissions are categorised into three different scopes according to their accepted approach. This sub-section will discuss many methods available to monitor ship activities, fuel consumption and modelling of air pollutants and GHG emitted during the process. A particular method is used depending on the approach of the emission measurement. Emissions can be projected by using fuel consumption. For this method emission factors of different gases must be applied. This approach was found to be inaccurate as there is uncertainty about the fuel consumption and after treatment technologies used on board. This problem can be solved by using direct measurement, but it increases the cost of installation for a ship-owner. Some of the methods discussed are described below

1. Use of Sniffer technology: Sniffers are quite useful with an accuracy of 15% for measuring the sulphur content in the fuel (BalzanyLööv et al., 2011). Sniffers are installed on a helicopter or in an unmanned aerial vehicle to follow the ship and measure the concentrations of CO_2, NO_x, and SO_2.
2. Differential Optical Absorption Spectrometry (DOAS): Berg at al., (2012) did the measurement of SO_x concentration by passing sea scattered solar light. The concentration of pollutant on multiplying with the speed of wind gives the flux of that pollutant. With the information of the fuel consumption emissions can be calculated accurately up to 40%.
3. Light Detection and Ranging (LIDAR) is a remote sensing technique used for the emissions measurement. This approach is sensitive to the wind direction and widely applicable for measurement of SOx. Like DOAS, LIDAR also uses the method of calculation of fuel consumption and the ship' speed. The limitation of this method is that not all the sulphur present in the fuel is converted into sulphur dioxide (Berkhout et al., 2012).
4. Unmanned aerial vehicles (UAVs) are the latest methods for measurement of high-resolution spatiotemporal emissions. UAVs are quite flexible to carry on or more sensors and can operate in different flight modes. Villa, Gonzalez, Miljievic, Ristovski, & Morawska (2016) evaluated that UAVs is a cost-effective method for measuring spatial and temporal variations of atmospheric CO_2.

5. Calculation of fuel consumption and resulting ship emissions are done by two methods namely top down and bottom up approach. (Second GHG study, 2009).
   i. The top-down approach is used at regional and international level. EDGAR[11] database is an example of emissions calculated from the top down approach. The top-down approach is prepared from domestic and international shipping data from LRTAP[12] and UNFCCC combining with the fuel statistics and emission factors.
   ii. The bottom-up method uses ship's activities tracked in AIS, LRIT[13], and IHSF. The ship's activities associated with ship's energy consumption can be used to calculate GHG emissions. In this method, fuel consumption is calculated by using the formula for individual ships of a specific type using averaged values. A constant sfoc[14] is required for calculation. As per Corbett and Koehler, (2003) the two-stroke engine is considered as SSD[15] engine as they operate at very slow speed (around 100 rpm) whereas the four stroke engine is considered as MSD[16] or HSD. Different types of ships will have different sfoc and hence different emissions.

3.5. Emission Inventory

"*The ultimate objective of UNFCCC is to achieve stabilisation of GHG concentration in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system.*"

(UNFCCC, 2016).

Estimating the value of the GHG concentration and keeping a record is an essential element. The LRTAP Convention requires countries parties to that convention should report their emissions of air pollutants. UNFCCC emission inventory is based on international bunker sales and calculated by using emission factor method. Table 4 shows the emissions of CO_2, NO_x, SO_x , PM, NMVOC as reported to UNFCCC by countries parties to Annex 1 and LRTAP. The emissions

11 The Emissions Database for Global Atmospheric Research (EDGAR) provides global past and present day anthropogenic emissions of greenhouse gases and air pollutants by country and on spatial grid. The current development of EDGAR is a joint project of the European Commission
12 The Convention on Long-range Transboundary Air Pollution was the first international legally binding instrument to deal with problems of air pollution on a broad regional basis.
13 Long-range identification and tracking (ships)
14 Specific fuel oil consumption
15 Slow Speed engine
16 Medium speed engine

calculated by using international bunker fuel data. ("IPCC/UNFCCC Reporting Guidelines and Associated Methodologies and Data Sources," 2004).

Table 4 Emissions recorded in UNFCCC and LRTAP

Inventory	Year	CO_2	NO_x	SO_x	$PM_{2.5}$	NMVOC	CO
UNFCCC	1990	111844	1331	1002	-	52	145
UNFCCC	2006	174593	1954	1581	-	79	187
UNFCCC	2010	150862	1873	1429	-	80	196
LRTAP	1990	-	1416	1056	95	53	152
LRTAP	2006	-	2051	1647	161	77	176
LRTAP	2010	-	1916	1460	148	72	159

Source: EEA, 2012a, and EEA, 2012b.

EFDB emission factor database is a library which collects data for emission factors and other parameters with background documentation and technical references for estimating greenhouse gas emissions. It contains the default data of IPCC. IPCC has set up a task force to run NGGIP[17] to produce its methodological assistance.

17 National Greenhouse Gas Inventories Programme was managed from 1991 by the IPCC

4. Air emission reduction measures

In this chapter, the author has analysed the various measures available to shipowners. This section also investigates the response of shipowners to different possible actions. Two measures namely MBM and Carbon tax are not fully developed or in practice globally. The author has used the analogy of land based application in some cases to show the effectiveness of the measures.

4.1. Technical measures

Energy Efficiency Design Index (EEDI) and SEEMP were approved in July 2011 by IMO and entered into force on 1 January 2013. This index is to make ships more efficient. If all the ships built are complying with EEDI between 2020 and 2024 it will improve energy efficiency by 20% and 30% after 2024 depending on the type of vessel (Third GHG study, 2014). The projection is EEDI will reduce global CO_2 reduction to 10–20% by 2030 against BAU scenario. ICCT[18] estimates that EEDI compliant ships deployed in 2015 will reduce 15-45 Mt of CO_2 annually by 2020 and between 141-263 Mt of CO_2 annually by 2030. The delay of implementation will reduce the benefits by 83% and 45% for 2020 and 2030 respectively.

“The EEDI is the first globally binding climate measure and sets energy efficiency parameters for the design of new ships.”

(Transport and Environment, 2013)

EEDI is important because that means a ship has to go for minimum efficiency standard specific to ship type. The life cycle of a vessel on average is around 25 years so it might take two decades before there will be energy efficient ships worldwide. IMO agreed to SEEMP and Energy Efficiency Operational Indicator (EEOI) for new and existing ships. SEEMP contains energy management plan for fuel-efficient practices. EEOI can be used by shipowners as a benchmark for their

[18] International Council on Clean Transportation

fleet performance. Attained EEDI for a particular ship type must not exceed the value at baseline estimated by IMO. In case the ship comes under the category of two different ships the EEDI value of the most effective regulations will be used as a reference. There have been some dicrepancies when reporting the EEDI value. A low EEDI ship can emit more CO_2 compared to the ship which has a higher EEDI depending on various factors like size of the ship. In inclement weather, while maintaining speed, a lower EEDI ship will emit more than a ship with a bigger engine. Another factor is applying EEDI on existing ships is more intricate, and it requires sea trials which can be complex and tedious processes.

According to the Kyoto protocol only developed countries have accepted to abide with the GHG emission targets. There is much opposition to these regulations as it was bound in all states. The developing countries (China, Brazil, India, South Africa and Saudi Arabia) looked at it as in conflict with the principle of common but differentiated responsibility (CBDR) in the UNFCCC. The main demands of developing countries were:

1. A differentiated application for energy efficiency measures, provide capacity building,
2. Provision of technical assistance to meet EEDI requirements and
3. A waiver of the period for an implementation date.

From shipowners' point of view, if they do not comply with these regulations, the value of non-compliant ships will go down in the second-hand market as charterers will prefer more efficient ships. When the fuel prices are high fuel-efficient ships are more in demand because efficiency reduces the total operational cost. Efficient design ships are more expensive, ship-owners can only benefit with low payback period when the fuel costs are low. Therefore, when fuel costs are very low, shipowners would avoid investment in capital and will go for cheaper or less efficient design. Shipowners are reluctant to invest in innovative design, and they are complacent with the efficiency of the ship. However, shipyards look for innovative design for shipowners as they want to compete in the market and lure the charterers when freight rates are low. According to Mortensen (2009), when freight rates are high, owners’ line up to order ship even if the capital investment is high. The behavior of shipowners is questionable and complex when it comes to comply with technical measures and a clear picture is needed for their strategy.

What needs to be done?

Air emissions including GHG emissions from all the sectors have reduced if compared to 2014 emissions to the year 1990 as shown Figure18. The policies implemented in other sectors are more stringent and efficient. Conversely, the transport sector has failed to reduce the emissions because of increase in population and world trade. There has been a tremendous development in the road and aviation sector for greenhouse gas reduction measures. The shipping industry accounts for very less percentage for GHG emission compared to global emissions. It is high time for the maritime industry to implement abatement measures as shipping will become one of the highest contributors for GHG by 2030 as projected (Third GHG study, 2014).

GHG emissions, analysis by source sector

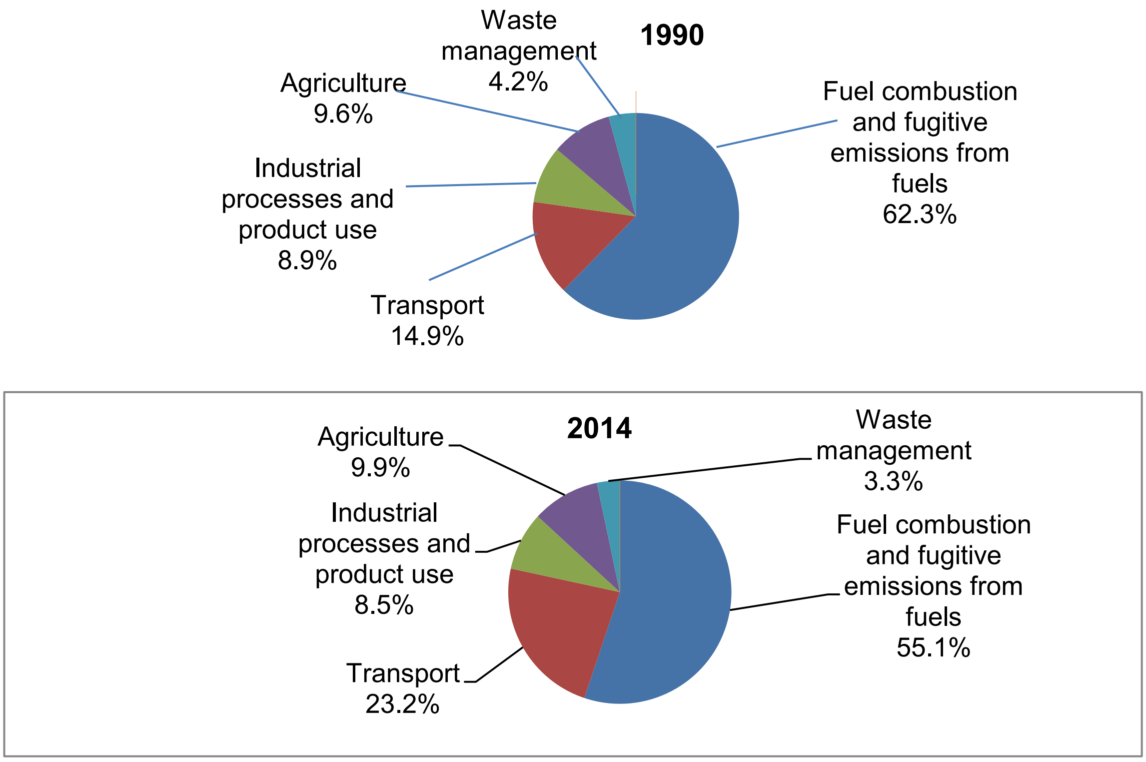


Figure 18. GHG emissions, analysis by source sector, EU-28, 1990 and 2014 (percentage of total)

Source: Eurostat, 2016

Since maritime is the most neglected sector when it comes to the emission reduction a comparison of ISO GHG Standards with maritime initiatives is made to see what elements are required to fulfill the criteria for abatement measures. Table 5 gives a brief description of maritime initiatives comparable to International Organisation for Standardization (ISO) standard for GHG emissions. All the ISO standards are compared with the maritime initiatives taken by IMO and EU council. Since EU Council and IMO are the main organization taking initiatives to reduce GHG emissions for maritime sector. The author has compared the actions taken by them against the standards sets by ISO. Life cycle assessment was found missing for the abatement technologies and alternative fuel. Life cycle assessment is necessary for to make changes in the design stage. There must be an approach to providing principles, framework, guidelines, environmental declaration and efficient application for life cycle assessment for ship's technical measures.

Table 5. Comparing ISO GHG standard with maritime initiatives

Standards	Contents[19]	Maritime industry initiatives
ISO Guide 64:1997	Guide for the inclusion of environmental aspects in product standards	Article 21 UNCLOS, Index of MEPC Resolutions and Guidelines related to MARPOL Annex VI, Resolution 8
ISO 14001:2004	Environmental management systems Requirements with guidance for use	Guidelines for calculation of reference lines for use with the (EEDI), SEEMP, Circular 681, MEPC Resolution 212(63)
ISO 14004:2004	Environmental management systems - General guidelines on principles, systems and support techniques	Regulation 2015/757 Chapter II Monitoring and reporting Section 1 Article 4, Resolution A 963 (23)
ISO 14015:2001	Environmental Management - Environmental assessment of sites and organizations (EASO)	SEEMP and ISM
ISO 14020:2000	Environmental labels and declarations - General principles	MEPC 231(65) provides reference lines
ISO 14021:1999	Environmental labels and declarations - Self-declared environmental claims (Type II environmental labelling)	Guidelines for calculation of reference lines for use with the (EEOI)
ISO 14024:1999	Environmental labels and declarations Type I environmental labelling-Principles and procedures	ECA regulations, EU directive, California directive, NSW marine pollution regulations
ISO 14025:2006	Environmental labels and declarations Type III environmental declarations	Missing
ISO 14031:1999	Environmental Management -Environmental performance evaluation -Guidelines	MEPC 245(66) EEDI calculation guidelines
ISO/TR 14032:1999	Environmental management -Examples of environmental performance evaluation (EPE)	MARPOL Annex VI Chapter 4
ISO 14040:2006	Environmental management - Life cycle assessment - Principles and framework	**Missing**

[19] Source. ISO GHG standard

ISO 14044:2006	Environmental management - Life cycle assessment – Requirements and guidelines	**Missing**
ISO/TR 14047:2003	Environmental management - Life cycle impact assessment Examples of application of ISO 14042	**Missing**
ISO/TR 14048:2002	Environmental management - Life cycle assessment Data documentation format	UNFCCC,EFDB.IPCC inventory Software,NGGIP
ISO/TR 14049:2000	Environmental management — Life cycle assessment — Examples of application of ISO 14041 to goal and scope definition and inventory analysis	LRTAP, AIS Based emissions technology, Bottom up and top down approach
ISO 14050:2002	Environmental management — Vocabulary	IPCC guidelines, UNFCCC , SEEMP
ISO/TR 14062:2002	Environmental management - Integrating environmental aspects into product design and development	EEDI, MSC.287(87), the International Goal-based ship construction standards
ISO 14063:2006	Environmental Management - Environmental Communication - Guidelines and examples	ISM, SEEMP, Marpol ANNEX VI and Example: NTC 2008 With Guidelines For Implementation
ISO14064-1:2006	Greenhouse gases - Part 1: Specification with guidance at the organization level for quantification and reporting of greenhouse gas emissions and removals	Regulation 2015/757 on the monitoring, reporting, and verification of carbon dioxide emissions from maritime transport
ISO 14064-2:2006	Greenhouse gases -Part 2: Specification with guidance at the project level for quantification, monitoring and reporting of greenhouse gas emission reductions or removal enhancements	Regulation 2015/757 on the monitoring, reporting, and verification of carbon dioxide emissions from maritime transport

ISO 14064-3:2006	Greenhouse gases - Part 3: Specification with guidance for the validation and verification of greenhouse gas assertions	MONITORING PLAN Verification Resolution13,14,15 Annex III
ISO 14065:2007	Greenhouse gases - Requirements for greenhouse gas validation and verification bodies for use in accreditation or other forms of recognition	EU Council, Clean shipping index, Regulation 2015/757 on the monitoring, reporting, and verification of CO_2 emissions from maritime transport
ISO 19011:2002	Guidelines for quality and/or environmental management systems auditing	MRV EMISSIONS REPORT Preparation Resolution 11, 12, Annex I and II, Verification Resolution. 13,14,15 Annex III

4.2. Market-Based Measures

MBM would place a price on emissions from international maritime transport. MBM can be effective in three ways:

4. Offsetting the growing maritime emissions
5. Providing an incentive for the shipowners to invest in low carbon and fuel efficient technology.
6. Generating funds fo the mitigation and adaptation actions in developing countries (Psaraftis, 2012).

Adoption of MBM will create revenue for climate finance by international shipping. At MEPC 59 (July 2009), after much discussion the committee came to the conclusion that technical, and operational measures are not enough to reduce the emissions. Ten MBMs have been submitted since then. No clear approach was available, and hence discussions were suspended at 65 MEPC meeting in 2013 MBM proposals on the table during 60 MEPC meeting in 2010 were as follows. MBM cannot be implemented globally because economically it is not feasible and many LDC[20] and SIDS[21] countries do not have the mature technology.

1. GHG fund
2. Leveraged Incentive Scheme(LIS)
3. Port State Levy(PSL)
4. Ship Efficiency and Credit Trading (SECT)
5. Vessel Efficiency system (VES)
6. The Global Emission trading system proposed by Norway.(GETS)
7. The Global Emission trading system proposed by the UK.
8. Emission Trading System by France (ETS)
9. Penalty on Trade and Development(PTD)
10. Rebate Mechanism(RM)

4.2.1. Methodology for selecting best marked based measures.

In the 57 MEPC meeting, nine principles were discussed for selection of MBM to debate further on GHG emissions. These nine principles are mentioned in

[20] Least Developed Countries
[21] Small Island Developing States

Appendix F. Nine criteria for assessing the MBM proposals based on these principles are referred to in Appendix G. The Expert group evaluated the measures at different levels of criteria and came to the conclusion that all actions require further elaboration and development for full assessment of all possible impacts in a comparable analysis. CBDR not stated properly and hence some countries opposed the idea. These nine principles were condensed into four principles after the second IMO GHG study.

1. Equal applicability to all countries corresponds to the second principle
2. Minimisation of competitive distortion corresponds to the fourth principle
3. Environmental effectiveness and cost-effectiveness correspond to the fifth principle
4. Non-prescriptive corresponds to the sixth principle

Moreover, five criteria selected based on the four principles are mentioned below:

1. Environmental effectiveness and cost-effectiveness; similar to criteria 1.2.7.8
2. Incentive to technological change; similar to criteria 3
3. The practical feasibility of implementation; similar to criteria 4
4. Compatibility with international law and IMO legal framework; similar to criteria 6 and 9
5. Financial and technological transfer.similiar to criteria 5.

The main principles which IMO should incorporate while proposing any MBM proposal must include CBDR and No more favorable treatment (NMFT) (Shi, 2016). Out of 10 MBM submitted to IMO, 2 MBM proposals incorporate the above mentioned two principles of CBDR and NMFT, which are rebate mechanism for international shipping and the port state levy. The fifth criteria exclude the application of CBDR and NMFT principles whereas Yubing Shi (2016) suggested the incorporation of CBDR and NMFT principles in the fifth criteria just like agreed by ICAO

Practical infeasibility of implementation due to the lack of support from stakeholders. ETS proposed to incorporate both CBDR and NMFT principle, but these make ETS approach most costly and hence doesn't fulfill the first criterion. In the case of shipping transport getting costly, it will cause a modal shift to other modes of transport. Shipping owners might choose different routes to get benefited from GHG emission reduction schemes. Hence it is clearly visible that its proposal violates the first and third criteria of selecting MBM.

4.2.2. EU Initiative

EU Council took the initiative in 2013 and developed a proposal on MRV(Monitoring, Review, and Verification). IMO is quite slow in reacting to the market-based proposal as it has many gaps and unequal participation of all the stakeholders. EU has adopted the MRV Regulation, and it came into force on 1 July 2015. IMO has the advantage of looking how it flares up in Europe before implementing any MBM proposals globally. EU has taken following methods:

1. MRV[22] of emissions (Regulation (EU) 2015/757)
2. Reduction targets for the shipping sector.(setting optimal level)
3. Application of an MBM (ETS)

The MRV system is the first step for implementation of any MBM reducing GHG emissions by ships at EU. Due to the lack of knowledge about costs, benefits and return on investment, there seems to be a delay in the complying with the measures on a global level. This kind of information will make shipowners do the cost-benefit analysis so that they are better equipped to make decisions on investments in abatement technologies. The impact assessment is done by the EU Council for the effective implementation of MRV regulation. It was evaluated that EU states will have environmental benefits of 2% reductions in annual GHG emissions whereas economic benefit would be around Euros 1.2 billion annual net savings because of reduced fuel bills.

As per the MRV regulation the following information must be recorded by the shipowners:

1. Description of the ship, shipowner and its management company.

[22] Regulation (EU) 2015/757 of the European Parliament and of the Council of 29 April 2015 on the monitoring, reporting and verification of carbon dioxide emissions from maritime transport, and amending Directive 2009/16/EC (Text with EEA relevance) states that
"All the ships exceeding 5000 GT regardless of flag or country or ownership must comply with the EU directive when calling EU port applicable from 1st January 2018.The Ships must have its own monitoring plan and must be verified by a classification society. Report of its emissions and activity data must be recorded and verified. On complying with above regulation she will be issued with Document of Compliance (DOC).All voyage must be reported when one port of call is in the EU to load or discharge cargo or to embark or disembark passengers."

2. Identification of emission source (from Main engines, auxiliary engines, boilers, gas turbines and Inert gas generators). The type of fuel used and its emission factors must be recorded.

3. Procedure for monitoring of voyages, fuel consumption must be stated in the plan.

4. All data must be recorded like fuel consumption at sea, at berth, at maneuvering, sailing distance, payload, time spent at sea transport work and energy efficient parameters.

5. Companies shall calculate CO_2 emissions by any method mentioned set out in Annex 1 of EU Directive 2015 / 757 and monitor the information by the rules in Annex II.

MRV system can become the first step for implementation of any measure reducing GHG emissions of ships at EU or global level. Due to the lack of knowledge about costs, benefits and return on investment there seems to have a delay in the complying with the measures on a global level. This kind of information will make ship-owners make the cost-benefit analysis and better equipped to make decisions on investments in abatement technologies. MBM proposals will not only help in reducing the pollution by polluter but will also increase the funds for investing. According to the results of the Impact Assessment, the implementation of MRV in EU states will have environmental and economic benefits of up to 2% reductions in annual GHG emissions and of up to Euros 1.2 billion annual net savings for the sector in 2030 due to reduced fuel bills. The annual savings will surpass the investment cost required for MRV system.

4.3. Operational Measures

This part of the dissertation identifies various kinds of abatement technologies and future energy efficiency measures available to the shipowners. These measures include new techniques and strategies that have the potential for energy efficiency and reduction in air emissions, ready to be retrofitted on board if the investment cost is not high and already used on land based industry and can be revised to be used in the maritime sector.

In marine diesel engines, NO_x is formed at peak temperatures. The NO_x reduction can be made in primary and secondary ways. Primary ways use methods to reduce NO_x during combustion. The secondary method involves reduction of NO_x after-treatment of the exhaust gas. In primary methods, NO_x reduction can be made by altering fuel injection and valve timing. In primary methods, fuel efficiency is decreased, and there are more PM emissions (Seddiek & Elgohary, 2014; Third GHG study, 2014).

1. Water during combustion method is used where injecting water reduces the temperature of the combustion chamber and prevents the formation of NO_x.

2. Exhaust Gas Recirculation (EGR) involves the use of exhaust gases in the scavenge air to reduce the oxygen concentration resulting in the reduction of NO_x by 70%. The drawback in the EGR method is that it requires an internal scrubber system when using high sulphur content fuels which increases the capital investment costs for shipowners (Miola et al., 2010).

3. Selective catalytic reduction (SCR) is an upstream exhaust gas treatment done with the use of urea as a catalyst. NO_x produced during combustion is converted into nitrogen and water. Urea consumption is around 1.5 litres per kg of NO_X formed.

Wet scrubbers are used to wash the SO_x from the exhaust gas by using scrubbing liquid. Three types of wet scrubbers are open loop, closed loop and hybrid. In the open type scrubber, power consumption is almost 2% of installed power. Seawater is used alongside $CaCO_3$ that forms gypsum with the sulphur dioxide. Residues are discharged into the sea after making the ph level neutral. Closed loop scrubbers use fresh water boosted with caustic soda to remove SO_x absorption. Power consumption is just 1% of the installed power. Hybrid scrubbers can use either of the two. Dry scrubbers use limestone in the uptake to absorb SO_x molecules instead of any scrubbing liquid. The most effective position is in the upstream of exhaust gas. Power consumption is 0.1% of the power.

90% can be reduced VOC and CO emissions with the use of SCR combined with an oxidation catalyst. PM can be reduced by use of scrubbers or SCR with an oxidation catalyst and catalytic diesel particulate filter (Effship report, 2012).

4.4. Emission Control and Energy Efficiency Measures

Various emission controls and energy efficiency measures are available for shipowners. These measures are selected by shipowners by some decision criteria. Table 6 summarises all kinds of technologies available in the market. Following legends are used to describe the table:

1. In the maritime industry, emission sources can be from engines(A), VOC tanks (Tank), auxiliary engines (A), auxiliary boilers (B) and the case of all these sources (all).
2. The column retrofittable denotes whether particular technology can fit on board on existing ships (yes-y) and new ships (no-n). Applicable operational modes show at which mode a specific measure is effective.
3. The modes are defined as open sea conditions (S), transition (T), manoeuvring (M), at berth (B), at anchorage (A) and all modes (all).
4. Energy and emission control is shown by the list of the pollutants and gives their potential reduction. The indicators used for an increase ↑ decrease ↓, and for either decrease or increase ↕.
5. If the value of the measure cannot be quantified is denoted as "to be determined." Emission reduction depends on various factors like engine loads, ship power configuration, fuels, operational measures, equipment parameters and other factors. Hence these specific conditions must be evaluated by case by case and denoted as (cbc).

The equipment category consists of engine technologies, boiler and after treatment technologies. The energy category includes fuels and alternative power systems whereas the operational category includes ship operational efficiencies and port terminal operational efficiencies.

Table 6.Various Ship Energy efficiency measures

Engine Technologies	applicable emission source	retrofittable	applicable operational modes	NOx	PM	SOX	HC	energy consumption
Repower	P/A	Y	All	≤80%↓	↓ cbc	—	—	↕ cbc
Remanufacture Kits	P/A	Y	All	↕ cbc	↓ cbc	—	↕ cbc	↕ cbc
Propulsion Engine Derating	P	Y	STM	↑ cbc	↕ cbc	—	tbd	↕ cbc
Common Rail	P/A	Y	All	≤25%↓	↓ cbc	—	—	≤5%
Exhaust Gas Recirculation	P/A	Y	All	≤60%↓	tbd	—	tbd	tbd
Rotating Fuel Injector Controls	P	N	STM	≤25%↓	≤40%↓	cbc	cbc	cbc
Electronically Controlled Lubrication Systems	P	Y	STM	—	≤30%↓	—	≤30 %↓	—
Automated Engine Monitoring/Control Systems	P/A	N	All	≤20%↓	tbd	≤3%↓	—	≤5% ↓
Valve, Nozzle, & Engine Timing NOx Optmization	P	Y	STM	↓ cbc	↕ cbc	—	↓ cbc	↑ cbc
Slide Valves	P	Y	STM	↓ cbc	↓ cbc	—	↓ cbc	↕ cbc
Continuous Water Injection	P/A	Y	All	≤30%↓	≤18%↓	—	—	—
Direct Water Injection	P/A	Y	All	≤60%↓	↕ cbc	—	↕ cbc	—
Scavenging Air Moistening/Humid Air Motor	P/A	Y	All	≤65%↓	↑ cbc	↑ cbc	—	↑ cbc
High Efficiency Turbochargers	P/A	Y	All	↓ cbc	↓ cbc	—	↕ cbc	↓ cbc
Two Stage Turbochargers	P/A	Y	All	≤40%↓	tbd	—	—	↓ cbc
Turbocharger Cut Off	P	Y	STM	≤40%↓	tbd	—	tbd	↓ cbc
Crank Case VOC Leakage	P	Y	STM	—	tbd	—	≤100 %↓	—
Boiler Technologies								
High-Efficiency Boilers	B	Y	All	↓ cbc	tbd	—	—	↓ cbc
Auxiliary Engine Waste Heat Recovery	B	Y	All	↓ cbc	↓ cbc	↓ cbc	↓ cbc	↓ cbc
After-Treatment Technologies								
Selective Catalytic Reduction (SCR)	All	Y	All	≤95% ↓	—	—	—	↑ cbc

Exhaust Gas Scrubbers - Wet	All	Y	All	≤5%↓	≤80% ↓	≤98% ↓	—	↑ cbc
Exhaust Gas Scrubbers - Dry	All	Y	All	≤5%↓	≤80% ↓	≤98% ↓	—	↑ cbc
Barge-Based Systems	AB	na	B	≤95% ↓	≤95% ↓	≤95% ↓	tbd	↑ cbc
Fuels								
Low Sulphur Fuels	All	NA	All	↓ cbc	↓ cbc	↓ cbc	—	↓ cbc
Liquefied Natural Gas - gas only	All	N	All	≤88% ↓	≤98% ↓	100% ↓	↑ cbc	↕ cbc
Liquefied Natural Gas - dual-fuel	All	Y	All	↕ cbc	≤78% ↓	97%↓	↕ cbc	↕ cbc
Water in Fuel	All	Y	All	≤30% ↓	—	—	—	—
Methanol	All	Y	All	↓ tbd	tbd	100% ↓	tbd	↓ cbc
Biofuels	All	Y	All	↑	tbd	↓ cbc	tbd	tbd
Alternative Power Systems								
On-Shore Power Supply	A	Y	B	≤95% ↓	≤95% ↓	≤95% ↓	≤95%↓	≤95% ↓
Barge Power Supply	A	Y	B	↕ cbc	↓ cbc	↓ cbc	↑ cbc	↕ cbc
Solar Power	A	Y	B	↓ cbc	↓ cbc	↓ cbc	↓ cbc	↓ cbc
Ship operational efficiencies								
Vessel Speed Reduction/Slow Steaming	All	Y	STM	↓ cbc	↓ cbc	↓ cbc	↓ cbc	↓ cbc
Optimizaton of Ship Reefer Systems	All	Y	All	↓ cbc	↓ cbc	↓ cbc	↓ cbc	↓ cbc
Optimizaton of Ship Systems	A	Y	All	↓ cbc	↓ cbc	↓ cbc	↓ cbc	↓ cbc
Optimization of Fleet Sizing to Maximize Vessel Efficiency All		Y	All	↓ cbc	↓ cbc	↓ cbc	↓ cbc	↓ cbc

Source: The table has been compiled by the author from various publications of IMO Study of Emission Control and Energy Efficiency Measures for Ships in Port area, IMO)

4.5. Carbon tax

"A carbon tax directly establishes a price on carbon in dollars per ton of emissions, which is factored into the price of goods and services based on their carbon content."

(Noah Kaufman, 2016).

A carbon tax is hard to price. To put carbon tax, optimal emission must be calculated so that the tax can be imposed over that cap. As per definition optimum level of pollution is where the marginal social damage of pollution equals to the combined marginal abatement process (Coase, 1936). There is a loss of welfare whenever the marginal private benefits of some productive activity are less than the sum of private costs and net externality costs. It can be achieved by imposing a tax on each unit of CO_2eq thereby forcing shipowners to reduce the pollution up to the efficient quantity. Using the carbon tax mechanism will make shipowners decide where, when and how much to invest in abatement measures. Economists would argue that the carbon price must be kept at a minimum level while other would claim without high carbon tax an immediate abatement or policy measures is difficult to implement. A ship-owner decision is to invest in the abatement technology, or retrofit option is based on the private production function.

Shipping activities give rise to negative externalities in the form of pollution, and these are not included in the cost functions of shipowners. However, they appear as costs to the society (Han, 2010). Pigou (1946) showed that centrally imposed taxes could mitigate divergences between the marginal private utility and marginal social utility. Economists believe that external cost of emitting a ton of CO_2 is far more than that of the private cost. This external cost is referred to as the social cost.

"*These externalities are the basis for the idea of imposing a tax on carbon emissions or adopting a similar policy such as a cap-and-trade system.*" *(Pindyck, 2013).*

Therefore, the nation can restore the social efficiency by imposing a carbon tax which makes it necessary to find the correct tax level. A carbon tax is a simple way of bringing economic calculation behind investments. Environmental agreements on a voluntary basis will tend to suffer from easy rider problems, and thus it will be difficult to realise the high potentials for joint environmental progress unless the social costs are increased or carbon taxes are imposed (Pigou,1946).

Figure 19 shows the pricing of carbon tax existing in some countries. The value of carbon tax is used in the next chapter for calculation of carbon tax avoided due to the abatement measure utilized by the Stena lines.

Carbon tax in countries

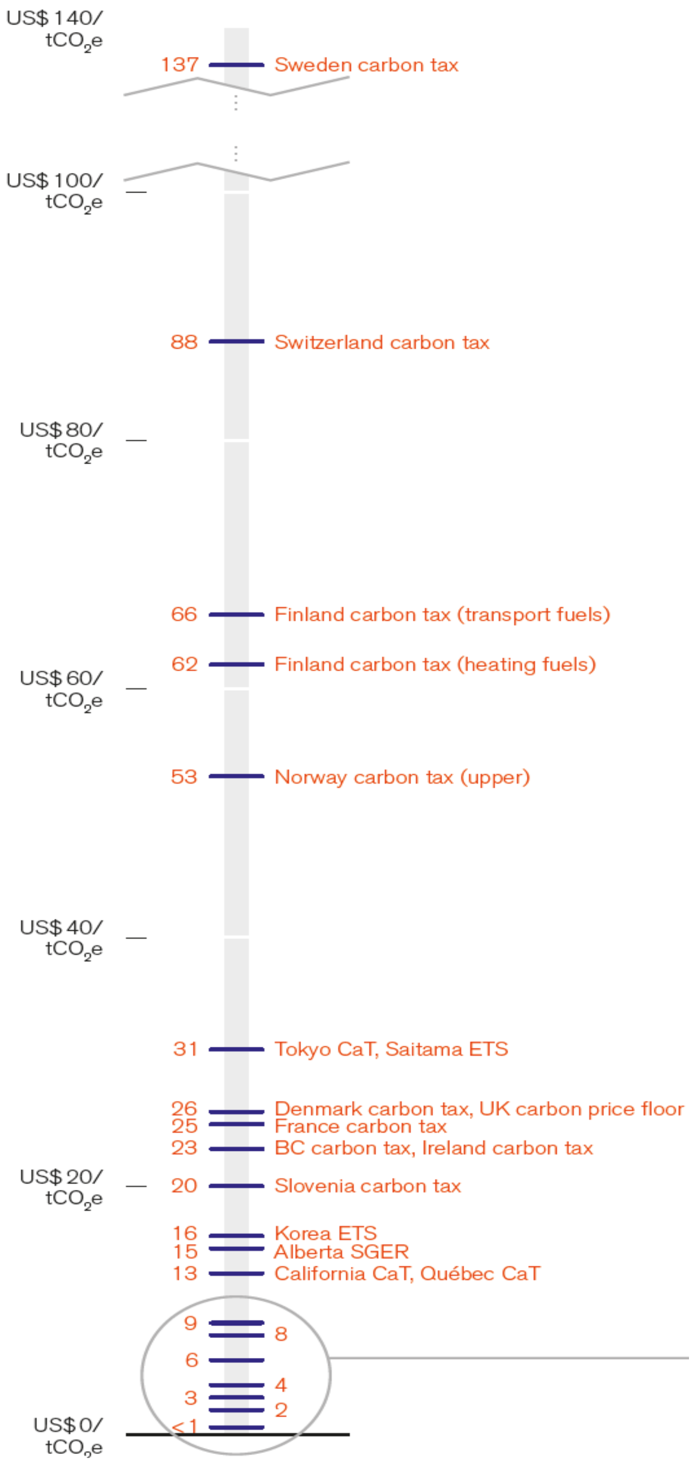


Figure 19 Carbon tax in many countries

Source: Carbon pricing watch 2016

5. Case Study of MV Stena Germanica.

In this chapter the author has chosen a case study for a ROPAX vessel to find out if the economic and environmental benefits borne by the shipowners after complying with the abatement measures are positive or negative. M.V. Stena Germanica which has four Wärtsilä engines with a total of 32 000 horsepower for propulsion has been chosen for the case study. The vessel was running into MGO before switching fuel to Methanol. The converted engines are of dual fuel type, which means that Methanol is the primary fuel, but they can still run on MGO as a backup. Blend Fuel oil is used onboard M.V. Stena Germanica. Costs and benefit for a retrofitted vessel were determined by looking at the capital and operational expenses compared to a conventional fuel variant MGO used earlier by Stena AB Lines.

5.1. Methanol as a future marine fuel

Methanol is the best alternative fuel for shipowners and is available within existing infrastructure (Haraldson, 2015). The price of Methanol has gone down by 50 % and is quite low compared to other existing alternative fuels (PLATTS, 2015). Methanol is easy to handle with slight modifications and is economically feasible. As per Buhaug et al. (2009) 300 million tons of HFO is consumed by the international shipping where as the shipping in SECA area accounts for 20 to 25 million tons of annual HFO consumption. Therefore, switching to Methanol in ECA will cause lower emissions. From the economic perspective in the eye of ship-owners, the cost of investment in Methanol conversion or other abatement technologies is the biggest barrier to the adoption.

Sources of Methanol.

Methanol can be produced from forest industry residuals or by carbon capture technology and from renewable feedstocks like LNG. Green Methanol development (Bio- and CO_2 captured Methanol) is leading towards zero emission

(Lasselle, 2015). Methanol can be produced from the dry distillation of wood traditionally. Sweden uses black liquor from a pulp and paper mills to produce Methanol. Biomass can be gasified for the production of synthesis gases. Synthesis gas is then converted to Methanol by processing just like in industrial Methanol production. Carbon dioxide captured from industrial processes can be converted back to syngas in its pure state and then converted into Methanol (Methanex, 2016). The raw material used is natural gas in most of the countries except in China where they use coal to generate, and it can also be produced by other methods like carnol process, bi-reforming and direct oxidising methane to form Methanol (Aasberg et al., 2008). There are a lot of new plants under construction to counter the demand for Methanol. U.S.A has increased their production of shale gas in last few years. Some of the manufacturers of Methanol are

1. Green Methanol Paper mill located in Pitea, (Sweden) and Svartsengi, (Iceland)
2. .Merchem in Edmonton, (Canada) and
3. Bio MCN in Delfijl, (Netherlands).

5.1.1. Life Cycle Assessment of Methanol

The impact of marine fuels from the well head to the propeller is assessed by life cycle assessment (LCA). Brynolf et al., (2014) studied different fuels for its impact on health and environments. They assessed different marine fuels for total energy reserve, GWP, SO_X, NO_X and PM emissions. The fuels used in the study were LNG, HFO; LBG, MeOH produced from natural gas and MeOH from forestry residues. Figure 20 assesses the impact of different fuels compared to HFO.

As previously discussed LCA is a tool used in ISO 14040 for quantifying the emissions and resource used. When comparing the life cycle impacts it is clearly seen that HFO has more energy for vessel propulsion but less economic and environmental benefit. Biofuels require more energy in harvesting, producing and transporting than the amount of energy they provide. There are almost no SO_x emissions from Methanol compared to other fuels. NO_x emissions are less because of reduced peak temperatures. The NO_x levels are in line with Tier III NO_x values.

Impact of different marine fuels

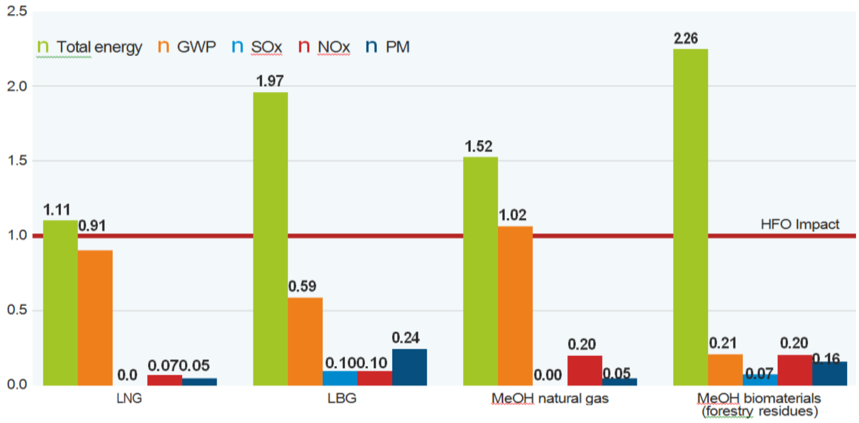


Figure 20

Source: Environmental Assessment of Present and Future Marine Fuels (Brynolf, 2014)

Methanol Challenges

The main hazard of Methanol is the low flashpoint, and it is the most important factor from the ship owner's perspective while making the decision for fuel switching as it poses challenges for storing and transporting. The flashpoint of Methanol is 11°C whereas the boiling point is around 65° C. There have been many regulations for low flashpoint fuel by IMO to mitigate the risk of fire and to enable the transport of Methanol by land or sea. The IGC[23] and IBC[24] code contains guidelines about transportation and carrying of Methanol as cargo on the vessel (Freundendahl, 2015).

The IGF[25] code contains mandatory provisions for the arrangement, installation, control and monitoring of machinery, equipment and systems using low flash point fuels, focusing initially on LNG (Maritime Safety Committee (MSC), 95th session, 3-12 June 2015). Methanol is highly toxic and corrosive in nature when it comes in contact with water (Tinnerberg, 2015) therefore, inerting of the tank is necessary. Carriage of Methanol is quite common in the land industry. There have been many guidelines for the transportation of Methanol (ISO 8217, 2012).

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[23] International Code of the Construction and Equipment of Ships Carrying Liquefied Gases in Bulk (**IGC Code**)
[24] The **IBC Code** provides an international standard for the safe carriage in bulk by sea of dangerous chemicals and noxious liquid substances
[25] The purpose of the International **Code** of Safety for Ship Using Gases or Other Low-flashpoint Fuels is to provide an international standard for ships

5.1.2. Methanol over LNG and MGO?

Anderson, Salo, and Fridell (2015) found in their analysis of the exhaust gases that around 85% of hydrocarbons emissions from LNG was Methane. At higher loads, methane emissions were found around 7g per Kg and on lower loads, it increased to 23- 36 g. This could be because of slow combustion at lower loads which allows small quantities of unburnt methane to avoid the combustion process known as "methane slip" (Hartl, 1996). As shown in Appendix C methane has higher GWP than CO_2. Thus, these emissions are significant. GWP of CH_4 is 21 times more than that of CO_2 over a 100-year lifetime span and 56 times higher over 20 years (IPCC, 1995). When comparing LNG and Methanol from the well head to the propeller, it was found that Methanol conversion cost is almost comparable with scrubber technology (Stefenson, 2015). The conversion cost of M.V. Stena Germanica was around 350 Euro/kW whereas the cost of BIT Viking to convert for LNG use is 1000 Euro/kW (Stefenson, 2015). Therefore, there is a clear distinction between LNG and Methanol considering economic and environmental perspective.

Reflections on fuel prices

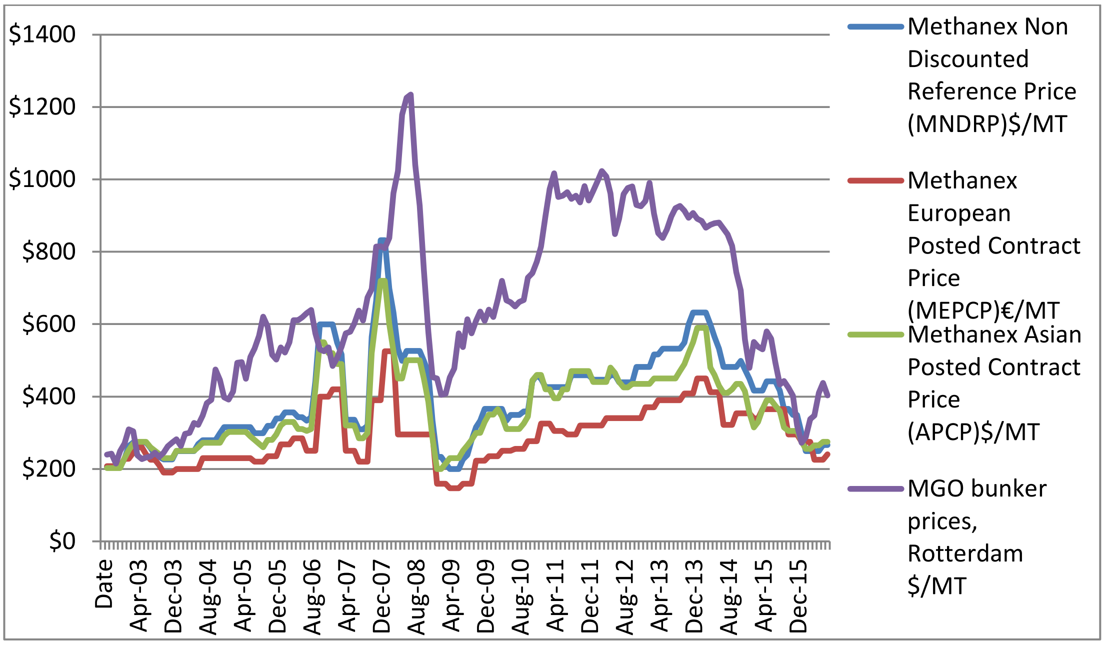


Figure 21 Comparison between MGO and Methanol price since 2002.

Source: Methanex and Clarkson database

In the case study, the fuel is changed from MGO to Methanol accordingly, the prices of the same are taken into consideration for comparison.

Figure 21 shows the fluctuation of the Methanol prices (Methanex, 2015) and MGO fuel prices (Clarkson, 2015) in last 14 years. As shown the prices of Methanol was about 50% less during 2008 to 2014 and during last three years, prices of Methanol was found to be close to the MGO price thus it makes Methanol a better substitute if there is enough technological improvement and mature technology. Global demand for distillate fuel oil is likely to increase in the ECA areas and which will cause the price of MGO to increase while the price of HFO expected to stay the same. The Methanol price is driven by market demand and stable feedstock (NG) prices. The company can use different fuel mix to hedge fuel price volatility. The uncertainty of the fuel price of the MGO has made shipping companies to go for dual fuel engines which will allow them to use MGO or Methanol for cost effective operations and still comply with the regulations. The fuel prices shown in the figure depends on the currency it is either in European posted contract price or the North America discounted reference price.

5.1.3. Methanol Test Results

As per the initial tests were done by Wårtsilå Sulzer, ZA40SD diesel engine on burning Methanol gives acceptable low Tier II NOx values and when combining with SCR comes under Tier III values. The value of CO (< 1g/kWh) and THC (Total Hydro Carbon) is acceptable (< 1g/kWh) and no "methane slip". Formaldehyde emissions were 10-15 ppm (the limit for shore industry is 25 ppm) and very low PM (FSN ~ 0.1 with HFO as a pilot). There was no presence of formic acid detected in exhaust gases (Wärtsila, 2015).

Figure 22 shows no reduction in output and load response remains unchanged when Methanol is compared to MGO. At the time of preliminary tests, it was observed that Methane has higher efficiency on lower load. As per the study carried out by Svensson et al., (2015) about the feasibility of alternative fuel for marine engines, it was found that on using Methanol, NO_x value is much lower than diesel oil and almost zero particulate matter.

Methanol preliminary tests

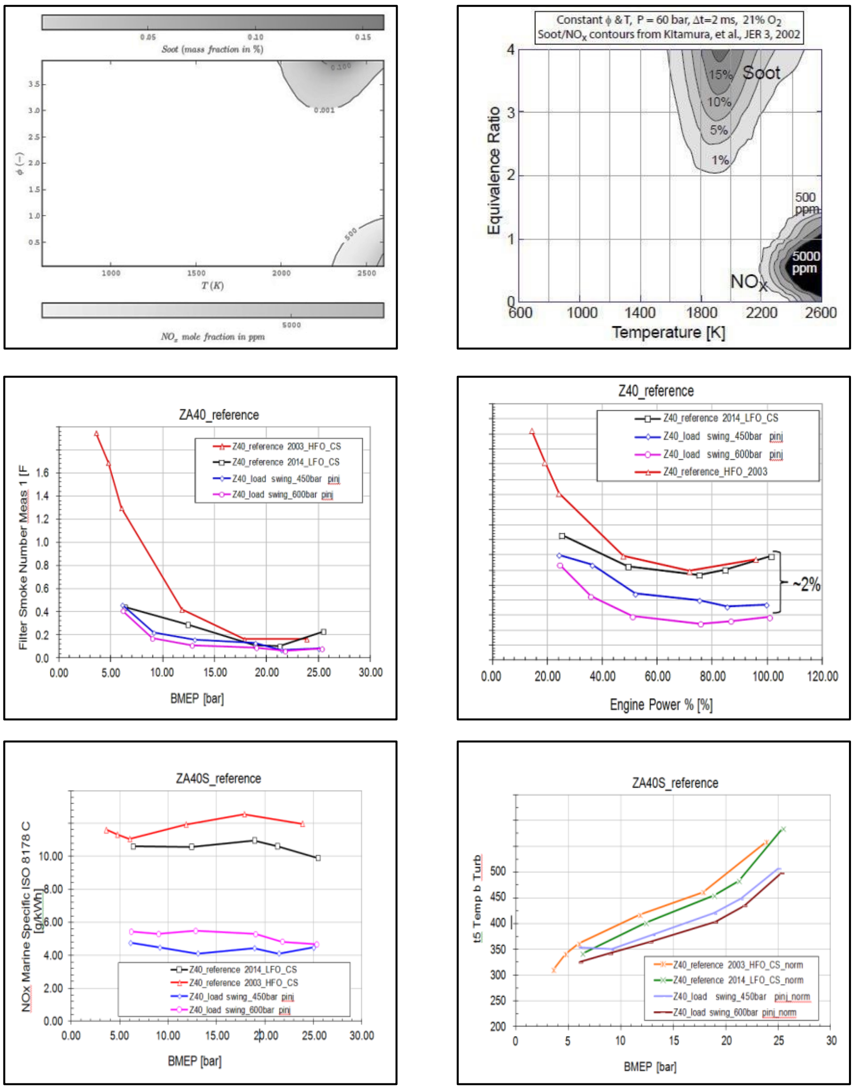


Figure 22 Methanol test results when burnt in marine diesel engine when compared to different fuel

Source: Toni Stojovescki, Wartsilä, 2015 and Svensson et al.,2015.

5.2. Conversion of Stena Germanica

MV Stena Germanica conversion of the main propulsion machinery was done in Remontowa Shipyard, Gdansk, Poland in March 2015. Methanol is combusted close to TDC (Top Dead Cylinder) by a small amount of pilot fuel which is diesel oil. High-pressure pipes, pumps and new engine control system for all four engines were installed. The Methanol storage tank was painted with zinc silicate. The common rail system is used for Methanol injection system. High-pressure Methanol pumps for supplying sealing oil and controlling oil to the fuel injectors are installed. A Unic C3 solution is installed for engine control. Cable of around 13 km in length was wired for electricity distribution (Stojcevski, 2015). Since Methanol does not require heating because of less viscosity, fuel separators are not needed instead seawater is used for cooling double bottom tanks. A dedicated pump room is required separate from the engine room and is considered as hazardous zone area. Figure 23 gives the timeline of Stena Germanica conversion (Stefenson, 2015).

Time line for conversion of MV Stena Germanica

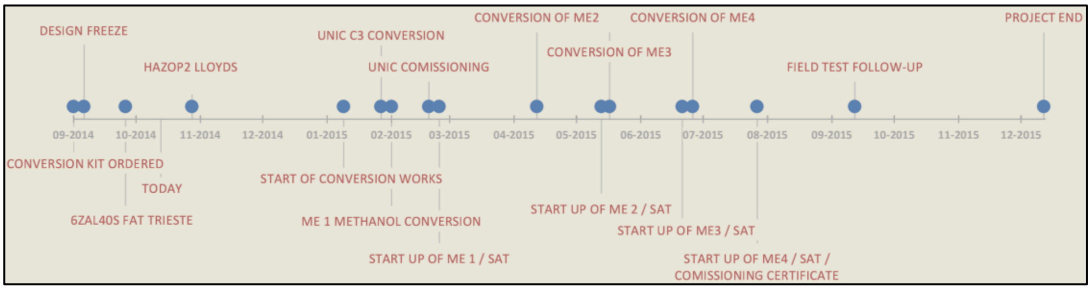


Figure 23

Source: Stefenson, 2015

5.2.1. Structural changes

Tank arrangements

Methanol can be carried into double bottom tanks with no special modifications required. On a macroscopic level, Methanol is not harmful to the environment in case of leakage into the sea. Methanol bunker tanks are needed to be inerted as it is highly corrosive in nature. Methanol is lighter than MGO, so more space is needed for it to be carried on board for the same amount of production of energy. Existing fuel or ballast tanks were converted to Methanol tanks.

Nitrogen system

A nitrogen supply system is given for two purposes i.e. inerting the bunker tank(s) and purging of the (Methanol) fuel system. A generator system is more beneficial and practical and is used for supplying Nitrogen on Stena Germanica instead of portable tanks. Machinery spaces must be designed gas safe whether for propulsion or power generation. Double- walled fuel piping is required to purge the inner pipe and to monitor the annular space for hydrocarbons.

Bunkering Installations:

Infrastructure requirements for bunkering are one of the core needs for maritime trade. Bunkering of ships can be carried out by ships or trucks. A bunkering terminal is necessary for supplying fuel to ship. According to Stefenson (2015), bunkering of vessels are carried out by trucks as there is enough experience for handling Methanol safely in road transport. Also, the risk is reduced as Methanol has low flashing point. Figure 24 shows the schematic diagram of machinery layout for the use of Methanol onboard M.V. Stena Germanica.

Schematic diagram of machinery layout for the use of Methanol

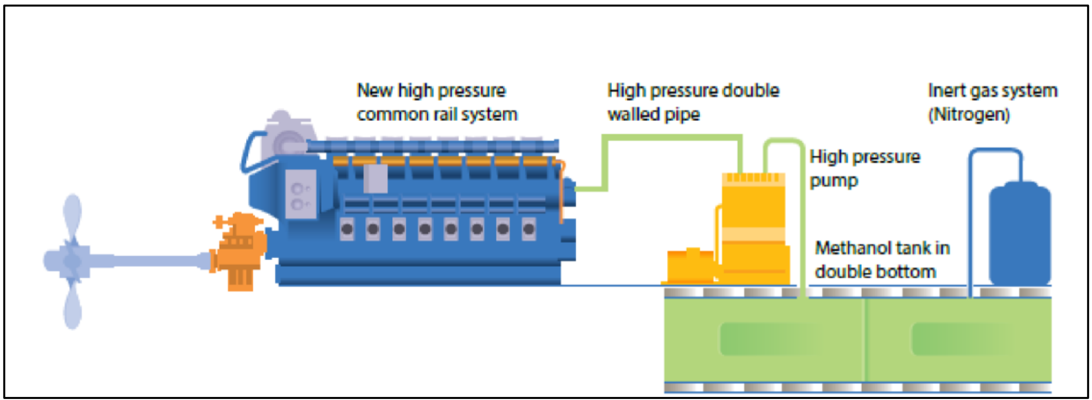


Figure 24

Source: Stefenson, 2015

5.2.2. Data collection and assumptions

The author has collected data for the case study by conducting interviews with the officials of Stena lines and from various publications published by Stena Lines. Table 7 will explain all the assumptions and facts used for calculation. The source of the information is mentioned. For getting the data, visit to the vessel was done in Göthenburg. The interview was conducted with the officials of Stena lines Mr. Per Stefenson and Mrs. Catherine Lee. During interview with Per Stefenson who is Marine Standards Advisor for Stena Rederi AB Technical Division following facts were provided and used by the author for the calculation of air emissions

The voyage route of the vessel is from Göteburg to Kiel and total time required is 14 days. 45000 cars or lorries are lifted from the road every year and around 1300 persons can travel. Before conversion, MGO consumption by Stena Germanica was 11000 tonnes/year. Methanol is 2.167 times lighter than the MGO hence the Methanol consumption will be 23800 tonnes. Total time required for retrofitting of Stena Germanica was 45 days. As per the officials, operational expenses before and after conversion did not change. It is difficult to predict as this is the first initiative taken by Stena AB Lines and still generator engines did not run the required hours due for maintenance. The other facts and machinery particulars are given in Appendix A and B which is used for the calculation.

Table 7 Data collection sources

Parameter name	SOURCE	Method
OPEX	STENA AB 2015 financial report	Literature review
Revenue		
Earning		
Useful Asset Life		
Emission Factor of fuels	Ph.D. thesis, Ms.Selma Brynolf	
Load Factor	IMO Third GHG study	
Cargo Capacity	M.V. Stena Germanica Particulars provided by Per Stefenson	
Passenger Capacity		
Machinery Particulars		
Methanol Fuel Price	Methanex	
MGO Fuel Price	Clarkson database	
Conversion factor	http://www.translatorscafe.com/	
Exchange rate	Sveriges Riksbank	
Inflation rate	Sveriges Riksbank	
Sweden Tax	tax Yearbook of Sweden 2014	
Carbon Tax	Carbon price watch 2016	
Marginal External cost CO_2	HEATCO project	
Marginal External cost SO_x	HEATCO project	
Marginal External cost PM	HEATCO project	
Marginal External cost NO_x	HEATCO project	
Methanol Specification	IMPCA	
Time for berthing	Per Stefenson	Interview
Time for sailing		
Time for manoeuvring		
Fuel Consumption		
CAPEX		
Depreciation	Straight line (Default)	Macroeconomic Assumptions
Discount Rate	Standard practice (10%)	

5.3. Environmental and Economic perspective

This section will discuss the environmental benefits and economic assessment for the conversion of the vessel MV Stena Germanica as per Figure 25.

Methodology used for financial analysis for MV Stena Germanica

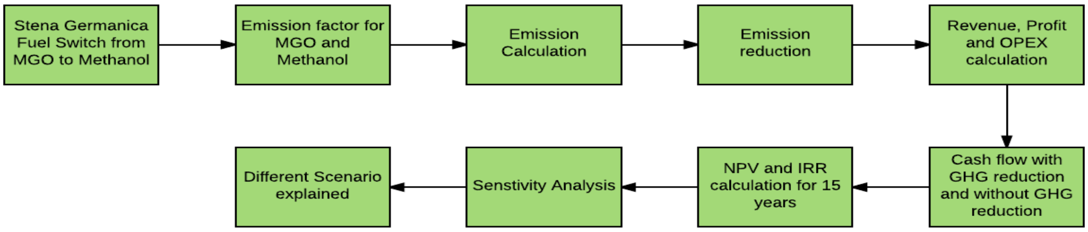


Figure 25

5.3.1. Environmental Benefits

Total emissions can be calculated by summing up emissions during standby, manoeuvring and cruise speed. MV Stena Germanica has no emissions during the port stay as they use cold ironing technology during the port stay. The vessel uses blend oil of which 15 % is MGO whereas the rest 85 % includes Methanol. The equation used for calculating emissions from MGO is given below (Banawan et al., 2009).

$$E = PLFefdT,$$

In the case of blend fuel oil of Methanol and MGO, the emission calculation is modified slightly depending on the ratio of mixing of the fuel. In this particular instance of conversion of Stena Germanica, the following formula is used.

$$E = PLF\ (0.15efd + 0.85efm)T,$$

Where *efd* is the emission factor of MGO, *efm* is emission factor of Methanol, *T* is the engine running time in hours, *and P* engine power at the maximum continuous rating, *LF* is load factor of the engine.

Table 8 provides machinery particulars and facts required for the calculation of the emissions. Load factor is assumed as 0.7 from the IMO greenhouse gas study for ROPAX vessels. Machinery particular are provided by the Stena lines. The vessel makes approximately 25 trips between Kiel and Gothenburg. 15 days are assumed for the ships' repair and maintenance.

Table 8 Machinery particulars and facts required for GHG emissions

	MGO			85 %MeOHng+ 15%MGO		
	Main Engine	Auxiliary Engine		Main Engine	Auxiliary Engine	
Manufacturer	Sulzer	Wartsila		Sulzer	Wartsila	
Model	8ZAL40S	6L26	9L26	8ZAL40S	6L26	9L26
No. of installed	4	1	1	4	1	1
MCR each in Kw	5760	1800	2700	5760	1800	2700
MCR TOTAL	23040	1800	2700	23040	1800	2700
Load factor at sea	0.7	0.7	0.7	0.7	0.7	0.7
LFat manoeuvring	0.7	0.7	0.7	0.7	0.7	0.7
No of days in One trip	14					
No of trips in one year	25 (assuming 15 days of repair and maintenance)					
No of running hours in one year	8400					

Table 9 shows the emission factors of different fuel under evaluation during combustion in marine engines. The data in parentheses represent values if abatement technologies are used to comply with the 0.1 % of sulphur and NOx Tier III regulations. As per the study, MGO was combined only with SCR unit. The emission factors of all the gases were converted from g/MJ to g/kWh by multiplying with the conversion factor.

Table 9 Emission factors for MGO and MeOH

Air emissions	Emissions to air [g/Mj fuel]		Emissions to air [g/kw fuel]	
	MeOHng	MGO	MGO	MeOHng
CO2	69	73	262.8	248.4
CH4	0	4.5E-4	0.00162	0
N2O	0	3.5E-3	0.0126	0
NOX	0.28	1.50	5.4	1.008
		0.28	1.008	0
SO2		0.047	0.1692	0
NH3		3.0E-4	0.00108	0
	0	(0.00290)	0.01044	0
PM10	0.0043	0.011	0.0396	0.01548
NMVOC	0	0.058	0.2088	0
CO	0	0.13	0.468	0

Source. Environmental Assessment of Present and future marine fuels, Selma Brynolf, 2014.

Emissions are calculated for both main engine and Auxiliary engine separately for MGO and Methanol. All the emissions evaluated are put in the tabular form. Table 10 give the air emissions from main engine and auxiliary engine before and after switching to Methanol.

Table 10 Calculations of air emissions

	Emission in tonnes					
	MGO			85 % MeOH + 15%MGO		
Gases	Main Engine	Auxiliary Engine		Main Engine	Auxiliary Engine	
CO_2	35602.88	2781.48	4172.21	33944.67	2651.93	3977.89
CH_4	0.22	0.02	0.03	0.03	0.00	0.00
N_2O	1.71	0.13	0.20	0.26	0.02	0.03
NO_X	731.57	57.15	85.73	20.48	1.60	2.40
SO_2	22.92	1.79	2.69	3.44	0.27	0.40
NH_3	0.15	0.01	0.02	0.21	0.02	0.02
PM_{10}	5.36	0.42	0.63	2.59	0.20	0.30
NMVOC	28.29	2.21	3.31	4.24	0.33	0.50
CO	63.40	4.95	7.43	9.51	0.74	1.11
C_2H_6	0.00	0.00	0.00	0.00	0.00	0.00
C_3H_8	0.00	0.00	0.00	0.00	0.00	0.00
TOTAL	36456.50	2848.16	4272.25	33985.43	2655.11	3982.67
Air emissions when using MGO				43576.91 tCO_2e		
Air emissions when using Dual fuel				40623.21 tCO_2e		
Total reduction in air emissions gases in one year				2953.70 tCO_2e		
Carbon tax				126.85 € / tCO_2		

It is apparent from the Figure 26 that the shift from MGO to MeOH has resulted in reduction of CO_2, CH_4, N_2O, NO_X, SO_2, PM_{10}, NMVOC, CO by 5%, 85%, 85%, 99%, 85%, 52%, 85% and 85% respectively (values in Appendix E).

Air emissions with MGO and Methanol in tonnes

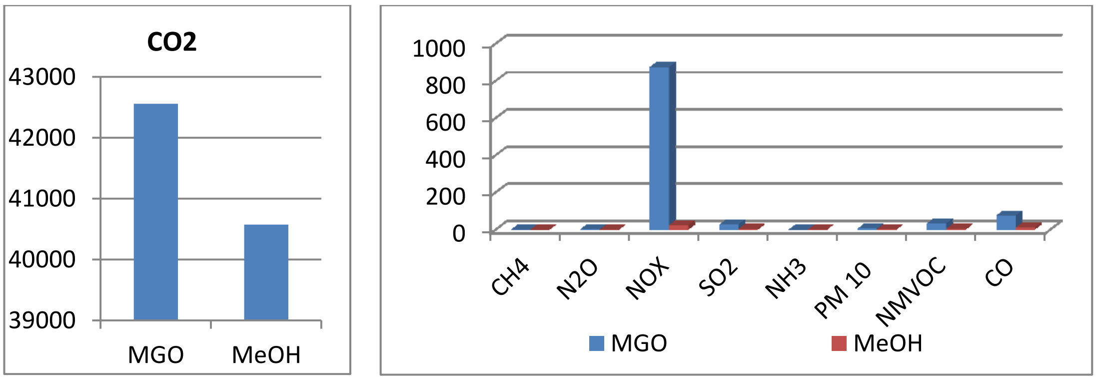


Figure 26

The emission reduction is used further for cash flow analysis of Stena lines to evaluate the economic benefit and also in Chapter 6 for external costs calculation.

5.3.2. Economic benefit

Factors included in the financial analysis are cargo capacity, passengers, duration of time at sea and other parameters. The interviewee stated that the conversion costs of 24 megawatts ROPAX ferry MV Stena Germanica cost around 22 million Euros. CAPEX includes internal storage tank on shore (7 million Euros), conversion of a bunker barge (2 million Euros) and complete conversion from MGO engine to dual fuel engine (13 million Euros). (Andersson, 2015; Stefenson, 2015). The author has limited this dissertation to ROPAX vessels. A similar kind of methodology can be used for other ships.

The earnings were taken from the consolidated income statement from the financial report of Stena AB 2015. All the values were then divided by the total capacity of the passengers and lane metres of all the vessels operated by Stena Lines to find out the revenue, expenses and profit earned by per person and per lanemetre. Table 11 gives the values by multiplying the capacity of the vessel with the values obtained for per passenger per lane metre to give the revenue, profit, and OPEX for M.V. Stena Germanica.

Table 11 Revenue, expenses, and profit for MV Stena Germanica

Capacity For Stena Germanica	Passenger	Lane metre	
	1300	4000	
Income statement	Million Euros passenger	Million Euros lm	Total in Million Euros
Revenue	11.428	35.162	46.589
Expenses	8.483	26.101	34.583
Profit	2.945	9.061	12.006

Table 12 shows the fuel price at the time of the start of the project of fuel switching from MGO to Methanol on Stena Germanica. The prices are given in both tonnes and One Million British Thermal Units (MMBTU units). The price of Methanol is from the Methanex historical fuel prices whereas the cost of MGO (Rotterdam) is from Clarkson database. Fuel cost is calculated by adding the consumption of Main engine and auxiliary engine.

Table 12 Fuel Consumption and price onboard M.V. Stena Germanica

FUEL	Consumption in tonnes	Consumption in MMBtu	Fuel cost per MMBtu	Fuel Cost	Euro per tonne
MGO	11000	436183	12.55	5474097	497.69[26]
MeOH (85%)	20290	804540	8.55	6878813	339[27]
MGO(15%)	1650	65427	12.55	821114.5	497.69
BLENDED FUEL	21940	869967	8.85	7699927.6	350.96

Fuel cost is the most critical component the operational expenses. Maintenance cost is found to be lower for Methanol than traditional fuels. As per technical paper of Wartsila 2-3.5% fuel savings can be observed for IMO compliant engines (Wärtsila, 2015). The operational cost will be reduced as the maintenance and monitoring will be done by the condition based maintenance approach. Since this technology is installed just a year before quantifying the reduced OPEX costs is difficult. The OPEX is assumed to be the same for both the fuel excluding the fuel costs. Wärtsila claims of reduced OPEX because of long service overhaul time required due to the less degrading performance and reduced component failures. Wärtsila claims of getting ROI[28] within two years if the engine is running for 5000 hours in a year. Cash flow analysis is generated for the vessel by using all the facts and assumptions mentioned above and are shown in Appendix D.

Other assumptions required for the calculation are discussed briefly. The discount rate or hurdle rate is assumed as 10%[29]. The carbon equivalent pricing is current carbon tax value in Sweden. The tax rate is assumed to be 22%[30] as per the national Swedish tax regime. Useful asset life is assumed as 15 years[31] after the conversion. The depreciation method used for the vessel is straight line depreciation. Macroeconomic assumptions made in the calculation are exchange rate and inflation which is taken as 0.93 Euro/USD[32] and 1.02%[33] respectively. After calculation of cash flow is done for MV Stena Germanica for the useful asset time. Net Present Value is calculated for the next 15 years. The NPV is the sum of the present values of all cash flows from the project (including initial investment), with

26 Source : Clarkson database
27 Source : Methanex fuel price
28 Return on Investment
29 Discount rate is chosen as 10%
30 Tax rate is taken from tax yearbook of sweden 2014 http://www.skatteverket.se/
31 Useful asset life is taken from STENA AB 2015 financial report
32 Exchange rate is taken from Sveriges Riksbank
33 The Riksbank's target is to maintain inflation at a rate of 2 per cent when measured by CPI.

the cash flows being discounted at 10%. NPV is calculated by the following equation (Juhász, 2011):

$$NPV(i,N) = \sum_{t=0}^{N} \frac{Rt}{(1+i)^t}$$

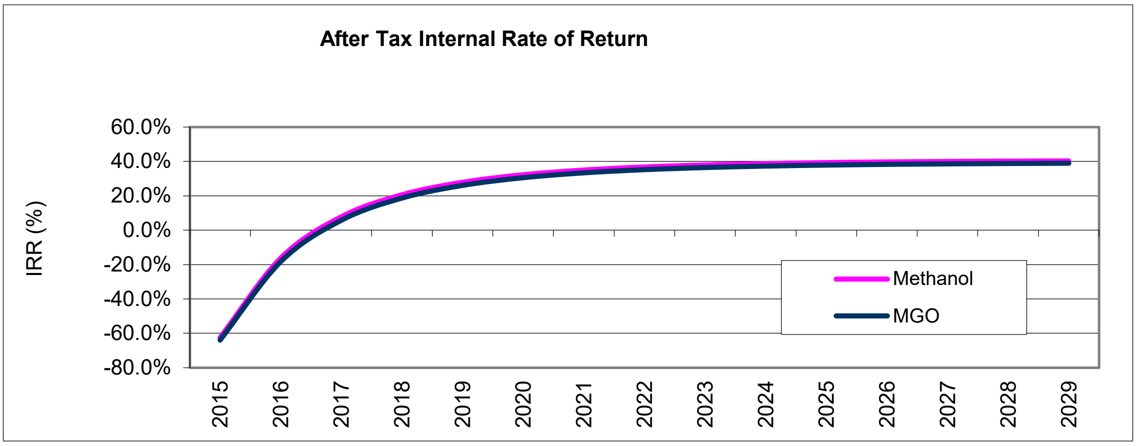
IRR is calculated for 15 years. IRR is the discount rate that sets the net present value equal to zero. Following equation is used for calculating the IRR (Juhász, 2011):

$$NPV(i,N) = 0 = \sum_{t=0}^{N} \frac{Rt}{(1+i)^t}$$

Where i=discount rate, N =total number of periods, Rt= Net cash flow, t= time of cash flow.

The payback period of a project is found by counting the number of years needed before cumulated forecast cash flows equal the initial investment.

After Tax Internal Rate of Return



	After Tax IRR	NPV (Euros)	Payback year
MGO (without reduction)	38.9%	5,01,32,044.5	4
MeOH (with reduction)	40.3%	5,25,21,783.1	4

Figure 27 IRR of a project with MGO and MeOH

Graphical representation of after-tax IRR for next fifteen years for MV Stena Germanica after switching fuel is shown in Figure 27. Project Return of Investment with emission reduction and without emission reduction is compared in this section. One of the main findings of the project was that the payback period came around four years. Secondly, the NPV is more than zero and lastly the IRR is above the discounted rate for the next 15 years. Table 13 gives IRR for next 15 years when using MGO and Methanol.

Table 13 IRR with GHG and without GHG reduction

Year	with GHG reduction	without GHG reduction
2015	-62.53%	-63.95%
2016	-16.28%	-18.31%
2017	7.79%	5.76%
2018	20.59%	18.67%
2019	27.86%	26.05%
2020	32.23%	30.52%
2021	34.97%	33.35%
2022	36.75%	35.19%
2023	37.94%	36.43%
2024	38.74%	37.28%
2025	39.30%	37.86%
2026	39.69%	38.28%
2027	39.96%	38.57%
2028	40.16%	38.78%
2029	40.30%	38.94%

5.3.3. Sensitivity analysis and possible scenarios

Sensitivity analysis for change in fuel price, CAPEX and Carbon tax

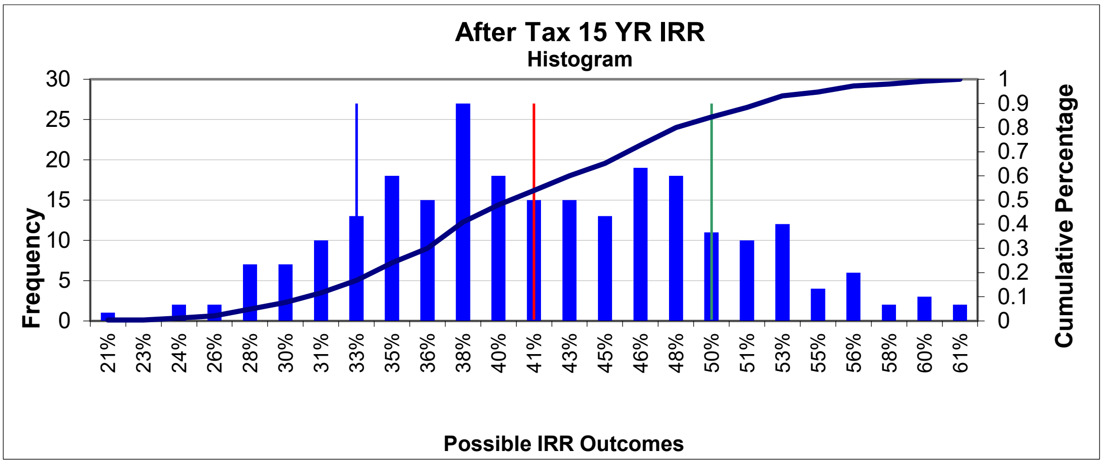


Figure 28.

Sensitivity analysis is done for the useful asset life as there will be fluctuation in fuel prices and capital investment at different market conditions. Consumption of fuel and energy prices are based on many assumptions, and it will affect the cash flow for the shipowners. There is a considerable amount of uncertainty because of various assumptions and with respect to the availability of fossil fuels. The objective is to evaluate the sensitivity of fuel prices to see the project feasibility. Monte Carlo simulation is used for the sensitivity analysis which runs 250 iterations of the model (Appendix I) randomly varying the value of the fuel prices, CAPEX, OPEX and carbon tax. The percentage change of the fuel prices, CAPEX and Carbon tax, was kept in between 40-50% of the current fuel prices. After running the simulation, Figure 28 is generated which shows the value of the possible IRR outcomes and its frequency. The sensitivity analysis generates IRR at 80%, 90%, and 95% confidence intervals. There is a 95 % probability that the project IRR will be between 19.20 % to 55.18%. There is a 90% probability that the project IRR will be between 22.10 and 52.29%. There is a 80% probability that the project IRR will be between 25.43% and 48.95%.

Furthermore, Scenario analysis is done only for the change in fuel prices. Four scenarios are taken to explain the project feasibility. IRR is calculated for the following scenario. When doing Scenario analysis for fluctuation in fuel oil prices the CAPEX, OPEX and Carbon tax was assumed constant at present value.

Scenario 1: When the fuel price of MGO is high, and Methanol is low.

Scenario 2: When the fuel price of Methanol is high and MGO is low.

Scenario 3: When the fuel price of both MGO and Methanol is low.

Scenario 4: When the fuel price of both MGO and Methanol is high

Table 14 Result of Sensitivity and Scenario Analysis

Scenario Analysis	MGO €/mmbtu	MeOH €/mmbtu	IRR
Scenario 1	5.14	12.75	51.27%
Scenario 2	14.89	13.20	22.57%
Scenario 3	7.24	8.58	45.03%
Scenario 4	10.20	14.10	36.34%
Sensitivity Analysis Results			
Confidence Level	0.95	0.9	0.8
Max Expected IRR	55.18%	52.29%	48.95%
Min Expected IRR	19.20%	22.10%	25.43%

After doing scenario analysis, it was found for all the four cases; the IRR is positive and above than hurdle rate. Table 14 shows the value of IRR at different prices of fuel.

Sensitivity Analysis

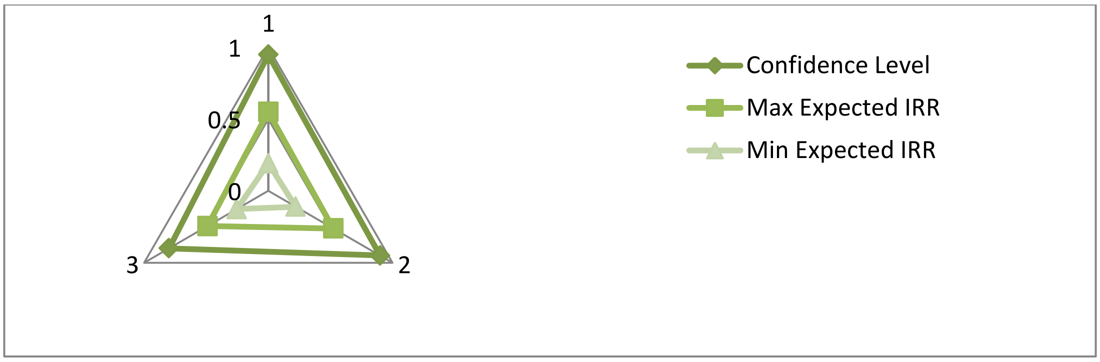


Figure 29 Sensitivity Analysis for change in fuel prices, CAPEX, OPEX, Carbon tax

From the Figure 29, it is apparent that switching to Methanol is cost effective measure for the shipowners in the long term. The ship will produce fewer air emissions, the NPV is positive for next 15 years. IRR is positive and above hurdle rate in all scenarios. The shipowner, will not go beyond the carbon cap as the emission from Methanol complies with CO_2, SO_x, and NO_x Tier III values. As the new MRV regulation is coming into force in January 2018, because of switching to new and clean fuel, Stena AB Lines will make a profit by avoid paying a carbon tax if implemented or get incentive in case of cap and trade program by selling their allocated carbon credit.

5.4. Rationale behind decision making

Converting emissions into monetary values will make it easy for the shipowners to incorporate the data into the financial and compliant strategies. A carbon tax can act as a tool to identify the operational inefficiency which increases overall OPEX of the vessel (Franc et al., 2013). On one hand compliant strategies which include carbon tax will reduce emissions and cost but on the contrary, it will identify revenue opportunities and drive capital investments. Efficiency standards will work in the long-term sustainability, but carbon tax can have an immediate impact in the near future within the extended period of complying with energy efficient regulations. The community of European shipowners believes that parallel measures should be taken to reduce the GHG emissions. In the long term technical and operational measures will help in reducing the targets (Nielson, 2012) but during this transition phase, MBM or a carbon tax can become the most effective measure to bring down the emissions.

6. Decision Framework for Shipowners

6.1. Gaps in Decision framework

From the above sections, it is clear that shipowners do not use air pollution cost and scenario projections in their decision framework. The ship emits black carbon as a secondary particle which affects the human health. These airborne particles lead to premature deaths, cardiovascular and respiratory diseases (Palaniappan et al., 2006). Ship emissions also contain carcinogenic particles. The emissions from ships must be controlled. There are methods to mitigate the maritime transport emissions and improve the health of the population affected by it. The question shipowners have in their mind whether the compliance cost of abatement measure is a small fraction of the pollution cost borne by the population or is it a large amount. In reality, there seem to be no effective measures taken to protect the health of the people by the maritime industry.

Emission projections are useful for the company to understand the significance of the actions taken by policy and decision makers (Vurren et al., 2011). Emission scenarios will project the emissions from maritime transport. Future Scenarios are most of the time neglected by ship owners as their main aim is to make profit. The purpose of these scenarios is not for future predictions but to explore the scientific and real-time implications.

6.1.1. Health cost Analysis

“Health cost analysis” must be developed to ensure that health is considered in the cost-benefit analysis of maritime transportation planning, policy, and decision-making (Vanherle et al., 2010). Since there is no standard methods or guidelines available to health cost analysis, calculating health cost will need different sets of data models and considerations as it will change the investment and policy decisions. There are three basic steps for health cost analysis and are discussed in detail.

1. Determining the affected population
2. The health impacts on that population
3. The cost of those health implications

Brandt et al., (2011) used this model and used the exposure-response relationship as a linear function. The case of European coastal population is discussed as our case study involves vessel operating in European coastal water and within ECA area. The researchers calculated impacts both for current conditions and for a scenario in which air quality standards were met. A total number of cases in Europe of the different impacts related to all the emissions in the Northern Hemisphere is shown in Table 15. The number of cases from various impacts is expected to be less in 2020 because of the new rules and policies adopted by IMO and shipowners.

Table 15 Number of cases in Europe of the different impacts related to all the emissions

Health Impact	No of cases in Europe			
Year	2000	2007	2011	2020
Chronic bronchitis	633000	535000	532000	418000
Restricted activity days	647000000	547000000	544000000	427000000
Respiratory admissions	37800	31400	31200	23800
Cerebrovascular admissions	81200	68600	68200	53600
Congestive heart failure	50200	42700	42500	35200
Lung cancer	96900	81900	81400	64000
Bronchodilator use,children	18900000	16000000	15900000	12500000
Bronchodilator use, adults	124000000	105000000	104000000	81800000
Cough, children	65300000	55200000	54900000	43100000
Cough, adults	128000000	108000000	107000000	84200000
Lower respiratory symptom children	25200000	21300000	21200000	16600000
Lower respiratory symptoms, adults	46000000	38800000	38600000	30400000
Acute mortality	49800	43900	43700	36200
Chronic mortality (YOLL)	7220000	6100000	6070000	4770000
Infant mortality	710	599	596	468

Source: Assessment of past, present and future health-cost externalities of air pollution in Europe and the contribution from international ship traffic using the EVA model system, Brandt et. al., 2013.

Economic valuation of air pollution (EVA) is an integrated model system based on an impact pathway chain to calculate the health-cost externalities. This model is used to derive the externalities of air pollution from a specific source or sector and is utilised for making policies to reduce emission control. (Friedrich and Bickel, 2001). The exposure-response relations and valuations used in the EVA system was applied to European conditions.

The exposure – response function form is used to calculate the impacts of emissions from shipping, δ-concentrations, and address-level population data are combined to estimate human exposure, and then the response is calculated using an exposure-response function (ERF) of the following form:

$$R = \alpha \, \Delta c \, P,$$

where

R is the response (e.g. in cases, days, or episodes); Δc is the additional concentration resulting from emissions of a particular emission source: P is the affected share of the population and α an empirically determined constant for the particular health outcome.

The exposure-response coefficients and the related valuation for morbidity and mortality used in the EVA system are summarized in Table 16. All the cases discussed by the Brandt et al. are defined by three attributes as follows.

1) The region where emission sources are located. The region in the work included is the full northern hemisphere and the Baltic Sea together with the North Sea.
2) Emission sectors were defined by using a selected nomenclature for air pollution (SNAP).
3) The emission year is chosen as per the relevance of their importance with the emission regulation related to the marine industry.

The table in Appendix H will explain which methodology used for model calculations for different years and sectors. The total external costs in million Euros for the whole of Europe per chemical compound for all the different scenarios are explained in Table 17. The externality caused because of different pollutant concentration is shown in the table for past, present and future scenarios. The external cost in million euros caused by Carbon, Sulphur and NItogen oxides and PM were extrapolated.

Table 16 Health effects, exposure-response functions, and economic valuation

Health effects (compounds)	Exposure-response coefficient (α)	Valuation, Euros (2006 prices)
	Morbidity[34]	
Chronic bronchitis (PM)	8.2×10−5cases/μg m^{-3} (adults)	52962 per case
Restricted activity days (PM)	8.4×10−4days/μgm^{-3} (adults)	131 per day
	−3.46×10−5days/μgm^{-3}(adults)	
	−2.47×10−4days/μgm^{-3}(adults> 65)	
	−8.42 × 10−5 days/μg m^{-3} (adults)	
Congestive heart failure (PM)	3.09 × 10−5 cases/μg m^{-3}	16409 per case
Congestive heart failure (CO)	5.64 × 10−7 cases/μg m^{-3}	
Lung cancer (PM)	1.26 × 10−5 cases/μg m^{-3}	21152 per case
	Hospital admissions	
Respiratory (PM)	3.46 × 10−6 cases/μg m^{-3}	7931 per case
Respiratory (SO_2)	2.04 × 10−6 cases/μg m^{-3}	
Cerebrovascular	8.42 × 10−6 cases/μg m^{-3}	10047 per case
PM	**Asthma, children (7.6%<16 yr**)	
Bronchodilator use	1.29 × 10−1 cases/μg m^{-3}	23 per case
Cough	4.46 × 10−1 days/μg m^{-3}	59 per day
Lower respiratory symptoms	1.72 × 10−1 days/μg m^{-3}	16 per day
	Asthma, adults (5.9 % >15 yr)	
Bronchodilator use (PM)	2.72 × 10−1 cases/μg m^{-3}	23 per case
Cough (PM)	2.8 × 10−1 days/μg m^{-3}	59 per day
Lower respiratory symptoms	1.01 × 10−1 days/μg m^{-3}	16 per day
	Loss of IQ	
Lead (Pb) (<3 year)∗	1.3 points/μg m^{-3}	24967 per point
Mercury (Hg) (foetus)∗	0.33 points/μg m^{-3}	24967 per point
	Mortality[35]	
Acute mortality (SO_2)	7.85 × 10^{-6} cases/μg m^{-3}	
Acute mortality (O_3)	3.27×10^{-6}∗SOMO35[36]cases/μgm^{-3}	2111888 per case
Chronic mortality, YOLL(PM)	1.138×10^{-3}YOLL/μgm^{-3}(>30 yr)	77199 per YOLL
Infant mortality (PM)	6.68×10^{-6}cases/μgm^{-3}(>9months)	3167832percase

Source: Contribution from the ten major emission sectors in Europe and Denmark to the health-cost externalities of air pollution using theEVA model system – an integrated modelling approach, Brandt et . al, 2013

[34] the incidence of disease : the rate of illness (as in a specified population or group)
[35] the number of deaths that occur in a particular time or place
[36] sum of means over 35 ppb for the daily maximum 8-hour values of ozone

Table 17 External costs in million Euros

Region/	Emission	CO	Total S	Total N	$PM_{2.5}$
SNAP	year	[MEuros]	[MEuros]	[MEuros]	[MEuros]
All/15	2000	0.775	27000	25200	6110
All/15	2007	0.707	23400	28500	5000
All/15	2011	0.688	21000	28700	4600
All/15	2020	0.849	24300	35400	4460
BaS-NoS/15	2000	0.038	11600	8170	2270
BaS-NoS/15	2007	0.051	5970	10100	1050
BaS-NoS/15	2011	0.051	3550	10400	725
BaS-NoS/15	2020	0.022	360	13200	490
All/all	2000	139	320000	331000	151000
All/all	2007	123	247000	307000	128000
All/all	2011	122	243000	307000	128000
All/all	2020	125	160000	235000	142000

Source: Assessment of past, present and future health-cost externalities of air pollution in Europe and the contribution from international ship traffic using the EVA model system, Brandt et. al., 2013

6.1.2. Emission Scenarios

Representative Concentrated Pathways (RCP)

Emission scenarios are future predictions based on socioeconomic energy and policy drives. There has been continuous improvement in the climate modelling technique. RCPs are the latest scenarios used for finding out the impact in the future due to regulations and policy interventions in the maritime industry (Bjørnæs, 2013). This climate projection tells about the future scenarios if certain factors will develop. This scenario helps in finding an alternative way for future conditions. The main motivating factor for this approach was to achieve specific climate change targets by reductions in emissions and adaptation to policy favouring climate change. The RCP model requires more input hence more complex and advanced compared to Special Report on Emissions Scenarios (SRES) used earlier in the fourth assessment report by IPCC and IMO in the second greenhouse gas study. As per IPCC RCPs are defined as follows.

"*RCPs are time and space dependent trajectories of concentrations of greenhouse gases and pollutants resulting from human activities, including changes in land use. RCPs provide a quantitative description of concentrations of the climate* *change pollutants in the atmosphere over time, as well as their radiative forcing in different time scale till 2100 (for example, RCP 6 achieves an overall impact of 6 watts per square metre by 2100).*"

(IPCC, 2013)

Scientists have used different scenarios for simulations and analysis of the fifth assessment report. Parallelly the community is making shared socio-economic pathways (SSP) for mitigation, adaptation, and analysis. These were assessed in the IPCCs Assessment Report (AR) 5 Working Group 3 Report released in March 2014. Assumptions taken by the scientists of the various modelling team for different scenarios are described in Table 18.

Table 18.Description of RCP scenarios

Scenario	Description	Type	CO2 eq	Comparable scenario	Modelling team	GHG	Publication
RCP 2.6	3w/m^2 before 2100 and 2.6w/m^2 by 2100	Peak scenario	490ppm	none	IMAGE	LOW GHG concentration level	Van Vuuren et al., 2006, 2007
RCP 4.5	Stabilisation Without overshoot pathway to 4.5 w/m^2 by 2100	Stabilization scenario	650 ppm	B1 SRES	GCAM37	Relatively ambitious emissions	Clarke et al. (2007), Smith and Wigley(2006)
RCP6.0	Stabilisation Without overshoot pathway to 6.0 w/m^2 by 2100		850 ppm	B2 SRES	AIM	Range of technology and strategies to reduce GHG emissions	Fujino et al. (2006) and Hijioka et al. (2008)
RCP 8.5	Rising adiative forcing to pathway leading to 8.5 w/m^2 by 2100	NO policy changes	1370 ppm	A1F1 SRES	MESSAGE	High GHG concentration	Riahi et al. (2007)

Source: Compiled by author from IPCC reports

[37] Global Chain Assessment Model

Alternative fuels and market driven challenges

Two main factors will determine the future bunker fuel mix of the international shipping:

1. Compliance costs of using the alternative fuels;
2. Compliance cost of abatement technology for environmental regulation.

In the emissions projection model used by IMO, two fuel mix scenarios were considered, a low LNG/constant ECAs case and a high LNG/extra ECAs case.

Shared Socioeconomic Pathways (SSP):

The five SSPs each have different narratives (Ebi et al., 2013) and are summarised with their main features in Table 19.

Table 19 Characteristics of SSP

Types of SSP	Characteristics
Characteristics of SSP1: Sustainability	Low for mitigation and adaptation, reduced inequality, high education, and improved health, Achieve development goals while reducing fossil fuel dependency. An environmentally aware world with rapid technology development and strong economic growth, even in low-income countries.
Characteristics of SSP2: Middle of the road	Moderate, An intermediate case between SSP1 and SSP3, Some progress towards achieving development goals, Dependency on fossil fuels is slowly decreasing, (O'Neill et al., 2013)
Characteristics of SSP3: Fragmentation	High for mitigation and adaptation, Slow reduction in fossil dependency, Slight increase in technological developments, Barriers to trade, Hard to maintain living standards, increase in population, Weak institutions, slow technological change in the energy sector, (O'Neill et al., 2013)
Characteristics of SSP4: Inequality	High for adaptation, low for mitigation. A high inequality in the world in which few high-income emitters are responsible for large part of GHG emissions compared to the low-income group which contributes microscopic to emissions. Scarcity of carbon technology

	development and policy, Low human capital, and economies are relatively isolated,
Characteristics of SSP5: Conventional development	High for mitigation, low for adaptation, Development is oriented towards economic growth as the solution to social and economic problems, High demand and engineered infrastructure, In the absence of climate policies, energy demand is high, and most of this demand is met with carbon-based fuels. Investments in alternative energy technologies are low, and there are few readily available options for mitigation.

Source: Adapted from Ebi et al., 2013 and O'Neill et al., 2013

Improvement in efficiency of vessels

Regulatory requirements will force shipowners to comply with the abatement options irrespective of their economic constraint. One scenario is about 60% improvement over current efficiency levels (excluding speed and alternative fuels), and another includes scenario which has 40% improvement over current levels.

Business as usual and policy scenarios (BAU)

Business as usual and policy scenarios combines with RCP and SSP for making a climate model projection together with improvement in efficiency of vessels and alternative fuels and market driven challenges. Scenario 1 where there is no policy taken to address air emissions is referred as BAU scenario whereas the other scenarios is in which IMO continues to adopt policies to address air emissions or the energy efficiency of ships. Kriegler et al. (2012) indicated the process and guidance of ways to combine both RCPs and SSPs for making a climate model projection. The scenario adopted by IMO was as follows:

- RCP8.5 combined with SSP5;
- RCP6 combined with SSP1;
- RCP4.5 combined with SSP3;
- RCP2.6 combined with SSP4/2.

Projected scenarios were presented graphically and in tabular form. Table 20 projects all the scenarios related to vessel's efficiency improvements and fuel mix along with RCP and SSP. Scenarios with good efficiency show less emission after 2035 or 2040. This proves that using abatement measure and new policies will result in less emission in long term. This will drive innovation and improve efficiency of the vessel. Scenarios with large improvements in efficiency exhibit decelerating emissions. The figure 30 shows that the BAU lines representing high-efficiency scenarios cross the lines of low-efficiency but higher growth scenarios. Technological development and less dependency on fossil fuels can offset higher demand as policy interventions will result in less emission. In all the cases emissions are more in BAU scenario than the scenario where there is improvement in efficiency or there is use of alternative fuel. These lower emission scenarios require additional regulatory environment and new policies beyond those that are currently used.

Table 20 Different Scenario

Scenario	RCP scenario	SSP scenario	Fuel mix(LNG, ECA)	Efficiency improvement
1	RCP8.5	SSP5	high LNG/extra ECA	High
2	RCP6.0	SSP1	high LNG/extra ECA	High
3	RCP4.5	SSP3	high LNG/extra ECA	High
4	RCP2.6	SSP4	high LNG/extra ECA	High
5	RCP8.5	SSP5	high LNG/extra ECA	Low
6	RCP6.0	SSP1	high LNG/extra ECA	Low
7	RCP4.5	SSP3	high LNG/extra ECA	Low
8	RCP2.6	SSP4	high LNG/extra ECA	Low
9	RCP8.5	SSP5	low LNG/no ECA	High
10	RCP6.0	SSP1	low LNG/no ECA	High
11	RCP4.5	SSP3	low LNG/no ECA	High
12	RCP2.6	SSP4	low LNG/no ECA	High
13 (BAU)	RCP8.5	SSP5	low LNG/no ECA	Low
14 (BAU)	RCP6.0	SSP1	low LNG/no ECA	Low
15 (BAU)	RCP4.5	SSP3	low LNG/no ECA	Low
16 (BAU)	RCP2.6	SSP4	low LNG/no ECA	Low

Source: Third GHG study from IMO, 2014

Graphical Representation

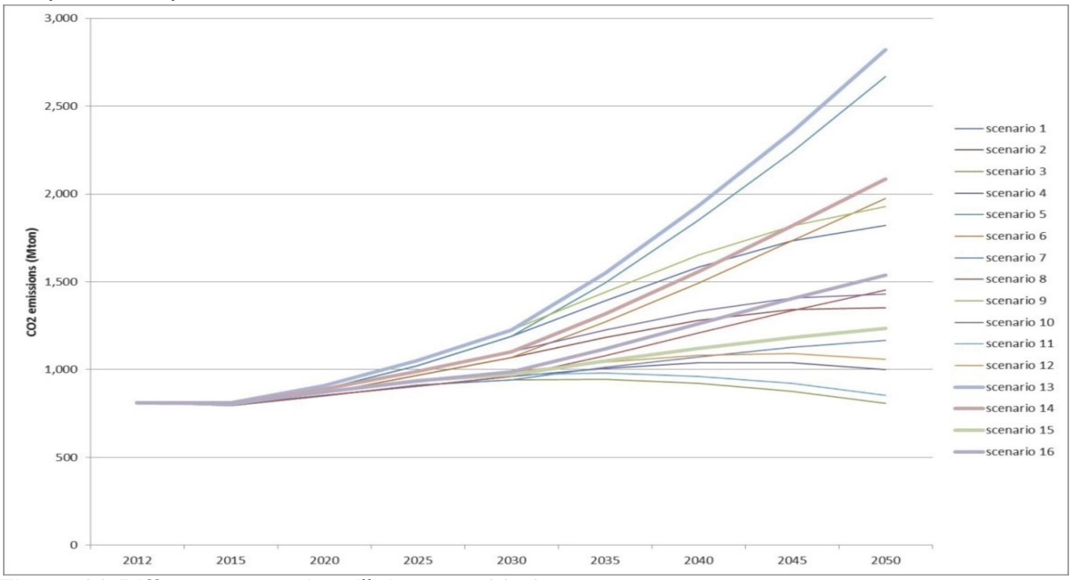


Figure 30 Different scenarios till the year 2050

Source: Third GHG Study from IMO, 2014.

6.2. Recommended Criteria for Decision framework

6.2.1. Calculation of External Cost for M.V. Stena Germanica

Shipping transport price fails to account for total social costs. In order to correct this market failure and promote effective solutions external costs of shipping need to be calculated. It is a prerequisite to internalise external costs so that it gives a clear insight of environmental impacts of shipping. A Voyage based model is used to calculate, the emissions are calculated on a yearly basis and then the external costs caused by air pollution. An external cost is calculated by multiplying the amount of emission and the marginal external costs per kg (Holland et al., 2002). Marginal external cost is taken from HEATCO projects which are based on the IMPACT pathway approach. HEATCO values have no sensitivity results as compared to the value of CAFE marginal external costs. The cost for PM is taken from the marginal external cost for urban metropolitan and outside built-up regions for Sweden and Germany where as the cost for CO_2, SO_x, and NO_2 is taken from the national value of the country mentioned in the case study. Figure 31 shows the impact pathway approach for calculation of external cost caused by air pollution.

Impact Pathway Approach.

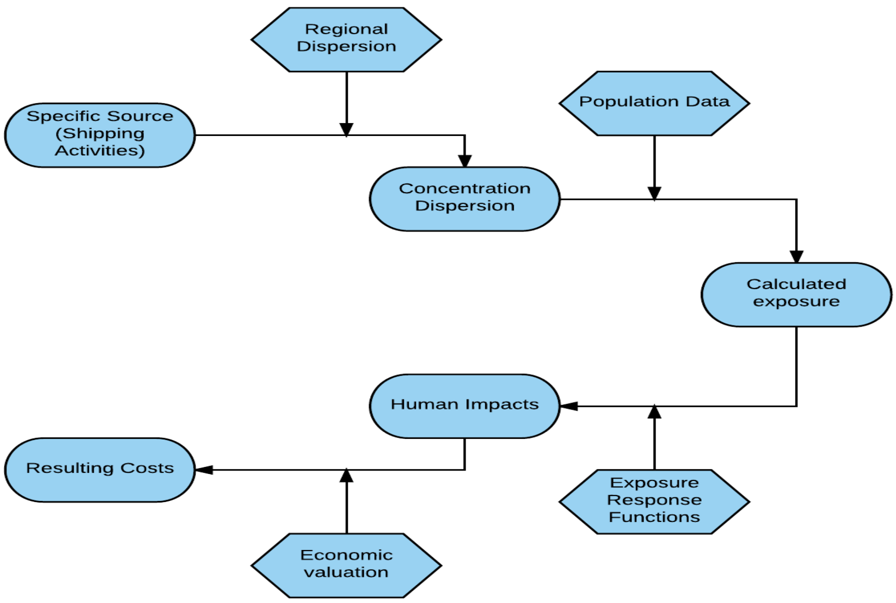


Figure 31 Impact Pathway Approach used for EVA modelling

Source: Adapted from Brandt et al., 2012

Only four gases CO_2, NO_x, SO_2, and PM, are taken into consideration. The main air pollutants which are causing externality to health costs are NO_x, PM, and SO_2 whereas CO_2 are responsible for climate change. Hence, external costs of CO_2 is put into climate change costs (Tzannatos, 2010). SO_x and NO_x convert into fine particles of sulphate, and nitrate aerosols after undergoing a chemical reaction and reduce the ozone layer. Moreover, other emissions during the burning of Methanol in the marine engine have negligible value (Wä, 2016). External costs are situation-specific and may vary from voyage to voyage. Therefore, in this calculation, we have used voyage based model which uses berthing, manoeuvring and sailing time for M.V. Stena Germanica. The total time of sailing is divided into berthing, manoeuvring, and free sailing from Kiel to Gothenburg and vice versa. Berthing time is taken as 2 hours at each port, each trip and the manoeuvring time is taken 12 hours on each trip, each port. Rest of the time is taken as the free sailing time. The total running time for the marine engines on board MV Stena Germanica is taken as 8400 hrs after calculation. The total power includes the power of the main and auxiliary engine used for sailing.

Emission amount at the free sailing stage is far greater than the levels at the manoeuvring and the berthing stages. This imbalance will become even more with the increase of sailing time and distance. Table 21 gives the value of all the external cost caused by the emissions during the trip from Gothenburg to Kiel.The overall externalities are evaluated around 9100278 Euros when using MGO which includes 1276697 Euros for climate change costs and 7823581 Euros for air pollution costs. Similarly for Methanol, overall externality came around 2683946 Euros which includes 1206741 and 1477205 as climate change and air pollution costs respectively. Change in the air pollution costs and climate costs because of fuel switching amounts evaluated as 6346376 and 69956 Euros respectively. The air pollution costs are calculated by adding the costs of NO_2, SO_x and PM whereas the costs of CO_2 are taken as climate change costs. The difference in the amount saved is considerable and put emphasis on the need for ship emissions control with primary focus on PM. Table 21 shows the total external costs of the trip made in one year. It is apparent that the external costs are more during the sailing stage when compared to the berthing and manoeuvring time. Despite the fact that the time at berth is quite less than the sailing time the external costs is still dominating because marginal external costs around the coastal area are high. Marginal external costs of PM are high due to its serious threats to the human health. The external costs in the sailing time are less because the exposure of the pollutant concentration to the population is quite less.

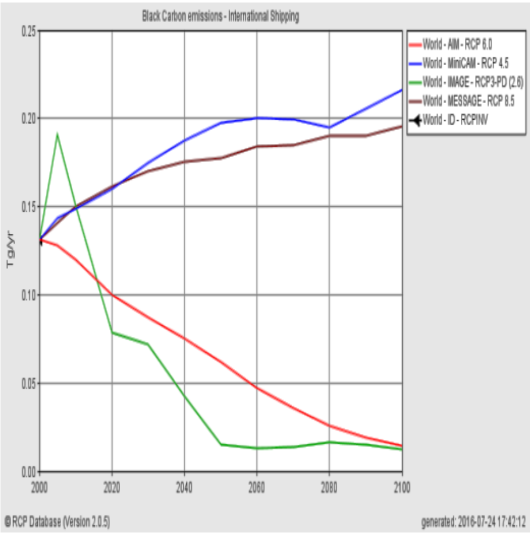
Table 21 Calculation of External cost for MV Stena Germanica

Voyage		**Berthing**	**Manoeuvring**	**Free Sailing**	**Berthing**	**Manoeuvring**	**Free Sailing**
Time in hours		**300**	**50**	**3850**	**300**	**50**	**3850**
Port		**Kiel**	**Kiel**	**Kiel**	**Gothenburg**	**Gothenburg**	**Gothenburg**
MGO	CO_2	1519877520	253312920	19505094840	1519877520	253312920	19505094840
	NO_X	31230360	5205060	400789620	31230360	5205060	400789620
	SO_2	978551	163092	12558075	978551	163092	12558075
	PM	229023	38170	2939124	229023	38170	2939124
MeOH	CO_2	1436596560	239432760	18436322520	1436596560	239432760	18436322520
	NO_X	5829667	971611	74814062	5829667	971611	74814062
	SO_2	0	0	0	0	0	0
	PM	89527	14921	1148930	89527	14921	1148930
Air Pollution cost factor	CO_2	0.03	0.03	0.03	0.03	0.03	0.03
	NO_X	12.7	12.7	12.7	4.1	4.1	4.1
	SO_2	10.9	10.9	10.9	4.2	4.2	4.2
	PM	227.6	227.6	33.6	231.3	231.3	17.0
MGO (External cost Euros)	CO_2	45596.3	7599.4	585152.8	45596.3	7599.4	585152.8
	NO_X	396625.6	66104.3	5090028.2	128044.5	21340.7	1643237.4
	SO_2	10666.2	1777.7	136883.0	4109.9	685.0	52743.9
	PM	52125.6	8687.6	98754.6	52972.9	8828.8	49965.1
	Total external Cost	505013.7	84168.9	5910818.6	230723.7	38453.9	2331099.3
MeOH (External cost Euros)	CO_2	43097.9	7183.0	553089.7	43097.9	7183.0	553089.7
	NO_X	74036.8	12339.5	950138.6	23901.6	3983.6	306737.7
	SO_2	0.0	0	0	0	0	0
	PM	20376.4	3396.1	38604.1	20707.6	3451.3	19531.8
	Total external Cost	137511.0	22918.5	1541832.3	87707.1	14617.9	879359.1

6.2.2. Future emission scenarios caused by Shipping

This section focuses only on climate change scenarios caused by the shipping sector. Other areas are beyond the scope of this study even though they have a major effect on the climate. The emissions caused in different scenarios are projected to the year 2100. All shipowners must consider the emission scenario before using any abatement or policy measures. These methods will help shipowners to abide by their commitments to decrease the emissions. The following figures are generated by the author from the RCP program available and show emission projections from the international shipping industry.

Projected level of air emissions at different scenarios



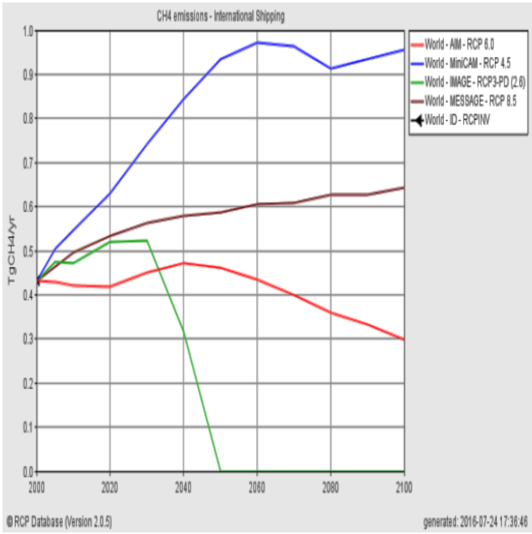
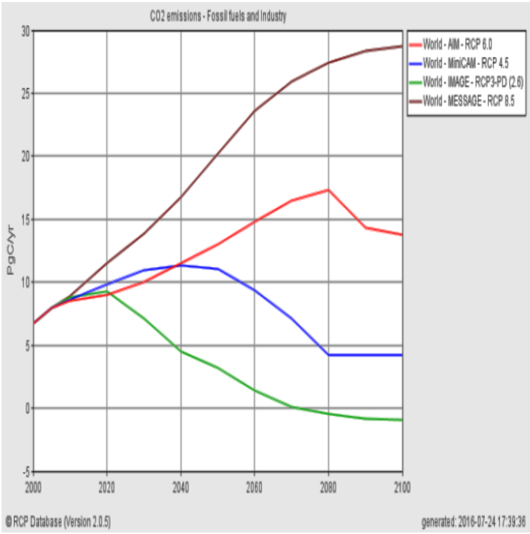


Figure 32 Black carbon emissions International shipping and Figure 33 CH_4 emissions-International shipping

Figures 32, 33, 34, 35, 36, and 37 shows the projected levels of black carbon emissions, methane, carbon monoxide, organic carbon emissions, and volatile organic compounds emissions cause by maritime sector globally by the year 2100. Figure 38 shows the projected concentration of CO2 equivalent present in the atmosphere due to the emission of GHGs by maritime sector globally by 2100.



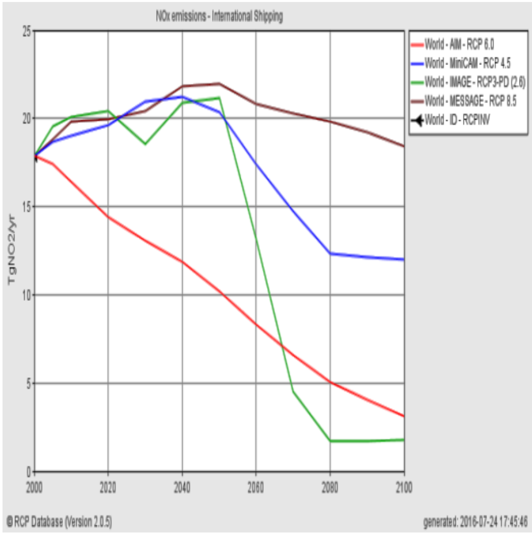
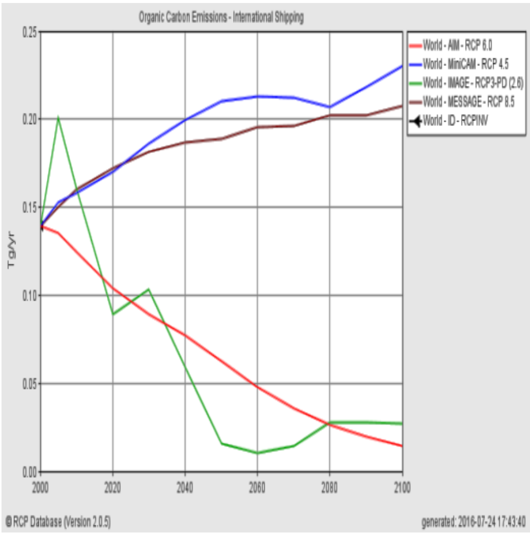


Figure 34 CO_2 emissions -International shipping Figure 35 NO_x emissions-International shipping



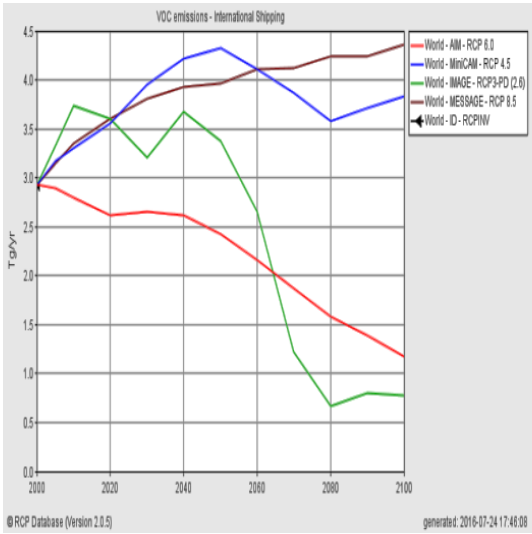


Figure 36 Organic carbon emissions-International shipping and Figure 37 VOC emissions-International shipping

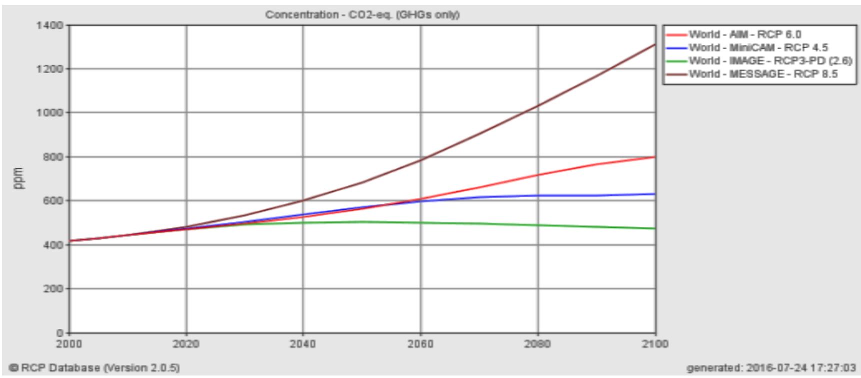


Figure 38 CO2 eq- International shipping

Source: Generated by author from RCP Database

6.2.3. Comparing Carbon Tax, MBM and Compliance Cost

From the empirical analysis of the case study of MV Stena Germanica, it can be concluded that the shipowners complying with measures to reduce air emissions will make profit in the long term whereas initially the governments can impose a carbon tax on shipowners. In the case study, the IRR was found positive for the next 15 years and the payback period was evaluated as four years. A shorter payback period will have a positive effect on shipowners forcing them to go for effective abatement measures.

In the case of Sweden where EU Council are ready to implement MRV system, it is interesting to see the reaction of the shipowners towards MBM. When Swedish government imposed a CO_2 tax, industrial installations were exempted which are covered by EU ETS. With the same analogy, Swedish government can impose a carbon tax on the ship owners whose ships are not complying with the EU ETS or abatement technology. These measures are required to set the emission below the set target. However, currently the price of the EU ETS is much lower than the Swedish carbon tax level. This will cause most of the shipowners to go for measures of emission reduction similar scenarios happened to industrial firms between 2005 and 2012 (Bonilla et al., 2012).

The regulations to put carbon tax for the polluter to pay more will make shipowners go for technical and operational measures. There should be a threshold limit for the optimal emissions. The limit must ensure that ships emitting more than a fixed amount of tonnes CO_2eq/year should pay the carbon tax. The threshold should be larger in the case of the EU ETS as it can be seen under a trading scheme and carbon tax that the price of emission permits are affected by the accuracy of monitoring emissions. Moreover, complying with the measures will certainly depend on the strength of MRV. Much needed monitoring procedures and abatement measures are quite costly to meet regulations and emissions trading scheme are costly even though in the long term, the regulation will provide real incentives for polluters to reduce emissions. Permit price will affect the decision making for shipowners to go for abatement measures.

6.3. Integrated Decision Framework

Decision framework for Shipowners

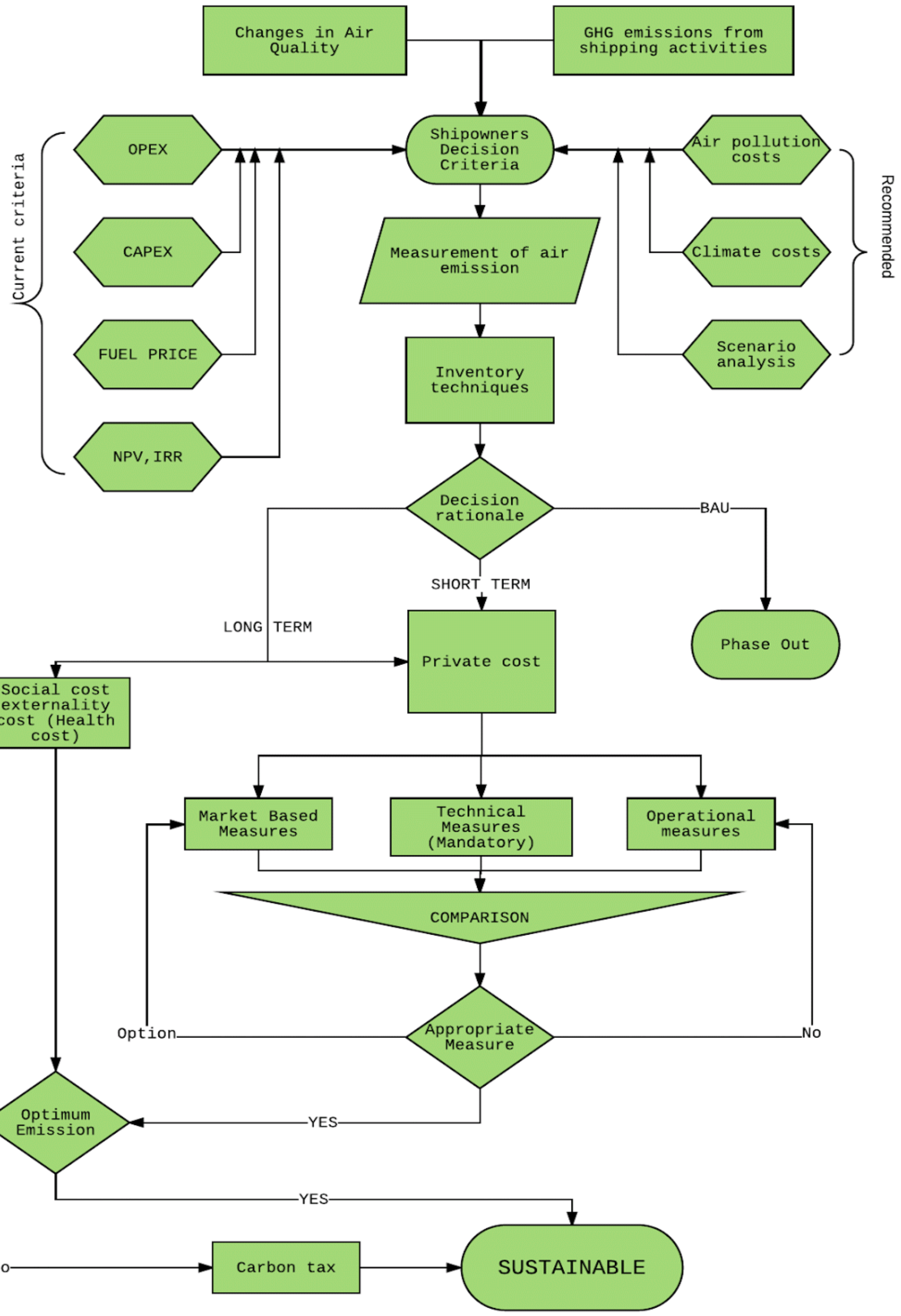


Figure 39

Decision framework analyses the criteria shipowner must consider while choosing the abatement measures for emission reduction. In current situation shipowner focuses on CAPEX, OPEX, fuel prices, shorter payback period. Because of high external costs, shipowner should consider the air pollution costs, climate costs and future scenarios while choosing appropriate measure. The decision framework designed by the author shown in Figure 39 gives various approaches for a shipowner to avoid air emission reduction and maintain their cash flow. In the framework there is emphasis on the implementation of carbon tax for reasons explained earlier. It can be seen clearly how carbon tax will push shipowners to comply with abatement measures for long term benefits and social benefits. Following are the recommendations derived from the decision framework which will help the shipowners to reduce the air emissions and reducing the social cost.

1. Comply with new technical and operational measures.
2. Investment decisions should account for impacts, costs, and benefits to health, throughout funding decision-making processes.
3. Internalising the health costs will help in understanding the cost trade-offs to the public, rather than speculating the externality costs.
4. Goal based maritime industry funding would allocate more investments to projects and efforts that support sustainable maritime transport.

The case of ship-owner complying with the air emission reduction measure or choosing to pay carbon tax will be discussed in detail. Following cases are reviewed as per Table 22 after making decision criterion for shipowners.

Table 22: Decision analysis for shipowner

Emission Reduction Measures	Shipowner Comply with measures	Shipowner does not comply measures
Carbon tax		
Ship owners pay tax	CASE 1	CASE 2
Ship owner does not pay tax	CASE 3	CASE 4

CASE 1 mentions that the shipowners are complying with emission reduction measures but still have to pay the tax because the emission is more than the optimal cap for emissions. This shipping line is directing towards sustainability and will have a profit in long term assuming the value of the carbon tax remains the same.

CASE 2 is about the phasing out of a ship owner who is not complying with abatement technology will have to pay a higher tax or buy emission credits from another shipowner. This is not a viable option due to the fact that with new stringent regulations the ships have to pay the heavy amount as tax and penalty to trade. Moreover, it will create a huge loss margin for the shipowners. The ships will be phased out from the market.

CASE 3 is an ideal situation for a shipowner where the ship has implemented state of the art abatement measures. In this case, the emissions will be reduced and will bring co-benefits to the shipowner by reducing health cost which is an externality to maritime transport. In the long term, the company will have higher IRR. The case study proves the positive behaviour of shipowners.

CASE 4 discusses the scenario where the market will reject the services provided by the shipowner. It is not an ideal situation as the shipping line will try to avoid the route where there are strict regulations and would continue without putting any measure. Moreover, shipowners are hesitant to comply with the abatement measures because of high capital costs and fear of losing business in the long term.

The social cost of carbon or health cost should be paid by the producer instead of by the society. In reality, taxpayers will pay for the uninsured population affected by the maritime transport morbidity. The population who is insured will end up driving up health insurance costs for others. There can be two feasible options. Firstly, ship owners will increase or decrease the freight rate making sure it is still competitive. Secondly, government should intervene in this competitive and dynamic market so that the ship owners internalise their costs for polluting the environment. The carbon tax must be set at the level which enables the company to go for the air reduction measures instead of paying the cost as a violation of the set cap. Importers, exporters, and shipper must pay the carbon tax which could be used to fund advanced equipment and technologies to mitigate the air reduction.

7. Conclusions and Recommendations

The dissertation proposes a decision framework for shipowners to make a compliant strategy to reduce air emissions. The framework is validated by using a case study of an ROPAX vessel which uses alternative fuel Methanol. The calculation helps to assess the environmental impact of shipping air emissions.

The calculation of external costs of air pollution after switching to Methanol fuel was evaluated around Euros 2683946 which includes air pollution costs of Euros1477204.9 and climate costs of Euros1206741.1. The estimation highlights the need for ship emission control with focus on PM, SO_x, CO_2, and NO_X.

There is a high level of uncertainty in the emission calculation in the maritime industry. This dissertation has analysed all the techniques available in the market for shipowners. There is an emphasis on shipowners to keep track of their emissions by choosing the most accurate method and reporting regularly.

The environmental benefits of 2953.70 tonnes of CO2eq were evaluated after switching to Methanol. In the case study of M.V. Stena Germanica, it was found that the NPV and IRR values are positive for the next fifteen years after discounting with the payback period of four years. The figure proves that the new regulation energy efficient and environmental complying technology will be in high demand. There is ample room for innovation and application of new efficient technology but choosing an appropriate reduction measure requires rational and systematic decision making.

It is proven from the case study that the environmental benefits of alternative fuel like Methanol are enough to offset the initial CAPEX and with more sailing time the benefits will be more to shipowners.

In the decision framework, the current strategy is based on the mature technology and economic consideration like OPEX, CAPEX, NPV, IRR, shorter payback period, fuel consumption and fuel prices. In this dissertation, it was concluded that the shipowners should include other factors in their decision-making criteria for long-term benefits. The main consideration recommended in this dissertation are Health cost analysis, calculation of external costs which includes air pollution costs and climate costs, and future emission scenario.

Another finding of this dissertation is an emphasis on the carbon tax and market-based measure in the short term for shipowners to reduce air emissions. A carbon tax sets a price on carbon dioxide emissions using the principle of polluter pays principle. Shipowners prefer the certainty in the price level while maintaining the cash flow analysis as it gives them the confidence to invest in low-carbon technology as also seen in the case study. Therefore, the carbon tax after implementation can bring the era of emission reduction measures and will develop innovation. The limitation of the carbon tax is it will be subjected to regulatory risk if implemented at national and regional level. Taxation will reduce marginal profit, but the long term benefits are large. To know the optimal tax, we should know the social cost.

In the case of ETS which is a preferred MBM right now, emission reductions are likely to offset by emissions increases elsewhere. Under MBM, there a guarantee in the level of emission reduction compared to the carbon tax. For instance, in an ETS price will be set indirectly by limiting total emissions and issuing tradable emissions allowances. Emissions reduction can be made by controlling the emissions through the cap, and the price is set by restricting the volume of emissions.

A well-designed carbon tax will provide motivation for shipowners to go for long term investments. The alma matter is ETS and carbon tax is secondary importance compared to addressing climate change (Triole, 2014). A hybrid policy that uses collar strategy could be the solution along with using emission reduction measures.

Methanol can lead to the sustainable shipping industry. Making a better bunkering infrastructure will also attract investors and ship owners. It is evident from the study that using Methanol as a fuel provides the greatest environmental benefits on the reduction of SO_x, PM, NO_x and CO_2 emissions, but the fleet-wide adoption of Methanol as a fuel will depend on the availability, financial considerations, and clear regulatory guidance.

Methanol has emerged as a strong alternative fuel option because of stringent air emissions regulations. The results demonstrated that by using technical measures, shipping will become more sustainable and will bring benefits to shipowners and the society by increasing the private cost and reducing the external costs or social cost.

In conclusion, the dissertation identifies the decision framework for shipowners to opt for the cost-effective means to regulate air emissions at international level. Complying with the environmental policies to reduce greenhouse gas emissions is necessary for sustainability, but it can also bring co-benefits to the shipowners. These interactions will have clear implications for policy design as many shipowners are committed to complying with ECA regulation even though in reality very few companies are in real action. The dissertation put emphasis on the benefits (costs) ship-owner can expect from pursuing air emissions reduction measures and regional air pollution policies simultaneously.

7.1. Further Recommendations

This dissertation answered questions which shipowners go through during decision making for complying with the abatement measures to reduce emissions and increase their profitability. Uncertainty and variability in the measurement and the policies around the globe at national and international level make it an intricate process and raises more questions. Some of the issues recognised by the author in this dissertation which require further study are:

1. Which are the standard methods applicable for the emission calculation and inventories for shipowners?
2. Pros and cons of complying with Market-based measures. How long will it be effective?
3. On what factors the optimal level of Air emissions from maritime industry can be decided?
4. What criteria shall be used when pricing Carbon or GHG emissions?

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Appendices

Appendix A Calculation of Revenue expense and profit.

	STENA LINE – VESSELS OWNED AND CHARTERED AS OF 31 DECEMBER 2015				
	Name	**Route**	**Vessel type**	**Passengers**	**Lanemetres**
	Scandinavia				
1	Stena Saga	Oslo–Frederikshavn	Night Ferry	2,000	1,032
2	Stena Carisma	Göteborg–Frederikshavn	HSS	900	765
3	Stena Danica	Göteborg–Frederikshavn	Day Ferry	2,274	1,640
4	Stena Jutlandica	Göteborg–Frederikshavn	RoPax	1,500	2,100
5	Stena Scanrail[3)]	Göteborg–Frederikshavn	RoPax	36	1,000
6	Stena Gothica[4)]	Göteborg-Fredrikshavn	RoPax	186	1,598
7	Stena Nautica	Varberg–Grenaa	RoPax	900	1,265
8	Stena Germanica III	Göteborg–Kiel	RoPax	1,300	3,800
9	Stena Scandinavica IV	Göteborg–Kiel	RoPax	1,300	3,800
10	Skåne	Trelleborg–Rostock	RoPax	600	3,295
11	Mecklenburg–Vorpommern[1)]	Trelleborg–Rostock	RoPax	600	3,202
12	Trelleborg	Trelleborg–Sassnitz	RoPax	848	1,189
13	Sassnitz	Trelleborg–Sassnitz	RoPax	1,000	1,071
14	Stena Vision	Karlskrona–Gdynia	RoPax	1,300	2,214
15	Stena Spirit	Karlskrona–Gdynia	RoPax	1,300	2,214
16	Stena Baltica[1)]	Karlskrona–Gdynia	RoPax	210	2,188
17	Scottish Viking[2)]	Nynäshamn–Ventspils	RoPax	880	2,250
18	Stena Flavia	Travemünde–Ventspils	RoPax	880	2,255
19	Urd	Travemünde–Liepaja	RoPax	186	1,598

20	Stena Hollandica III	Hoek van Holland–Harwich	RoPax	1,200	5,500
21	Stena Britannica III	Hoek van Holland–Harwich	RoPax	1,200	5,500
22	Severine	Rotterdam–Harwich	RoRo	12	1,760
23	Capucine	Rotterdam–Harwich	RoRo	12	1,760
24	Stena Transporter	Hoek van Holland–Killingholme	RoPax	300	4,056
25	Stena Transit	Hoek van Holland–Killingholme	RoPax	300	4,056
26	Stena Scotia	Rotterdam–Killingholme	RoRo	12	1,692
27	Stena Hollandica III	Hoek van Holland-Harwich	RoPax	1,200	5,566
28	Stena Britannica III	Hoek van Holland-Harwich	RoPax	1,200	5,566
29	Severine[1)]	Rotterdam-Harwich	RoRo	12	1,760
30	Capucine[1)]	Rotterdam-Harwich	RoRo	12	1,760
31	Stena Transporter	Hoek van Holland-Killingholme	RoPax	300	4,056
32	Stena Transit	Hoek van Holland-Killingholme	RoPax	300	4,056
33	Stena Scotia	Rotterdam-Killingholme	RoRo	12	1,692
	Irish Sea				
34	Stena Adventurer	Holyhead–Dublin	RoPax	1,500	3,400
35	Stena Superfast X	Holyhead-Dublin	RoPax	1,200	1,924
36	Stena Nordica[6)]	Holyhead–Dublin	RoPax	405	1,950
37	Stena Explorer[3)]	Holyhead–Dun Laoghaire	HSS	1,500	1,100
38	Stena Europe	Fishguard–Rosslare	RoPax	1,400	1,120
39	Stena Superfast VII[1)]	Cairnryan–Belfast	RoPax	1,200	1,924
40	Stena Superfast VIII[1)]	Cairnryan–Belfast	RoPax	1,200	1,924
41	Stena Lagan	Belfast–Liverpool	RoPax	970	2,250
42	Stena Mersey	Belfast–Liverpool	RoPax	970	2,250

43	Stena Performer[1)]	Belfast–Heysham	RoRo	12	2,166
44	Stena Precision[1)]	Belfast–Heysham	RoRo	12	2,166
45	Stena Hibernia	Belfast–Heysham	RoRo	12	1,692
46	Stena Horizon[1)]	Rosslare-Cherbourg	RoPax	970	2,250
		Total	148995	35,623	1,13,372
		MILLION SEK	**EURO TO SEK**	**MILLION EURO**	
	Ferry Revenue	12491.000	9.537	1309.741	
	Ferry Expenses	9272.000	9.537	972.213	
	Ferry Profit	3219.000	9.537	337.528	
			MILLION EURO	**MILLION EURO**	
	Revenue per person / per lane metre		0.009	0.009	
	Expenses Per person / per lane metre		0.007	0.007	
	Profit per person / per lane metre		0.002	0.002	
	CAPACITY FOR STENA GERMANICA	**passenger**	**lane metre**		
		1300.000	4000.000		
		MillionEuros passenger	**Million Euros lm**	**Total in Euros**	**Total in USD**
	Revenue for stena germanica	11.43	35.16	46589666.41	51714529.71
	Expenses for stena germanica	8.48	26.10	34583250.89	38387408.49
	Profit for stena germanica	2.94	9.06	12006415.51	13327121.22

Appendix B. Particulars for MV Stena Germanica

Ship Particulars / IMO 9145176							
STENA GERMANICA				Delivered at	2010	Bow Thruster	1
Name:	STENA GERMANICA	(effective 2010-09)		Cabins	85	Manufacturer	Rolls Royce
	Stena Germanica III	(effective 2010-07)		LOA	240.5	Output	2500 Kw
	Stena Hollandica	(effective 2001-02)		LBP	221.75	Auxiliary Engine	1
IMO Number:	IMO 9145176			Moulded Breadth	28.7	Manufacturer	Wartsila
Flag:	Sweden					Model	6L26
Port of registry:	Gothenburg			Depth to the main deck	9	Output	1800 Kw
Call sign:	SLDW			Draught, design	6	Auxiliary Engine	2
MMSI:	266331000			LPP/Bm	7.73	Manufacturer	Wartsila
Ship status:	In Service/Commission	(effective 2012-02-12)		Bm/Td	4.78	Model	9L26
Characteristics				LPP/Td	36.96	Output	2700 Kw
				Gross Tonnage	51837	No of Vehicles Deck	4
Type:	Passenger/Ro-Ro Ship (Vehicles)			Net Tonnage	23007	No of Moveable	1

						Vehicle deck	
	Lengthened - 200705			DeadWeight Design Draught even keel	10670	Total Lane Length	4000 m
Date of build:	2001-02	SPN058110				Free height on Main trailer deck	5m
Gross tonnage:	51,837			Service Speed	22 Knots	Total Passengers	1300
Deadweight:	10670 tonnes			MainEngine		Number of beds	1375
TEU:				Manufacturer	Sulzer	Number of Cabins	490
Insulated capacity:				Model	8ZAL40S		
Length overall:	241.26 m				4 Installed		
Length between perpendiculars:	223.11 m			MCR each	5760KW		
Length registered:	226.45 m			RPM @MCR	510		
Main engines:	Number of main engines	4					
	Max. power	24,000 kW		MCR TOTAL	23040 kW		
	Model	8ZAL40S		Classification society:	Lloyd's Register		
	Designer	Sulzer		Registered owner:	STENA LINE SCANDINAVIA AB (1249369)		
	Builder code	ITL602870		Ship manager:	STENA LINE SCANDINAVIA AB (1249369)		

Propulsion:	OIL ENGINE(S), GEARED DRIVE			Group beneficial owner:	STENA AB (0403119)		
Service speed:	22 knots			Operator:	STENA LINE SCANDINAVIA AB (1249369)		

Appendix C Global warming potential of GHG gases

Species	Chemical formula	Lifetime (years)	Global Warming Potential (Time Horizon)		
			20 years	100 years	500 years
CO2	CO2	variable §	1	1	1
Methane *	CH4	12±3	56	21	6.5
Nitrous oxide	N2O	120	280	310	170
HFC-23	CHF3	264	9100	11700	9800
HFC-32	CH2F2	5.6	2100	650	200
HFC-41	CH3F	3.7	490	150	45
HFC-43-10mee	C5H2F10	17.1	3000	1300	400
HFC-125	C2HF5	32.6	4600	2800	920
HFC-134	C2H2F4	10.6	2900	1000	310
HFC-134a	CH2FCF3	14.6	3400	1300	420
HFC-152a	C2H4F2	1.5	460	140	42
HFC-143	C2H3F3	3.8	1000	300	94
HFC-143a	C2H3F3	48.3	5000	3800	1400
HFC-227ea	C3HF7	36.5	4300	2900	950
HFC-236fa	C3H2F6	209	5100	6300	4700
HFC-245ca	C3H3F5	6.6	1800	560	170
Sulphur hexafluoride	SF6	3200	16300	23900	34900
Perfluoromethane	CF4	50000	4400	6500	10000
Perfluoroethane	C2F6	10000	6200	9200	14000
Perfluoropropane	C3F8	2600	4800	7000	10100
Perfluorobutane	C4F10	2600	4800	7000	10100
Perfluorocyclobutane	c-C4F8	3200	6000	8700	12700
Perfluoropentane	C5F12	4100	5100	7500	11000
Perfluorohexane	C6F14	3200	5000	7400	10700

Appendix D Cash flow for Stena AB Lines from M.V.Stena Germanica

				2015	2016	2017	2018	2019	2020
			Local Inflation	1	1.0102	1.020504	1.030913	1.041428	1.052051
	Operating Costs		Euro		29109154	29406067	29706009	30009011	30315102
			US$		31300165.59	31619427	31941945	32267753	32596884
	Profit		Euro		12006415.51	12246544	12491475	12741304	12996130
			US$		12910124.21	13168327	13431693	13700327	13974334
	MGO Costs		Euro		5474096.65	5583579	5695250	5809155	5925338
			US$		5886125.43	6003848	6123925	6246403	6371331
	GHG Reduction		Euro		374608.7202	374608.7	374608.7	374608.7	374608.7
			US$		402805.0755	402805.1	402805.1	402805.1	402805.1
	Sub-Total		US$		50499220.3	51194407	51900369	52617289	53345355
	Total Revenues		US$		50499220.3	51194407	51900369	52617289	53345355
Operating Costs	O&M		Euro		29109154	29406067	29706009	30009011	30315102
			US$		31300165.59	31619427	31941945	32267753	32596884
	MethanolFuel		Euro		7699207.95	7699208	7699208	7699208	7699208
			US$		8278718.226	8278718	8278718	8278718	8278718
	Total Operating Costs		US$		39578883.82	39898146	40220664	40546472	40875603
	EBITDA		US$		10920336.49	11296261	11679705	12070817	12469752
	EBITDA Margin		(%)		0.216247626	0.220654	0.225041	0.229408	0.233755
Depreciation	D&A		Straight Line		1577060.932	1577061	1577061	1577061	1577061
	EBIT		US$		9343275.554	9719201	10102644	10493756	10892691
	EBT		US$		9343275.554	9719201	10102644	10493756	10892691
Taxes	Federal Taxes		Pass Through		2055520.622	2138224	2222582	2308626	2396392
	Net Income		US$		7287754.932	7580976	7880062	8185130	8496299

Pre Tax Cash on Cash	Operating Income		US$		10920336.49	11296261	11679705	12070817	12469752
	Cash After Debt Service		US$		10920336.49	11296261	11679705	12070817	12469752
Pre-Tax w/Carbon	Distributable Cash			-23655913.98	10920336.49	11296261	11679705	12070817	12469752
		IRR	49.31%		-0.538367588	-0.040624	0.201282	0.323835	0.390669
Pre Tax w/o Carbon	Distributable Cash			-23655913.98	10487212.75	10863138	11246581	11637694	12036628
			47.57%		-55.67%	-6.54%	17.68%	30.07%	36.89%
After-Tax Return	Fed Tax Benefit (Payment)		US$		-2055520.622	-2138224	-2222582	-2308626	-2396392
with GHG reduction	Distributable Cash		US$		10920336.49	11296261	11679705	12070817	12469752
	Net Cash Flow			-23655913.98	8864815.864	9158037	9457123	9762191	10073360
					2015	2016	2017	2018	2019
	A/T Cash Flow			-23655913.98	8864815.864	9158037	9457123	9762191	10073360
	NPV	56475035.59		-23655913.98	8058923.513	7568626	7105277	6667708	6254764
	Payback Year	4		-23655913.98	-15596990.47	-8028365	-923087.9	5744620	11999384
		IRR	40.30%		-62.53%	-16.28%	7.79%	20.59%	27.86%
After-Tax Return	Fed Tax Benefit (Payment)		US$		-1960233.4	-2042937	-2127294	-2213339	-2301105
w/o GHG reduction	Distributable Cash		US$		10487212.75	10863138	11246581	11637694	12036628
	Net Cash Flow			-23655913.98	8526979.349	8820201	9119287	9424354	9735523
					2015	2016	2017	2018	2019
	A/T Cash Flow			-23655913.98	8526979.349	8820201	9119287	9424354	9735523
	NPV	53905424.2		-23655913.98	7751799.408	7289422	6851455	6436961	6044994
	Payback Year	4		-23655913.98	-15904114.57	-8614692	-1763237	4673724	10718718
		IRR	38.94%		-63.95%	-18.31%	5.76%	18.67%	26.05%

2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
1.062782	1.073622	1.084573	1.095636	1.106811	1.118101	1.129506	1.141027	1.152665	1.164422
30624317	30936685	31252239	31571012	31893036	32218345	32546972	32878951	33214316	33553102
32929373	33265252	33604558	33947324	34293587	34643382	34996744	35353711	35714319	36078605
13256053	13521174	13791597	14067429	14348778	14635754	14928469	15227038	15531579	15842210
14253820	14538897	14829675	15126268	15428793	15737369	16052117	16373159	16700622	17034635
6043845	6164722	6288016	6413777	6542052	6672893	6806351	6942478	7081328	7222954
6498758	6628733	6761308	6896534	7034465	7175154	7318657	7465030	7614331	7766618
374608.7	374608.7	374608.7	374608.7	374608.7	374608.7	374608.7	374608.7	374608.7	374608.7
402805.1	402805.1	402805.1	402805.1	402805.1	402805.1	402805.1	402805.1	402805.1	402805.1
54084756	54835687	55598345	56372932	57159650	57958710	58770323	59594705	60432077	61282662
54084756	54835687	55598345	56372932	57159650	57958710	58770323	59594705	60432077	61282662
30624317	30936685	31252239	31571012	31893036	32218345	32546972	32878951	33214316	33553102
32929373	33265252	33604558	33947324	34293587	34643382	34996744	35353711	35714319	36078605
7699208	7699208	7699208	7699208	7699208	7699208	7699208	7699208	7699208	7699208
8278718	8278718	8278718	8278718	8278718	8278718	8278718	8278718	8278718	8278718
41208091	41543970	41883276	42226042	42572305	42922100	43275462	43632429	43993037	44357323
12876665	13291717	13715069	14146889	14587345	15036610	15494861	15962276	16439040	16925339
0.238083	0.242392	0.246681	0.250952	0.255204	0.259437	0.263651	0.267847	0.272025	0.276185
1577061	1577061	1577061	1577061	1577061	1577061	1577061	1577061	1577061	1577061
11299604	11714656	12138008	12569828	13010284	13459549	13917800	14385215	14861979	15348278
11299604	11714656	12138008	12569828	13010284	13459549	13917800	14385215	14861979	15348278
2485913	2577224	2670362	2765362	2862263	2961101	3061916	3164747	3269635	3376621
8813691	9137432	9467647	9804466	10148022	10498448	10855884	11220468	11592344	11971657
12876665	13291717	13715069	14146889	14587345	15036610	15494861	15962276	16439040	16925339
12876665	13291717	13715069	14146889	14587345	15036610	15494861	15962276	16439040	16925339
12876665	13291717	13715069	14146889	14587345	15036610	15494861	15962276	16439040	16925339

0.429315	0.452662	0.467217	0.476525	0.482587	0.486589	0.489256	0.491049	0.492262	0.493086
12443542	12858593	13281946	13713765	14154221	14603487	15061737	15529152	16005916	16492215
40.86%	43.28%	44.81%	45.79%	46.43%	46.86%	47.15%	47.35%	47.48%	47.57%
-2485913	-2577224	-2670362	-2765362	-2862263	-2961101	-3061916	-3164747	-3269635	-3376621
12876665	13291717	13715069	14146889	14587345	15036610	15494861	15962276	16439040	16925339
10390752	10714493	11044708	11381527	11725083	12075509	12432945	12797529	13169405	13548718
2020	2021	2022	2023	2024	2025	2026	2027	2028	2029
10390752	10714493	11044708	11381527	11725083	12075509	12432945	12797529	13169405	13548718
5865309	5498229	5152438	4826878	4520527	4232392	3961519	3706988	3467916	3243455
17864693	23362921	28515359	33342238	37862764	42095157	46056676	49763664	53231580	56475036
32.23%	34.97%	36.75%	37.94%	38.74%	39.30%	39.69%	39.96%	40.16%	40.30%
-2390626	-2481937	-2575075	-2670075	-2766975	-2865814	-2966629	-3069460	-3174348	-3281334
12443542	12858593	13281946	13713765	14154221	14603487	15061737	15529152	16005916	16492215
10052916	10376656	10706871	11043690	11387246	11737673	12095108	12459692	12831568	13210881
2020	2021	2022	2023	2024	2025	2026	2027	2028	2029
10052916	10376656	10706871	11043690	11387246	11737673	12095108	12459692	12831568	13210881
5674609	5324865	4994834	4683603	4390276	4113983	3853874	3609129	3378953	3162580
16393327	21718192	26713026	31396629	35786905	39900888	43754762	47363891	50742844	53905424
30.52%	33.35%	35.19%	36.43%	37.28%	37.86%	38.28%	38.57%	38.78%	38.94%

Appendix E Air emissions reduction

Emissions in tonnes	MGO	MeOH	Ratio	% reduction
CO2	42556.57056	40574.484	0.95	5
CH4	0.262335024	0.0393503	0.15	85
N2O	2.04038352	0.3060575	0.15	85
NOX	874.45008	24.484602	0.03	99.07
SO2	27.39943584	4.1099154	0.15	85
NH3	0.174890016	0.2535905	1.45	
PM 10	6.41263392	3.0926384	0.48	52
NMVOC	33.81206976	5.0718105	0.15	85
CO	75.7856736	11.367851	0.15	85

Appendix F Nine principles for MBM

The Experts‟ analysis of the proposed MBM should be based on following principles.

(1) ‘effective in contributing to the reduction of total global greenhouse gas emissions;

(2) binding and equally applicable to all flag States in order to avoid evasion;

(3) cost-effective;

(4) able to limit, or at least, effectively minimize competitive distortion;

(5) based on sustainable environmental development without penalizing global trade and growth;

(6) based on goal-based approach and not prescribe specific methods;

(7) supportive of promoting and facilitating technical innovation and R&D in the entire shipping sector;

(8) accommodating to leading technologies in the field of energy efficiency; and

(9) practical, transparent, fraud-free and easy to administer

Appendix G Nine criteria for MBM

The Experts" analysis of the proposed MBM should address the following nine criteria:

1 Environmental effectiveness.

2 Cost-effectiveness and potential impact on trade and sustainable development.

3 The potential to provide incentives to technological change and innovation.

4 The practical feasibility of implementing MBM.

5 The need for technology transfer to and capacity building within developing countries, in particular, the least developed countries (LDCs) and the small island development states (SIDS) Introduction to the MBM.

6 The relation with other relevant Conventions (UNFCCC, Kyoto Protocol, and WTO) and the compatibility with customary international law.

7 The potential additional administrative burden and the legal aspects for National Administrations to implement and enforce MBM.

8 The potential additional workload, economic burden and operational impact for individual ships, the shipping industry and the maritime sector as a whole, of implementing MBM.

9 The compatibility with the existing enforcement and control provisions under the IMO Legal framework

Appendix H Areas consider for Health Cost Analysis

Region/ SNAP	Emission year	Emission scenario (or the "tag")
All/15	2000	Int. ship traffic for the year 2000 (S = 2.7 %)∗ whole model domain (EMEP = 2000)
All/15	2007	Int. ship traffic for the year 2007, NoS/BaS: S = 1.5 %∗, whole domain (EMEP = 2006)
All/15	2011	Int. ship traffic for the year 2011, NoS/BaS: S = 1.0 %∗, whole domain (EMEP = 2006)
All/15	2020	Int. ship traffic for the year 2020, NoS/BaS: S = 0.1 %∗, whole model domain (NEC-II)
BaS-NoS/15	2000	Int. ship traffic for the year 2000 (S = 2.7 %)∗ whole model domain (EMEP = 2000)
BaS-NoS/15	2007	Int. ship traffic for the year 2007, NoS/BaS: S = 1.5 %∗, whole domain (EMEP = 2006)
BaS-NoS/15	2011	Int. ship traffic for the year 2011, NoS/BaS: S = 1.0 %∗, whole domain (EMEP = 2006)
BaS-NoS/15	2020	Int. ship traffic for the year 2020, NoS/BaS: S = 0.1 %∗, whole model domain (NEC-II)
All/all	2000	All emissions (anthropogenic; GEIA/EDGAR; EMEP 2000 + natural; international ship traffic as All/15 for the year 2000)
All/all	2007	All emissions (anthropogenic; GEIA/EDGAR; EMEP 2006 + natural; international ship traffic as All/15 for the year 2007)
All/all	2011	All emissions (anthropogenic: GEIA/EDGAR, EMEP 2006 + natural; international ship traffic as All/15 for the year 2011)
All/all	2020	All emissions (anthropogenic: GEIA/EDGAR; NEC-II + natural; international ship traffic as All/15 for the year 2020)

Appendix I: Data for Sensitivity Analysis

Summary of Assumptions						
	CO2	**O&M**	**Capex**	**Project Fuel**	**Displaced Fuel**	**15 Yr Aft Tax**
Status	**euro per ton**	**Euros**	**Euros**	**euro /mmbtu**	**euro/mmbtu**	
Mean	**126.85**		**22000000.00**	**8.85**	**12.55**	**40.81 %**
Std Dev.	**18.07**		**2327588.93**	**2.81**	**1.91**	**21.15 %**
Min	**50.00**		**15000000.00**	**5.00**	**5.00**	**62.99 %**
Max	**150.00**		**25000000.00**	**15.00**	**15.00**	**8.10%**
Iterations						**15 Yr Aft Tax**
1	147.96	29109154	19345515	12.42	13.69	33.80 %
2	140.07	29109154	20492838	7.81	9.24	46.45 %
3	118.27	29109154	20467291	7.90	10.87	45.99 %
4	123.62	29109154	17642115	13.75	9.04	31.68 %
5	110.10	29109154	24922208	6.75	8.37	41.25 %
6	140.69	29109154	22861729	10.84	13.57	33.38 %
7	135.72	29109154	20309722	7.24	12.60	48.61 %
8	121.64	29109154	17427336	8.87	11.69	49.84 %
9	140.09	29109154	22865536	9.54	12.20	37.04 %
10	129.79	29109154	20138393	7.20	12.52	49.08 %
11	117.25	29109154	21840014	7.88	14.73	43.34 %
12	126.06	29109154	19996645	9.70	10.11	41.26 %
13	101.49	29109154	24017684	11.38	13.34	30.09 %

14	111.74	29109154	20711903	7.51	12.28	46.64 %
15	142.49	29109154	19809427	9.88	13.63	41.23 %
16	126.97	29109154	24132998	10.73	12.59	31.93 %
17	93.03	29109154	23497837	10.54	13.09	32.93 %
18	146.40	29109154	18839718	8.33	12.73	48.53 %
19	114.93	29109154	22801376	11.66	11.90	30.89 %
20	141.22	29109154	20252225	10.78	14.31	37.54 %
21	104.13	29109154	21887654	9.70	13.00	37.76 %
22	138.69	29109154	23295941	12.76	12.11	27.45 %
23	116.98	29109154	22082024	8.24	12.34	41.85 %
24	141.23	29109154	21154833	5.93	13.54	50.90 %
25	118.10	29109154	21345897	9.88	11.72	38.24 %
26	104.05	29109154	23277812	11.45	13.20	30.81 %
27	115.63	29109154	20355170	7.75	10.44	46.67 %
28	147.89	29109154	17307533	8.22	12.88	52.93 %
29	133.67	29109154	23211960	11.93	14.51	29.81 %
30	108.12	29109154	21528455	7.06	11.08	46.32 %
31	130.22	29109154	23619829	10.12	13.41	34.27 %
32	139.43	29109154	17409348	5.42	14.71	62.99 %
33	125.56	29109154	20188068	10.88	12.32	37.15 %
34	119.81	29109154	22429721	12.02	12.61	30.37 %
35	113.57	29109154	21701426	11.82	14.97	31.85 %
36	135.08	29109154	22354511	8.40	13.31	41.09 %
37	108.30	29109154	19496661	12.65	14.35	32.37 %

38	102.37	29109154	20240485	6.87	11.81	49.58 %
39	114.36	29109154	24270470	8.25	9.52	38.28 %
40	135.11	29109154	19332929	13.63	13.97	29.69 %
41	108.08	29109154	23468013	8.81	13.06	37.89 %
42	117.74	29109154	22219755	8.96	12.62	39.53 %
43	138.23	29109154	22457213	11.14	11.87	33.05 %
44	136.63	29109154	21762382	7.41	11.17	45.08 %
45	95.97	29109154	15976572	8.10	10.02	56.78 %
46	118.96	29109154	24000652	7.02	12.92	42.06 %
47	137.36	29109154	24055840	10.01	13.45	34.07 %
48	104.67	29109154	23848622	9.19	14.37	36.27 %
49	125.87	29109154	21921456	7.21	12.00	45.27 %
50	141.93	29109154	24015651	10.60	9.01	32.56 %
51	102.45	29109154	21991960	6.65	10.62	46.56 %
52	114.47	29109154	23126193	12.82	12.53	27.26 %
53	105.84	29109154	22768919	9.75	8.82	36.28 %
54	145.51	29109154	23528244	9.92	10.15	35.09 %
55	123.15	29109154	24555017	11.87	12.62	28.36 %
56	139.40	29109154	18926200	11.49	12.94	37.51 %
57	149.00	29109154	24386968	6.12	12.30	44.13 %
58	130.27	29109154	20074838	8.71	13.03	44.34 %
59	102.70	29109154	16720256	6.90	7.00	59.18 %
60	97.60	29109154	24504783	10.75	12.96	31.17 %
61	114.53	29109154	23217283	6.53	12.79	44.73 %

62	132.70	29109154	20727864	9.89	12.60	39.41 %
63	102.31	29109154	17098613	10.14	9.15	45.72 %
64	147.89	29109154	23742837	7.20	14.76	42.26 %
65	135.27	29109154	23034342	12.87	10.70	27.40 %
66	121.11	29109154	19315709	6.40	13.75	53.59 %
67	142.60	29109154	23012955	7.25	12.73	43.33 %
68	123.11	29109154	18036552	11.12	11.90	40.32 %
69	106.88	29109154	22150017	10.34	14.22	35.49 %
70	127.65	29109154	21977098	10.19	12.27	36.41 %
71	107.89	29109154	20626229	9.41	11.48	40.84 %
72	115.47	29109154	20112687	6.33	12.65	51.79 %
73	134.44	29109154	20528435	8.25	14.35	44.93 %
74	110.09	29109154	24040883	9.24	11.69	35.92 %
75	110.12	29109154	22371819	7.20	12.32	44.31 %
76	108.94	29109154	23784393	8.05	10.22	39.51 %
77	125.53	29109154	20327270	5.26	10.85	54.83 %
78	127.43	29109154	20440765	11.42	12.52	35.07 %
79	138.91	29109154	20556967	5.79	11.38	52.69 %
80	130.46	29109154	23398239	8.84	11.12	38.11 %
81	144.90	29109154	23910080	14.84	11.81	21.15 %
82	123.52	29109154	24638233	6.32	11.23	42.93 %
83	115.00	29109154	18736268	10.47	12.13	41.06 %
84	136.10	29109154	19880313	8.19	13.11	46.49 %
85	127.73	29109154	22983647	7.75	14.85	41.82 %

86	135.85	29109154	21720637	7.58	10.71	44.65 %
87	124.05	29109154	23032811	9.07	11.01	37.96 %
88	130.80	29109154	22969847	8.90	13.54	38.62 %
89	106.68	29109154	20389966	7.75	13.31	46.50 %
90	100.59	29109154	20351037	6.06	9.79	51.90 %
91	126.23	29109154	20260888	10.86	14.29	37.10 %
92	146.06	29109154	22404094	9.84	13.83	36.96 %
93	133.90	29109154	23007952	5.75	10.37	47.50 %
94	108.61	29109154	21922412	12.94	11.25	28.22 %
95	128.88	29109154	20879619	10.42	11.74	37.47 %
96	112.34	29109154	23815134	6.08	13.44	44.87 %
97	119.77	29109154	19310769	5.73	8.84	55.85 %
98	140.35	29109154	23208858	5.46	11.10	47.97 %
99	83.23	29109154	23575440	12.98	10.20	26.02 %
100	131.83	29109154	21592277	10.28	13.27	36.76 %
101	138.43	29109154	18287236	7.57	7.34	52.46 %
102	132.75	29109154	21759869	11.10	12.65	34.10 %
103	131.46	29109154	20173664	10.64	11.30	38.00 %
104	149.26	29109154	19006118	9.54	10.59	44.07 %
105	137.39	29109154	20391461	6.29	11.43	51.49 %
106	110.41	29109154	22732276	9.63	14.14	36.71 %
107	126.29	29109154	22542404	13.18	11.86	26.99 %
108	122.71	29109154	20499516	12.26	14.35	32.30 %
109	100.13	29109154	22127663	8.51	10.93	40.82 %

110	121.17	29109154	17374195	6.72	10.47	58.00 %
111	94.05	29109154	24546325	8.95	10.01	35.85 %
112	87.27	29109154	22446736	9.62	12.79	36.96 %
113	97.29	29109154	20440372	8.68	12.62	43.36 %
114	136.34	29109154	24559223	8.18	10.19	38.26 %
115	136.82	29109154	23311689	8.61	11.84	38.97 %
116	121.03	29109154	23255221	6.71	14.33	44.22 %
117	126.74	29109154	20283683	6.55	12.27	50.79 %
118	110.29	29109154	24123403	11.07	11.80	30.87 %
119	139.07	29109154	24948371	8.16	14.82	37.76 %
120	149.06	29109154	20198217	5.44	10.73	54.82 %
121	138.76	29109154	20753936	11.59	11.69	34.15 %
122	125.37	29109154	21366891	10.29	11.12	37.04 %
123	132.42	29109154	23491607	8.26	12.42	39.59 %
124	125.61	29109154	22969138	8.64	10.16	39.30 %
125	124.61	29109154	21094146	11.16	11.10	34.81 %
126	100.11	29109154	24134540	9.89	10.41	33.95 %
127	113.56	29109154	23646106	10.04	11.20	34.30 %
128	119.17	29109154	22091038	10.90	9.76	34.07 %
129	134.57	29109154	20797066	7.59	14.84	46.46 %
130	84.54	29109154	19826322	6.89	14.07	50.30 %
131	131.62	29109154	23488516	10.84	14.56	32.47 %
132	141.23	29109154	20720547	8.07	10.95	45.17 %
133	112.50	29109154	17690119	8.52	11.27	50.34 %

134	131.92	29109154	21726595	9.59	14.16	38.61 %
135	111.67	29109154	20207042	13.22	10.39	29.55 %
136	124.92	29109154	21095363	5.74	6.18	51.45 %
137	92.24	29109154	23833856	6.82	11.26	42.63 %
138	143.72	29109154	20378391	10.75	11.97	37.45 %
139	137.65	29109154	24048757	5.78	14.87	45.52 %
140	121.60	29109154	24224611	5.47	10.07	45.91 %
141	130.68	29109154	15743628	9.14	11.12	53.78 %
142	112.53	29109154	20823261	7.39	10.86	46.80 %
143	145.70	29109154	18667279	6.46	10.47	55.43 %
144	119.50	29109154	24289404	8.61	12.27	37.35 %
145	121.43	29109154	22251948	11.29	13.62	32.75 %
146	103.38	29109154	18780602	8.01	13.29	49.26 %
147	128.73	29109154	20204857	11.33	10.01	35.73 %
148	116.07	29109154	18812343	7.07	14.50	52.57 %
149	130.17	29109154	22695301	9.44	12.93	37.52 %
150	120.13	29109154	21528763	14.58	11.11	23.90 %
151	107.97	29109154	18782996	5.39	13.70	58.39 %
152	113.40	29109154	21060043	11.41	10.92	34.00 %
153	124.94	29109154	22988833	10.74	12.06	33.34 %
154	109.74	29109154	21289598	5.47	8.76	51.68 %
155	122.17	29109154	22933489	10.14	12.14	35.09 %
156	113.55	29109154	21286767	5.03	13.51	53.07 %
157	106.71	29109154	23423803	5.58	12.94	46.92 %

158	138.10	29109154	21270576	6.93	11.80	47.53 %
159	123.45	29109154	21254840	10.67	13.46	36.03 %
160	134.57	29109154	21934490	5.89	12.45	49.24 %
161	127.11	29109154	22237225	9.01	11.16	39.42 %
162	137.97	29109154	18769567	6.30	11.86	55.62 %
163	130.95	29109154	18087209	12.79	12.59	34.44 %
164	117.60	29109154	22993279	9.28	11.54	37.38 %
165	126.11	29109154	21557869	11.83	13.14	32.15 %
166	139.82	29109154	20089730	10.41	12.01	38.98 %
167	137.04	29109154	24374367	9.33	13.72	35.45 %
168	111.51	29109154	19284086	11.27	9.83	37.29 %
169	113.53	29109154	18251461	6.18	13.82	57.22 %
170	109.85	29109154	22696289	9.21	13.25	37.97 %
171	132.78	29109154	18583676	14.89	11.01	26.44 %
172	130.37	29109154	22187647	13.01	13.20	27.92 %
173	140.28	29109154	24019203	11.04	11.53	31.35 %
174	121.06	29109154	21820516	9.81	12.46	37.71 %
175	145.65	29109154	19923912	7.31	11.69	49.36 %
176	104.53	29109154	20770261	9.20	8.53	41.17 %
177	148.75	29109154	22885276	10.28	11.31	35.03 %
178	122.32	29109154	22931422	7.17	11.13	43.49 %
179	133.74	29109154	19276716	6.40	12.32	53.84 %
180	124.15	29109154	22621162	8.19	9.42	41.13 %
181	108.78	29109154	19681861	12.01	12.74	34.18 %

182	118.44	29109154	17969194	7.90	14.60	51.88 %
183	109.26	29109154	21099854	6.19	12.64	49.89 %
184	113.37	29109154	20696616	6.76	10.73	49.05 %
185	135.47	29109154	22711531	7.56	14.61	42.89 %
186	139.05	29109154	20551635	5.07	13.52	55.00 %
187	104.35	29109154	24708804	8.62	10.80	36.60 %
188	94.99	29109154	19638051	10.02	13.94	40.57 %
189	89.18	29109154	20413368	9.13	12.39	41.91 %
190	124.75	29109154	22104018	8.42	13.97	41.36 %
191	109.88	29109154	23276327	9.20	10.25	37.10 %
192	117.57	29109154	20625044	6.17	13.78	51.11 %
193	112.97	29109154	21327422	8.91	14.62	41.16 %
194	109.83	29109154	23666252	7.23	11.99	41.95 %
195	116.64	29109154	21352577	7.67	13.31	44.90 %
196	122.88	29109154	21650097	5.88	13.08	49.77 %
197	134.55	29109154	22521908	6.86	14.69	45.25 %
198	101.83	29109154	22748799	9.74	10.84	36.29 %
199	128.01	29109154	21266768	8.08	9.86	43.94 %
200	126.90	29109154	23347897	11.30	13.84	31.35 %
201	95.42	29109154	23745250	7.45	10.90	41.10 %
202	73.04	29109154	21256192	7.43	9.29	45.37 %
203	109.57	29109154	21958826	11.74	12.54	31.70 %
204	144.33	29109154	20595222	9.24	10.00	41.80 %
205	140.45	29109154	22236040	10.60	14.69	34.96 %

206	139.59	29109154	24746612	6.85	9.41	41.52 %
207	111.08	29109154	21819485	6.66	10.67	46.95 %
208	112.08	29109154	20765327	7.32	13.49	47.11 %
209	141.93	29109154	20606152	7.86	13.74	46.07 %
210	108.59	29109154	20185385	9.53	12.72	41.27 %
211	110.47	29109154	23753961	9.50	14.15	35.60 %
212	149.25	29109154	21443533	10.05	13.63	37.88 %
213	130.63	29109154	21788884	11.11	13.01	34.01 %
214	140.04	29109154	23001947	6.09	14.03	46.60 %
215	129.11	29109154	22371136	12.19	14.96	30.07 %
216	127.57	29109154	24610948	13.81	11.53	23.17 %
217	132.02	29109154	23413698	12.06	14.99	29.21 %
218	132.63	29109154	21834590	9.17	12.19	39.69 %
219	134.88	29109154	23314152	12.97	10.92	26.83 %
220	145.05	29109154	22907921	12.30	14.63	29.26 %
221	130.32	29109154	21899544	11.19	10.85	33.61 %
222	136.62	29109154	17540004	9.67	13.20	46.81 %
223	128.24	29109154	21646180	5.13	10.98	52.11 %
224	124.18	29109154	20443478	6.59	11.81	50.26 %
225	118.71	29109154	22425830	9.15	10.62	38.63 %
226	123.81	29109154	19978349	7.58	10.38	48.12 %
227	142.09	29109154	21910925	8.98	13.02	40.23 %
228	127.46	29109154	20379634	11.21	11.72	35.81 %
229	143.52	29109154	17700008	9.13	9.15	48.45 %

230	109.67	29109154	24201854	12.07	10.32	28.09 %
231	93.52	29109154	23262268	6.72	14.92	43.89 %
232	121.31	29109154	22770077	13.13	11.45	26.81 %
233	106.78	29109154	24430297	10.63	12.36	31.64 %
234	96.67	29109154	20097576	8.13	12.54	45.79 %
235	104.89	29109154	23396935	13.55	13.87	24.82 %
236	144.61	29109154	20879274	5.86	12.83	51.78 %
237	129.09	29109154	18292163	9.13	13.92	46.82 %
238	76.89	29109154	23554558	9.24	13.54	36.30 %
239	127.72	29109154	21944437	10.35	11.93	36.00 %
240	121.20	29109154	22045230	5.62	12.34	49.69 %
241	113.39	29109154	21087590	7.89	10.32	44.73 %
242	132.03	29109154	20784841	8.40	11.92	43.94 %
243	138.05	29109154	22493812	12.63	11.09	28.74 %
244	131.26	29109154	15075113	7.81	11.15	61.69 %
245	113.22	29109154	18548585	9.39	9.84	45.14 %
246	112.94	29109154	20696004	7.32	13.02	47.28 %
247	137.12	29109154	23536265	7.26	12.50	42.35 %
248	126.27	29109154	21361101	7.63	11.16	45.09 %
249	117.43	29109154	23608896	10.29	9.21	33.71 %
250	130.56	29109154	21442633	9.05	12.83	40.69 %