UNIVERSITY OF KWAZULU-NATAL

CARBON EMISSIONS COMPLIANCE AND ITS IMPACT ON TRANSPORT COSTS

By

Mary Mitchelle Gounder

210554696

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School of Accounting, Economics and Finance

Unit of Maritime Law and Maritime Studies

Supervisor: Professor Trevor Jones

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I would like to thank my family for their continued support and encouragement during this process. To Prof Trevor Jones, thank you for your patience and understanding in this journey. A special dedication to my dad, Varda Gounder (1939-2017), who inspired me to forge my own path in life.

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ACRONYMS AND ABBREVIATIONS

CO	Carbon Monoxide
CO_2	Carbon Dioxide
ECA	Emission Control Area
GHG	Greenhouse Gas
HFO	Heavy Fuel Oil
IMO	International Maritime Organisation
IPCC	Intergovernmental Panel on Climate Change
ISPS	International Ship and Port Facility Security Code
MARINTEK	Norwegian Marine Technology Research Institute
MARPOL	International Convention for the Prevention of Pollution from Ships
MDO	Marine Diesel Oil
MEPC	Marine Environment Protection Committee
MGO	Marine Gas Oil
NO_x	Nitrogen Oxides
PSC	Port State Control
SEMP	Ship Efficiency Management Plan
SO_x	Sulphur Oxides
TEU	Twenty Foot Equivalent Unit
UNCTAD	United Nations Conference on Trade and Development
UNEP	United Nations Environment Programme
UNFCC	United Nations Framework Convention on Climate Change

GLOSSARY OF TERMS

Distillate: Any product obtained by distilling petroleum and condensing the vapours.

Exhaust Emissions: Any substance which, if introduced into the sea atmosphere, is liable to create hazards to human health, ecosystems, or marine life.

Fuel Viscosity: A measure of resistance of the fuel to flow at a stated temperature. According to ISO, the kinematic viscosity of heavy fuels.

Hull: The structural body of a ship, including shell plating, framing, decks, bulkheads, etc.

International Shipping: Shipping between ports of different countries, as opposed to domestic shipping. International shipping excludes military and fishing vessels.

Propeller: A revolving screw-like device that drives the ship.

ABSTRACT

The United Nations has increased its focus on environment issues that have been contributing to climate change. After the formation of the United Nations Framework Convention on Climate Change in 1994, the International Maritime Organisation (IMO) was tasked with emission reduction in ships. The Marine Environmental Protection Committee (MEPC), which is a committee within the IMO, commenced with its focus on Greenhouse Gas (GHG) Emissions at its 39th session. The MEPC commissioned studies on greenhouse gas emissions from ships. The MEPC also prepared the draft Annex VI which contained regulations for control of air pollution from ships. MARPOL Annex VI entered into force in 2005. The regulations provided specifications for the reduction of Sulphur emissions and Nitrogen emissions with deadlines for Emission Control Areas (ECAs) as well as globally. The ECA regulations for sulphur reduction have been in place since 1 January 2016.These regulations have put ship owners under immense pressure to comply. If there is non-compliance, the ship owners either receive a fine or their ships are detained. Considerable costs are involved in reducing sulphur emissions, as ship owners either build new ships or retrofit old ships with new exhaust cleaning systems or with modifications to their propulsion machinery. As this study will show the costs have not, so far, been passed on to the end user, as freight rates have not increased based on the compliance costs. The freight rates within the shipping industry are purely based on demand/supply factors. If costs are passed on to customers, then these additional costs are likely to impact on the spectrum of freight rates faced by transport users in both bulk and general cargo markets. This would be similar to the Carrier Security charge that shipping lines implemented after the International Ship and Port Facility Security (ISPS) Code came into force in 2004.

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CHAPTER ONE

INTRODUCTION

1.1 Background and Context

Since the 1960s and 1970s, there has been evidence of increasing concentrations of carbon dioxide in the atmosphere (Buhaug, 2009). However, it was not until 1988 that the Intergovernmental Panel on Climate Change (IPCC) was created, issuing the First Assessment Report in 1990, stating that global warming was real, and urging that the matter be addressed (IPCC, 1990). These findings spurred governments to create the United Nations Framework Convention on Climate Change, which was ready for signature in 1992.

It was the adoption of the Kyoto Protocol that featured binding targets for industrialised countries and the European Community for reducing greenhouse gas (GHG) emissions which marked the turning point. The Protocol, which entered into force on 16 February 2005, contains provisions for reducing GHG emissions from shipping (UNFCC, 1997). Due to the global nature of the industry, the Protocol has tasked the emission reduction in shipping to the International Maritime Organisation (IMO). Due to the fact that the ratification of the International Convention for the Prevention of Pollution from Ships (MARPOL) of 1973 covers the prevention of pollution of the marine environment by ships, the IMO has made considerable progress with addressing the pollution from ships. The MARPOL convention was amended and adopted Annex VI, which regulated air pollution from ships in May 2005 (IMO, 2006). This resolution invited the Marine Environment Protection Committee (MEPC) to consider feasible reduction strategies for CO_2 as well as for other atmospheric and marine pollutants. The IMO, in cooperation with the United Nations Framework Convention on Climate Change (UNFCCC) undertook a study of emissions from ships as part of the global inventory of emissions (UNFCC, 1997).

In 2000, the first IMO GHG Study on GHG emissions from ships was published, which estimated that ships engaged in international trade in 1996 contributed about 1.8% of the world total CO_2 emissions (IMO, 2000). In 2003, the IMO Assembly adopted resolution A.963(23) on IMO Policies and practices related to the reduction of greenhouse gas emissions from ships, which urged MEPC to identify and develop the mechanism(s) needed to achieve the limitation or reduction of GHG emissions from international shipping (IMO: 2000).

According to the Second IMO GHG Study in 2009, the CO_2 emissions from ships have been steadily increasing from 562 million tonnes in 1990, to 1,050 million tonnes in 2007. Shipping contributes up to 3.3% of the of the global carbon emissions (IMO, 2009a). “The emissions of CO_2 from shipping leads to positive ‘radiative forcing’ (a metric of climate change) and to long-lasting global warming. In the shorter term, the global mean radiative forcing from shipping is negative, and implies cooling; however, regional temperature responses and other manifestations of climate change may nevertheless occur. In the longer term, emissions from shipping will result in a warming response as the long-lasting effect of CO_2 will overwhelm any shorter-term cooling effects.” (IMO: 2009)

The Third IMO GHG Study was recently published in 2014, stating that the future expectation for emissions is an increase between 50% and 250% in the period from 2012 to 2050. This is due, in particular, to the projected increase of the demand for the transportation of unitised cargo (IMO, 2014).

1.2 Scope of the Proposed Research Work

Within this context, the scope of the proposed research work will investigate the following questions:

What changes can be made to vessel design in the shipbuilding industry to reduce carbon emissions and what are the cost implications of these changes?

The study considers specific changes that can be made while ships are in the design and building stage such as the Energy Efficient Design Index (EEDI) for new ships and the Ship Energy Efficiency Management Plan (SEEMP) (IMO, 2009b).

The IMO GHG Study has categorised options for reducing carbon emissions as follows: improving energy efficiency, using renewable energy sources (e.g. wind and sun), using fuels with less total fuel-cycle emissions per unit of work done (biofuels and natural gas) and using emission-reduction technologies (IMO, 2009a).

What regulations have been proposed or are in place to reduce the carbon emissions in the shipping industry?

Some of the principal regulatory instruments that will be interrogated in the course of the research are:

- Regulation 12 of MARPOL Annex VI prohibits emissions of ozone-depleting substances as well as the prohibition of new installations that use ozone-depleting substances (IMO, 2006).
- Regulation 13 of MARPOL Annex VI addresses Nitrogen Oxide emissions (IMO, 2006).
- Regulation 14 of MARPOL Annex VI addresses Sulphur Emissions which is capped globally at 4.5% and in SO_X Emission Control Areas (SECA), the sulphur content of fuel oil used on board ships must not exceed 1.50% by mass. This was further reduced in SECA to 1.0% and as of 1 January 2015, where the sulphur content should not exceed 0.10% (IMO, 2006).
- Regulation 15 of MARPOL Annex VI addresses emissions of Volatile Organic Compounds (VOCs). This regulation deals with ports and terminals that are under the jurisdiction of parties to the annex and should regulate emissions of VOCs from tanker loading (IMO, 2006).

Are the costs of reducing carbon emissions being absorbed by the shipping companies or are the costs passed on to customers as additional freight charges or as special surcharges?

Shipping companies are required to find solutions to reducing their carbon emissions using the categories of options from the IMO. However, the costs associated with the changes need to be analysed, as each shipping company may use a different option, whether it be using different types of fuel, scrubbers, etc. To ascertain whether the costs are being passed on to customers, shipping line tariffs are accessed. Costs may be passed on as additional freight or as a standalone surcharge.

1.3 Study Overview

This study has seven chapters. Chapter One describes the background, scope and the study overview. Chapter Two provides the literature overview which will be a summary of the literature used to support the research. Chapter Three covers the description of the methodology used for the study. Chapter Four addresses some of the technical processes that can be incorporated into shipbuilding and post shipbuilding in the form of retro-fitted equipment to reduce emissions. Chapter Five will discuss the regulations that are currently in place or proposed to reduce emissions. Chapter Six covers the case studies of two major carrying lines (Maersk Line and Viking Line) to set out their respective approaches to reducing their emissions. Chapter Seven provides an analysis of the impact of the regulations on the shipping industry and effects that they may have on the shippers.

CHAPTER TWO

LITERATURE REVIEW

The aim of this chapter is to provide more details on the regulations, the organisations that are involved in developing the regulations to which the global shipping industry need to adhere, as well as the studies and conventions that form the basis for these regulations. It is important to take cognisance of the fact that shipping companies are based in various countries, and within those countries there are various legislative practices. So, organisations such as the IMO, which forms part of the UN, play an important role in developing regulations that diverse nations need to follow for a common goal.

The literature review is confined to an interrogation of relevant agencies, conventions and sessions hosted by the organisations that will be reviewed in this chapter.

2.1 Organisations and Agencies

2.1.1 United Nations

The United Nations is an international organisation founded in 1945. It is currently made up of 193 Member States. The mission and work of the United Nations are guided by the purposes and principles contained in its founding Charter. Each of the 193 Member States of the United Nations is a member of the General Assembly. States are admitted to membership in the UN by a decision of the General Assembly upon the recommendation of the Security Council. The main organs of the UN are the General Assembly, the Security Council, the Economic and Social Council, the Trusteeship Council, the International Court of Justice, and the UN Secretariat. All were established in 1945 when the UN was founded. The UN system, also known unofficially as the "UN family", is made up of the UN itself and many affiliated programmes, funds, and specialised agencies; all with their own membership, leadership, and budget. The programmes and funds are financed through voluntary rather than assessed contributions. The Specialised Agencies are independent international organisations funded by both voluntary and assessed contributions.

2.1.2 International Maritime Organisation

The International Maritime Organisation (IMO) is a specialised agency within the United Nations. The IMO has created a comprehensive shipping regulatory framework, addressing safety and environmental concerns, legal matters, technical cooperation, security, and efficiency. Its main role is to create a regulatory framework for the shipping industry that is fair and effective, universally adopted and universally implemented. Its role is to create a level playing-field so that ship operators are obliged not to compromise on safety, security, and environmental performance. This approach also encourages innovation and efficiency (IMO, 2016).

The IMO measures cover all aspects of international shipping – including ship design, construction, equipment, manning, operation and disposal – to ensure that this vital sector remains safe, environmentally sound, energy efficient, and secure. The Organisation's Member States, civil society and the shipping industry work together to ensure a continued and strengthened contribution towards a green economy and growth in a sustainable manner. The promotion of sustainable shipping and sustainable maritime development is one of the major priorities of the IMO in the coming years (IMO, 2016).

2.1.3 The Marine Environment Protection Committee (MEPC)

The MEPC is a committee within the IMO structures and consists of all Member States. It is empowered to consider any matter within the scope of the Organisation concerned with prevention and control of pollution from ships. Its main focus is the amendment and adoption of conventions and other regulations and ensuring that measures are implemented to ensure their enforcement.

The Maritime Safety Committee (MSC) and MEPC are assisted in their work by a number of sub-committees, which are also open to all Member States:

- Sub-Committee on Human Element, Training and Watch keeping (HTW);
- Sub-Committee on Implementation of IMO Instruments (III);
- Sub-Committee on Navigation, Communications and Search and Rescue (NCSR);
- Sub-Committee on Pollution Prevention and Response (PPR);
- Sub-Committee on Ship Design and Construction (SDC);
- Sub-Committee on Ship Systems and Equipment (SSE); and
- Sub-Committee on Carriage of Cargoes and Containers (CCC).

The meetings that the MEPC conducts have been the catalyst for the studies and changes within the MARPOL Annexures. The detailed Table 1 in Chapter 3, below, highlights all the updates from the meetings where greenhouse gases have been addressed and the progress made thus far with the regulations (IMO, 2016).

2.2 Conventions and Regulatory Instruments

A Convention is an agreement between states or nations, which resembles a treaty: ordinarily applied to agreements prior to an execution of an official treaty or which serve as its foundation; or to international agreements for the regulation of international affairs of common interest not within the ambit of commercial transactions or politics (Bouvier, 2008).

The regulations that govern GHG emissions within the maritime industry are based on a foundation of various international conventions. The review of the conventions begins with the United Nations Framework Convention on Climate Change (UNFCCC) which focused on the stabilisation of the GHG concentrations in the atmosphere. The Kyoto Protocol, which is linked to the UNFCCC, recognised that developed countries are principally responsible for the high GHG emission levels. The Kyoto Protocol was followed by the Paris Agreement in 2016. During this time, the MARPOL convention has been updated following several studies and discussions that have been conducted.

2.2.1 United Nations Framework Convention on Climate Change

The ultimate objective of this Convention, and any related legal instruments that the Conference of the Parties may adopt, is to achieve, in accordance with the relevant provisions of the Convention, the stabilisation of greenhouse gas concentrations in the atmosphere to a level that would prevent dangerous anthropogenic interference with the climate system (UN, 1992). Such a level should be achieved within a time frame sufficient to allow ecosystems to adapt naturally to climate change, to ensure that food production is not threatened, and to enable economic development to proceed in a sustainable manner.

The UNFCCC entered into force on 21 March 1994. The 197 countries that have ratified the Convention are called Parties to the Convention. Preventing “dangerous” human interference with the climate system is the ultimate aim of the UNFCCC (UN, 1992).

2.2.2 Kyoto Protocol

The Kyoto Protocol is an international agreement linked to the United Nations Framework Convention on Climate Change, which commits its Parties to setting internationally binding emission reduction targets.

Recognising that developed countries are principally responsible for the current high levels of GHG emissions in the atmosphere as a result of more than 150 years of industrial activity, the Protocol places a heavier burden on developed nations under the principle of common but differentiated responsibilities. The Kyoto Protocol was adopted in Kyoto, Japan, on 11 December 1997 and entered into force on 16 February 2005 (UNFCC, 1997).

2.2.3 Paris Agreement

On 5 October 2016, the threshold for entry into force of the Paris Agreement was achieved. The Paris Agreement entered into force on 4 November 2016. The first session of the Conference of the Parties serving as the Meeting of the Parties to the Paris Agreement (CMA 1) took place in Marrakech, Morocco from 15-18 November 2016 (UN, 2015).

This aim of this Agreement was to strengthen the global response to the threat of climate change using the following means:

(a) Holding the increase in the global average temperature to well below 2°C above pre-industrial levels and pursuing efforts to limit the temperature increase to 1.5°C above pre-industrial levels, recognising that this would significantly reduce the risks and impacts of climate change;
(b) Increasing the ability to adapt to the adverse impacts of climate change and foster climate resilience and low greenhouse gas emissions development, in a manner that does not threaten food production.
(c) Making finance flows consistent with a pathway towards low greenhouse gas emissions and climate-resilient development (UN, 2015)

2.2.4 International Convention for the Prevention of Pollution from Ships (MARPOL)

Adoption: 1973 (Convention), 1978 (1978 Protocol), 1997 (Protocol - Annex VI); Entry into force: 2 October 1983 (Annexes I and II).

"The International Convention for the Prevention of Pollution from Ships (MARPOL) is the main international convention covering prevention of pollution of the marine environment by ships from operational or accidental causes. The MARPOL Convention was adopted on 2 November 1973 at the IMO. The Protocol of 1978 was adopted in response to a spate of tanker accidents in 1976 and 1977. As the 1973 MARPOL Convention had not yet entered into force, the 1978 MARPOL Protocol was absorbed into the parent Convention. The combined instrument entered into force on 2 October 1983. In 1997, a Protocol was adopted to amend the Convention, and a new Annex VI was added, which entered into force on 19 May 2005. MARPOL has been updated by amendments through the years. The Convention includes regulations aimed at preventing and minimising pollution from ships - both accidental pollution and that from routine operations - and currently includes six technical annexes." (IMO, 2006)

Annex I: Regulations for the Prevention of Pollution by Oil

Annex II: Regulations for the Control of Pollution by Noxious Liquid Substances in Bulk

Annex III: Prevention of Pollution by Harmful Substances Carried by Sea in Packaged Form

Annex IV: Prevention of Pollution by Sewage from Ships

Annex V: Prevention of Pollution by Garbage from Ships

Annex VI: Prevention of Air Pollution from Ships (entered into force 19 May 2005)

This study focuses on Annex VI which sets the limits on sulphur oxide (SO_x) and nitrogen oxide (NO_x) emissions from ship exhausts and prohibits deliberate emissions of ozone-depleting substances in designated emission control areas. A chapter adopted in 2011 covers mandatory technical and operational energy efficiency measures aimed at reducing greenhouse gas emissions from ships. More details on the discussions conducted with regard to the regulating the industry with regard to Annex VI will be outlined in Chapter 3 (MEPC62, 2011).

2.3 Studies Conducted by IMO on GHG Emissions

During the MEPC sessions, a working group was instructed to conduct studies on the impact of the GHG emissions from ships (see Table 3.1. in Chapter 3) (MEPC42, 1998). The IMO GHG studies were published in the years 2000, 2009 and 2014, and were conducted to assess the contribution made by international shipping to climate change. Following the IMO GHG STUDY (2000), the Energy Efficiency Design Index (EEDI) and the Ship Energy Efficiency Management Plan (SEEMP) were developed to promote reductions in greenhouse gases through all stages of a ship's lifespan. Both these documents will be discussed further on in this chapter.

2.3.1 IMO GHG STUDY 2000

As a follow-up to the resolution at MEPC 43 (see Table 3.1. in Chapter 3), the IMO Study on Greenhouse Gas Emissions from Ships was completed and presented to MEPC 45 in June 2000 (MEPC45, 2000). "This study established that ships contributed 1.8% of the world's total CO_2 emissions (for 1996) and also states that there is no other mode of transport that has a better record, according to the transport work carried out. It also identified a number of areas in which there was considerable potential for the further reduction of CO_2 emissions from ships; such as optimisation of hull shape; hull maintenance; propeller design and maintenance; fuel choices; machinery monitoring; ship-routing considerations, including speed reduction and optimising vessel trim, engine performance, propeller pitch and rudder angles. The study cautioned, however, that if none of the measures are applied, the projected annual growth in fleet size could lead to an increase in fuel consumption of some 72 percent between the years 2000 and 2020." (IMO, 2000).

The IMO has been specifically requested to regulate the emissions from ships under the Kyoto Protocol of the UNFCCC (MEPC47, 2002).

2.3.2 IMO GHG STUDY 2009

It was estimated that international shipping emitted 870 million tonnes of CO_2 in 2007, no more than about 2.7% of the global total of that year (IMO, 2009a).The mid-range scenarios showed that by 2050, those emissions could grow by a factor of two to three if no regulations to stem them are enacted (IMO, 2009a).

2.3.3 IMO GHG STUDY 2014

According to estimates presented in the Third IMO GHG Study 2014, international shipping emitted 796 million tonnes of CO_2 in 2012, which accounted for no more than about 2.2% of the total emission volume for that year (IMO, 2014). In 2007 it was estimated that international shipping emitted 885 million tonnes of CO_2, approximately 2.8% of the global emissions of CO_2 for that year. In 2011, IMO adopted a suite of technical and operational measures, which together provide an energy efficiency framework for ships. These mandatory measures entered into force as a 'package' on 1 January 2013, under Annex VI of the International Convention for the Prevention of Pollution from Ships (the MARPOL Convention). These measures address ship types responsible for approximately 85% of CO_2 emissions from international shipping and, together, they represent the first-ever, mandatory global regime for CO_2 emission reduction in an entire industry sector (IMO, 2014). The mid-range forecasted scenarios presented in the Third IMO GHG Study 2014 show that by 2050 CO_2 emissions from international shipping could grow by between 50% and 250%, depending on future economic growth and energy developments (IMO, 2014).

2.3.4 Energy Efficiency Design Index (EEDI)

The EEDI for new ships is the most important technical measure and aims at promoting the use of more energy-efficient (less polluting) equipment and engines. The EEDI was presented at MEPC 59 (MEPC59, 2009). The EEDI requires a minimum energy efficiency level per capacity mile (e.g. tonne mile) for different ship type and size segments. Since 1 January 2013, new ship design has needed to meet the reference level for each respective ship type (IMO, 2009b). The EEDI is expected to stimulate continued innovation and technical development of all the components influencing the fuel efficiency of a ship from its design phase. The EEDI provides guidelines on the use of emission reducing solutions during the design phase and operational phase of a ship, however, the choice of technologies used for a specific ship is left to the ship designers and builders (IMO, 2009b).

The CO_2 reduction level (grams of CO_2 per tonne mile) for the first phase is set to 10%, and will be tightened every five years to keep pace with technological developments of new efficiency and reduction measures (IMO, 2009b). Emission reduction rates have been established until the period 2025 and onwards and covers the following ship types: tankers, bulk carriers, gas carriers, general cargo ships, container ships, refrigerated cargo carriers, and combination carriers (IMO, 2009b). In 2014, the MEPC adopted amendments to the EEDI regulations to extend the scope of EEDI to: LNG carriers; ro-ro cargo ships (vehicle carriers); ro-ro cargo ships; ro-ro passenger ships; and cruise passenger ships with non-conventional propulsion (MEPC68, 2015). These ship types are responsible for approximately 85% of the CO_2 emissions from international (IMO, 2011).

2.3.5 Ship Energy Efficiency Management Plan (SEEMP) and Energy Efficiency Operational Indicator (EEOI)

The Ship Energy Efficiency Management Plan (SEEMP) was presented at MEPC 59 following the IMO GHG 2000 study (MEPC59, 2009). SEEMP is a guide that provides measures that can be implemented in the operational phase of a vessel to improve the energy efficiency of a ship. The SEEMP proposed the Energy Efficiency Operational Indicator (EEOI) as a monitoring tool enabling operators to measure the fuel efficiency of a ship in operation and to gauge the effect of any changes in operation, e.g. improved voyage planning or more frequent propeller cleaning, or introduction of technical measures such as waste heat recovery systems or a new propeller. The SEEMP urges the ship owner and operator to consider new technologies and practices when seeking to optimise the performance of a ship (IMO, 2009b).

2.4 Conclusion

The IMO has worked consistently, since being mandated by the Kyoto Protocol, towards studying and implementing regulations regarding GHG emissions from ships. The amendments and additions in the MARPOL convention focus on the regulatory aspect of reducing GHG emissions. And the EEDI, SEEMP and EEOI focuses on the operational aspects of implementing the new regulations such as the options available during the design, shipbuilding and operational phases of a vessel. The options will be discussed in detail in Chapter 4 and the regulatory framework specific to reducing GHG emissions will be discussed in Chapter 5.

CHAPTER THREE

METHODOLOGY

This study surveys the documents from all the Marine Environmental Protection Committee (MEPC) sessions from 1997 to 2016. The MEPC, which forms a part of the IMO, meets every nine months and discusses various topics related to pollution to which international shipping contributes. These topics include, but are not limited to, sewage, pollution prevention, ship design, phase out of single hull tankers, etc. For the purposes of this research, the principal focus of which is greenhouse gas (GHG) emissions, a detailed chronology of the deliberations and discussions of the MEPC in the context of greenhouse gas emissions, is set out in tabular form below. These meetings and discussions have led to the three IMO GHG studies (discussed in Chapter 2) and the Energy Efficiency Design Index, as well as the Ship Energy Efficiency Management Plan (SEEMP) documents. Furthermore, a range of regulations have been developed and legislated. This unfolding activity of the MEPC, and its resultant regulatory instruments, are viewed to be of central importance in this research study, and a detailed interrogation of these processes consequently provides the methodological underpinnings of the research.

3.1. A Detailed Chronology of MEPC Discussions and Regulatory Processes

The purpose of including a chronological review of the MEPC sessions in this study is to highlight the role that the MEPC has played in ensuring that the relevant regulations, studies, measures and solutions are discussed and implemented.

Table 1 A detailed chronology of MEPC discussions, Source: This study

Session	Date	Progress on GHG Emissions
39th	10 to 14 March 1997	During this meeting, the Committee prepared a draft Annex VI, one chapter of which contains Regulations for Control of Air Pollution covering ozone depleting substances, volatile organic compounds and shipboard incineration and the most controversy surrounded the sulphur content of fuel used on board ships. It was proposed that the sulphur content of fuels on boards should not exceed 5% and requirements in the Sulphur Emission Control Areas such as the Baltic would be limited to 1.5%. (MEPC39, 1997)
40th	18 to 25 September 1997	The focus of this meeting was on toxic antifouling paints and not on air pollution. (MEPC40, 1997)
41st	30 March to 3 April 1998	The focus of this meeting was on toxic antifouling paints and not on air pollution. (MEPC41, 1998)
42nd	2 to 6 November 1998	**Programmes to monitor air pollution from ships agreed** The guidelines set out a formula for calculating the yearly average sulphur content, based on sampling and testing of residual fuel.

		The aim of the monitoring programme is to ensure action can be taken if the average sulphur content is seen to be rising. **Greenhouse gases study agreed** The principal purpose of the study would be to examine greenhouse gas emissions reductions possible through different technical, operational, and market-based approaches. Specific pollutants to be studied include carbon dioxide, nitrogen oxide, particulate matter, and hydrocarbons. **Interim guidelines on NO_x technical code approved** The MEPC approved an MEPC Circular on Interim Guidelines for the application of the NO_x technical Code (MEPC42, 1998).
43rd	28 June to 2 July 1999	The MEPC adopted an MEPC resolution on Guidelines for Monitoring the World Wide Average Sulphur Content of Residual Fuel Oils Supplied for Use on Board Ships. The guidelines are intended to establish an agreed method to monitor the average sulphur content of residual fuel oils supplied for use on board ships (MEPC43, 1999).
44th	6 to 13 March 2000	The Committee approved a proposed amendment to regulation 14(3)(a) of Annex VI to MARPOL 73/78 to include the North Sea as a SO_x Emission Control Area. It will take effect after the entry into force of the 1997 Protocol to MARPOL 73/78 (MEPC44, 2000).
45th	2 to 6 October 2000	The MEPC considered a study commissioned by IMO into greenhouse gas emissions from ships and agreed to discuss, at its next session, the development of a document outlining IMO policy on the issue. The study follows the adoption in 1997 of Annex VI of MARPOL on Regulations for the Prevention of Air Pollution from Ships (MEPC45, 2000).
46th	23 to 27 April 2001	The MEPC reviewed submission relating to greenhouse gas emissions from ships and agreed to establish a Working Group (MEPC46, 2001).
47th	4 to 8 March 2002	The MEPC adopted the Guidelines for the Sampling of Fuel Oil for Determination of Compliance with Annex VI of MARPOL 73/78 (MEPC47, 2002).
48th	7 to 11 October 2002	The Committee made progress in developing a draft Assembly resolution on greenhouse gas emissions from ships and invited Members to submit comments on the draft to the next meeting of the MEPC (MEPC48, 2002). The resolution urges the MEPC to identify and develop the mechanisms for the reduction of GHG emissions from international shipping. The MEPC is required to establish a GHG emissions

		baseline and develop methodology expressed as a GHG-Index for ships. It also calls on governments to promote and implement voluntary measures to reduce GHG emissions from international shipping (MEPC48, 2002).
49th	14 to 18 July 2003	The MEPC finalised a draft Assembly resolution on IMO Policies and Practices related to reduction of Greenhouse Gas Emissions from Ships, for submission to the Assembly in November-December (MEPC49, 2003).
50th	1 to 4 December 2003	Focus on phase-out of single hull tankers (MEPC50, 2003).
51st	29 March to 2 April 2004	The MEPC noted that the international rules on prevention of air pollution by ships in Annex VI of MARPOL 73/78 (in the 1997 protocol to the MARPOL convention) could enter into force before the end of 2005 (MEPC51, 2004).
52nd	11 to 15 October 2004	Regulations for the Prevention of Air Pollution from Ships, contained in MARPOL Annex VI, will enter into force on 19 May 2005. The MEPC further reviewed the draft amendments to MARPOL Annex VI which were approved at previous sessions of the Committee, with a view to their adoption at MEPC 53. The draft amendments relate to the designation of the North Sea area as a "SO_x Emission Control Area". The Committee made progress on developing draft Guidelines on the CO_2 Indexing Scheme and urged Members to carry out trials using the scheme and to report to the next session (MEPC52, 2004). Meanwhile, the Committee recognized that IMO guidelines on greenhouse gas emissions have to address all six greenhouse gases covered by the Kyoto Protocol (Carbon dioxide (CO_2); Methane (CH_4); Nitrous oxide (N_2O); Hydro fluorocarbons (HFCs); Per fluorocarbons (PFCs); and Sulphur hexafluoride (SF_6) (MEPC52, 2004).
53rd	18 to 22 July 2005	The MEPC adopted amendments to the Regulations for the Prevention of Air Pollution from Ships in MARPOL Annex VI, including one on the new North Sea SOx Emission Control Area (SECA). MARPOL Annex VI entered into force on 19 May 2005 and sets limits on sulphur oxide (SO_x) and nitrogen oxide (NO_x) emissions from ship exhausts and prohibits deliberate emissions of ozone-depleting substances. The MEPC adopted Guidelines on on-board exhaust gas-SO_x cleaning systems; Survey Guidelines under the Harmonized System for Survey and Certification for MARPOL Annex VI; Unified

		interpretations of MARPOL Annex VI; and Guidelines for Port State Control under MARPOL Annex VI. The MEPC also adopted amendments to update the NO_x Technical Code. The MEPC approved Interim Guidelines for Voluntary Ship CO_2 Emission Indexing for Use in Trials (MEPC53, 2005). The Committee agreed on the need to undertake a review of Annex VI and the NO_x Technical Code with a view to revising the regulations to take account of current technology and the need to further reduce emissions from ships (MEPC53, 2005).
54th	20 to 24 March 2006	MEPC adopted amendments to the Regulations for the Prevention of Air Pollution from Ships in MARPOL Annex VI, including one on the new North Sea SO_x Emission Control Area (SECA). MARPOL Annex VI entered into force on 19 May 2005 and sets limits on sulphur oxide (SO_x) and nitrogen oxide (NO_x) emissions from ship exhausts and prohibits deliberate emissions of ozone-depleting substances (MEPC54, 2006). MEPC adopted Guidelines on on-board exhaust gas-SO_x cleaning systems; Survey Guidelines under the Harmonized System for Survey and Certification for MARPOL Annex VI; Unified interpretations of MARPOL Annex VI; and Guidelines for Port State Control under MARPOL Annex VI. MEPC also adopted amendments to update the NO_x Technical Code. MEPC approved Interim Guidelines for Voluntary Ship CO_2 Emission Indexing for Use in Trials. **Review of Annex VI** The Committee agreed on the need to undertake a review of Annex VI and the NO_x Technical Code with a view to revising the regulations to take account of current technology and the need to further reduce emissions from ships (MEPC54, 2006).
55th	9 to 13 October 2006	During this session, eight unified interpretations were agreed upon relating to the implementation and enforcement of MARPOL Annex VI, the NO_x Technical Code and related guidelines. The standard form of the Sulphur Emissions Control Area (SECA) Compliance Certificate to facilitate uniform enforcement and port State control were agreed upon.

		A correspondence group to be established to develop wash water discharge criteria for exhaust gas SO_x cleaning systems was approved (MEPC55, 2006).
56th	9 to 13 July 2007	The MEPC endorsed a proposal by Secretary-General Mitropoulos to commission a comprehensive study, by an informal cross government/industry scientific group of experts, to review the impact on the environment, on human health and on the shipping and petroleum industries, of applying any of the proposed fuel options to reduce SO_x and particulate matter generated by shipping, and the consequential impact such fuel options could have on other emissions, including CO_2 emissions from ships and refineries, taking into account the availability of CO_2 abatement technologies. **Update of the 2000 IMO Greenhouse Gas (GHG) Study** The MEPC confirmed the need to update the 2000 IMO GHG Study, and agreed a timeframe, scope and terms of reference for that purpose (MEPC56, 2007).
57th	31 March to 4 April 2008	Proposed amendments to the MARPOL Annex VI regulations to reduce harmful emissions from ships and progressing the Organization's work on the regulation of greenhouse gas emissions from ships were approved (MEPC57, 2008).
58th	6 to 10 October 2008	The revised Annex VI, and the associated NO_x Technical Code, will enter into force on 1 July 2010, under the tacit acceptance amendment procedure. The Committee approved the usage of the draft Interim Guidelines on the Method of Calculation of the Energy Efficiency Design Index for new ships, for calculation/trial purposes with a view to further refinement and improvement (MEPC58, 2008).
59th	13 to 17 July 2009	The MEPC agreed to disseminate a package of interim and voluntary technical and operational measures to reduce greenhouse gas emissions from international shipping. Interim Guidelines on the Method of Calculation, and voluntary verification, of the Energy Efficiency Design Index (EEDI) for new ships, and guidance on the development of a Ship Energy Efficiency Management Plan (SEEMP), for new and existing ships. **Market-based instruments** **Greenhouse gas study 2009** The MEPC was assisted in its deliberations by the outcome of the Second IMO GHG Study on greenhouse gas emissions from ships, 2009 (MEPC59, 2009).

		ECA proposal approved The MEPC approved a proposal to designate specific portions of the coastal waters of the United States and Canada as an Emission Control Area (ECA). The ECA would be for the control of emissions of nitrogen oxides (NO_x), sulphur oxides (SO_x), and particulate matter, under the revised MARPOL Annex VI Prevention of Air Pollution from Ships, which was adopted in October 2008 and is expected to come into force on 1 July 2010. The draft amendments to the revised MARPOL Annex VI concerning the proposed ECA will be submitted to MEPC 60 (March 2010) for adoption (i.e. after the deemed acceptance date of the revised MARPOL Annex VI on 1 January 2010).Currently, the revised Annex lists two areas for the control of SOx emissions: the Baltic Sea area and the North Sea, which includes the English Channel (MEPC59, 2009).
60th	22 to 26 March 2010	The Committee adopted amendments to the MARPOL Convention to formally establish a North American Emission Control Area, in which emissions of sulphur oxides (SO_x), nitrogen oxides (NO_x) and particulate matter from ships will be subject to more stringent controls than the limits that apply globally. Another new MARPOL regulation, to protect the Antarctic from pollution by heavy grade oils, was also adopted (MEPC60, 2010).
61st	27 September to 1 October 2010	**Market-based measures** The Committee also held an extensive debate on how to progress the development of suitable market-based measures (MBMs) for international shipping, following the submission of a comprehensive report by an Expert Group, which had carried out a feasibility study and impact assessment of several possible market-based measures submitted by governments and observer organisations. The MBM proposals under review ranged from a contribution or levy on all CO_2 emissions from international shipping, or only from those ships not meeting the EEDI requirement, via emission trading systems, to schemes based on a ship's actual efficiency, both by design (EEDI) and operation (SEEMP). **Emission Control Area proposal put forward to next session for adoption: "**The MEPC approved a proposal to designate certain waters adjacent to coasts of Puerto Rico (United States) and the Virgin Islands (United States) as an ECA for the control of emissions of nitrogen oxide (NO_x), sulphur oxide (SO_x), and particulate matter under MARPOL Annex VI Regulations for the

		prevention of air pollution from ships, and agreed to consider the proposal for adoption at its next session." (MEPC61, 2010)
62nd	11 to 15 July 2011	**Energy efficiency measures adopted** "Mandatory measures to reduce emissions of greenhouse gases (GHGs) from international shipping were adopted by Parties to MARPOL Annex VI represented in the MEPC." **United States Caribbean Emission Control Area adopted** **Other Annex VI issues** "The MEPC adopted Guidelines for reception facilities under MARPOL Annex VI and Guidelines Addressing Additional Aspects of the NO_x Technical Code 2008, with regard to particular requirements related to marine diesel engines fitted with selective catalytic reduction (SCR) systems." (MEPC62, 2011) "The MEPC approved, for future adoption, draft amendments to the NO_x Technical Code 2008, relating to engines not pre-certified on a test bed and to NO_x-reducing devices. It also agreed on terms of reference for the review of the status of technological developments to implement the Tier III NO_x emission standard." (MEPC62, 2011) **Black carbon measures to be further considered.**
63rd	27 February 2012 to 2 March 2012	The MEPC adopted the following guidelines intended to assist in the implementation of MARPOL Annex VI: • 2012 Guidelines on the Method of Calculation of the Attained Energy Efficiency Design Index (EEDI) for New Ships; • 2012 Guidelines for the Development of a Ship Energy Efficiency Management Plan (SEEMP); • 2012 Guidelines on the Survey and Certification of the Energy Efficiency Design Index (EEDI); and • Guidelines for Calculation of Reference Lines for Use with the Energy Efficiency Design Index (EEDI). The MEPC continued its intensive consideration of proposed market-based measures (MBMs), which would complement the technical and operational measures already adopted. The NO_x technical code amendments were adopted (MEPC63, 2012).
64th	1 to 5 October 2012	"The MEPC continued its work on further developing technical and operational measures relating to energy-efficiency measures for ships, based on a work plan agreed at the previous session. This follows the adoption of the new chapter 4 of MARPOL Annex VI, which will enter into force on 1 January 2013, and includes new requirements mandating the Energy Efficiency Design Index

		(EEDI), for new ships, and the Ship Energy Efficiency Management Plan (SEEMP) for all ships. The MEPC adopted amendments to the 2012 Guidelines on the method of calculation of the attained EEDI for new ships (resolution MEPC.212(63)), relating to the calculation of shaft-generator power and shaft-motor power." (MEPC64, 2012)
65th	13 to 17 May 2013	**Resolution on technical cooperation for energy efficiency measures adopted**. **Update of GHG emissions estimate gets go-ahead** **Development of energy-efficiency measures for ships continued** The MEPC continued its work on further developing technical and operational measures relating to energy-efficiency measures for ships. **Draft NOx Technical Code amendments approved:** The MEPC approved draft amendments to the NO_x Technical Code concerning use of dual-fuel engines. **Guidelines for implementation of MARPOL Annex VI regulation 13 agreed: "**The MEPC adopted guidelines, as required by regulation 13.2.2 of MARPOL Annex VI, in respect of non-identical replacement engines not required to meet the Tier III limit; and a unified interpretation on the "time of the replacement or addition" of an engine for the applicable NO_x Tier standard for the supplement to the IAPP Certificate." (MEPC65, 2013)
66th	31 March to 4 April 2014	**Energy-efficiency measures for ships considered** Adoption of the 2014 Guidelines on the Method of Calculation of the Attained Energy Efficiency Design Index (EEDI). **NOX Technical Code guidelines adopted** **Sulphur review correspondence group established** "The sulphur content (expressed in terms of % m/m – that is, by weight) of fuel oil used on board ships is required to be a maximum of 3.50% m/m (outside an Emission Control Area (ECA)), falling to 0.50% m/m on and after 1 January 2020. Depending on the outcome of a review, to be completed by 2018, as to the availability of compliant fuel oil, this requirement could be deferred to 1 January 2025." (MEPC66, 2014)
67th	13 to 17 October 2014	The Third IMO GHG Study 2014 estimates that international shipping emitted 796 million tonnes of carbon dioxide (CO2) in 2012, against 885 million tonnes in 2007. This represented 2.2% of the global emissions of CO_2 in 2012, against 2.8% in 2007. (IMO, 2014)

		Energy-efficiency measures for ships considered **Fuel oil quality proposals discussed**
68th	11 to 15 May 2015	**Further development of energy-efficiency guidelines for ships** **The MEPC adopted the following amendments:** - The 2014 Guidelines on survey and certification of the Energy Efficiency Design Index (EEDI) and endorsed their application from 1 September 2015'. - The 2013 Interim Guidelines for determining minimum propulsion power to maintain the manoeuvrability of ships in adverse conditions, for the Level 1 minimum power lines assessment for bulk carriers and tankers, and agreed on a phase-in period of six months for the application of the amendments. - The 2014 Guidelines on the method of calculation of the attained EEDI for new ships. **Revised air pollution guidance and requirements agreed** The Committee agreed to proceed with the development of guidelines for the sampling and verification of fuel oil used on board ships (MEPC69, 2016). **Fuel oil quality correspondence group re-established** **Black carbon definition agreed** "The MEPC agreed on a definition for Black Carbon emissions from international shipping, based on the definition provided by Bond et al., which describes Black Carbon as a distinct type of carbonaceous material, formed only in flames during combustion of carbon-based fuel, and distinguishable from other forms of carbon and carbon compounds contained in atmospheric aerosol, due to its unique physical properties." (MEPC69, 2016)
69th	18 to 22 April 2016	**Mandatory system for collecting ships' fuel consumption data approved Adoption of amendments to MARPOL** The MEPC adopted amendments to MARPOL and the NO_x Technical Code 2008, with expected entry into force on 1 September 2017: – Amendments to MARPOL Annex VI regarding record requirements for operational compliance with NO_X Tier III emission control areas; – Amendments to the NO_x Technical Code 2008 to facilitate the testing of gas-fuelled engines and dual fuel engines. **Energy efficiency of international shipping** "The Energy-Efficiency Design Index (EEDI) for new ships and associated operational energy-efficiency measures for existing

		ships became mandatory in 2013, with the entry into force of relevant amendments to MARPOL Annex VI." **Fuel oil quality** The report of a correspondence group established to consider possible quality-control measures prior to fuel oil being delivered to a ship was considered by the MEPC. Following some discussion, the Committee encouraged the fuel oil supply industry to develop draft best practice for fuel oil providers and submit this best practice to the Committee for consideration at a future session. **Decision on sulphur limit to take place at MEPC 70**
70th	24 to 28 October 2016	**Adoption of mandatory data collection system for fuel oil consumption:** The MEPC adopted mandatory MARPOL Annex VI requirements for ships to record and report their fuel oil consumption. **Roadmap for reducing GHG emissions approved: "**The MEPC approved a Roadmap for developing a comprehensive IMO strategy on reduction of GHG emissions from ships, which foresees an initial GHG reduction strategy to be adopted in 2018." **Energy efficiency of international shipping** "The Committee considered the report of a correspondence group on the status of technological developments relevant to implementing Phase 2 (1 Jan 2020-31 Dec 2024) of the EEDI (Energy Efficiency Design Index) regulations. The energy-efficiency regulations require IMO to review the status of technological developments and, if proven necessary, amend the time periods, as well as the EEDI reference line parameters for relevant ship types, and reduction rates."(MEPC70, 2016) **2020 global sulphur cap implementation date decided:** 1 January 2020 was confirmed as the implementation date for a significant reduction in the sulphur content of the fuel oil used by ships. The decision to implement a global sulphur cap of 0.50% m/m (mass/mass) in 2020 represents a significant cut from the 3.5% m/m global limit currently in place and demonstrates a clear commitment by IMO to ensuring shipping meets its environmental obligations. (MEPC70, 2016) **North Sea and Baltic Sea emission control areas for nitrogen oxides (NO_x) approved:** The MEPC approved the designation of the North Sea and the Baltic Sea as emission control areas (ECA) for nitrogen oxides (NO_x) under regulation 13 of MARPOL Annex VI. The draft amendments to formally designate the NO_x ECAs will

		be put forward for adoption at the next session of the Committee (MEPC 71) (MEPC70, 2016). **Bunker delivery note amendments approved** **Interpretations for SCRs under NOX Technical Code** The MEPC approved unified interpretations to the NO_x Technical Code 2008 related to the approval of selective catalytic reduction systems to meet NO_x standards (MEPC70, 2016)

3.2. Conclusion

The time frame covered in this study spans over 20 years. In this time, significant strides have been made with regard to the regulation of GHG emissions from ships. The MEPC sessions have led to GHG emissions studies, amendments to the MARPOL convention, and guidelines for implementing these regulations. The guidelines not only consider the ships but also the reporting and procedures to be followed by the regulatory authorities. Each session brings more stringent regulations, and it is up to the shipping industry to implement the proposed changes to adhere to these regulations. In chapter 7, this study will consider the costs associated with these changes.

CHAPTER FOUR

REDUCING EMISSIONS

There are numerous options for reducing emissions from vessels, however this would depend on the stage that the vessel is in; that is, during shipbuilding or post shipbuilding. Table 2, below, distinguishes between the Design and Operations stages, and provides categories within each stage whereby emission reduction can be addressed (IMO, 2009a). This chapter will discuss some of the technical processes that can be incorporated into the shipbuilding phase, focusing on the structural aspects. The analysis of the post shipbuilding phase will include retro-fitted equipment and fuels that can be used to reduce emissions.

Table 2 Principal options for improving energy efficiency, Source: (Bazari, 2011)

DESIGN	OPERATION
Concept, design and capability Hull and superstructure Power and propulsion systems	Fleet management, logistics and incentives Voyage optimisation Energy management

4.1. A Brief Historical Regulatory Context

In March 2000, the first study of the Greenhouse Gas Emissions from ships was submitted to the IMO by MARINTEK. The objective of the study was to examine the greenhouse gas emissions reduction through different technical, operational and market-based approaches (MARINTEK, 2000). The following strategy was proposed for the policy implementation by IMO to curb GHG emissions:

1. voluntary agreements on GHG emission limitations between the IMO and ship owners;
2. working on designing emission standards for new and existing vessels; and
3. pursuing the possibilities of credit trading (IMO, 2000).

The subsequent GHG study in 2009 found exhaust gases to be the primary source of emissions from ships with carbon dioxide being the most important GHG emitted by ships. Technical and operational measures were identified as having the most potential for reducing GHG emissions (IMO, 2009a). According to the IMO GHG study of 2009, there are four categories for reducing emissions from ships. They are as follows:

1. Improving energy efficiency, i.e. doing more useful work with the same energy consumption. This applies to both the design and the operation of ships.
2. Using renewable energy sources, such as the wind and the sun.
3. Using fuels with less total fuel-cycle emissions per unit of work done, such as biofuels and natural gas.
4. Using emission-reduction technologies i.e., achieving reduction of emissions through chemical conversion, capture and storage, and other options (IMO, 2009a).

Improving energy efficiency is key as this would mean the same amount of work is done using less energy, which in turn means less fuel burned and reductions in emissions of all exhaust gases (IMO, 2009a).

4.2. Design and Shipbuilding Phase

The OECD (2010) Council Working Party on Shipbuilding (WP6) report on Environmental and Climate Change Issues in the Shipbuilding Industry identified several issues related to climate change that are relevant to the shipbuilding sector. The environmental impact of shipbuilding is considerable as the building of ships depends on a large number of processes which lead to significant emissions of GHG (OECD, 2010). The activities in shipbuilding that are of the highest environmental concern with regards to GHG emissions are set out in the sub-sections that follow below.

4.2.1 Metal Working Activities

Shipbuilding is a basic metal industry and depends heavily on the use and forming of steel. The cutting and welding activities form the basic structure of ships. Thermal, oxyfuel gas and plasma arc cutting all have different processes, but each process emits significant amounts of metal oxide fumes and other pollutants. The emissions from welding include GHG, toxic chemicals, ozone, carbon monoxide, nitrogen oxides, sulphur dioxide and lead. One way to minimise welding fumes is to employ capture and collection systems. Electric arc welding consumes large quantities of electricity and shipyards can minimise their GHG footprint by obtaining their electricity from renewable sources, or sources that do not burn fossil fuel (OECD, 2010).

The significance of the environmental impact of steel production largely depends on how the steel is produced. When using the blast furnace/basic oxygen furnace (BF/BOF) process, which depends on virgin iron ore as well as coking coal, GHG emissions are very high, and there are concerns associated with the mining of coal and iron ore (OECD, 2010). The other process used to produce steel is the electric arc furnace (EAF), which depends mostly on scrap steel. This process does not require the use of coke and is far less environmentally damaging; however, it is heavily dependent on availability and cost of scrap steel. Another advancement in steelmaking is the development of ultra-light and high strength steel, which offers considerable weight saving potential for ships and could increase the resistance of vessel hulls to corrosion (OECD, 2010).

One indication of the shipbuilding industry's environmental impact can be found in the extensive use of steel, which accounts for about 3% of global steel consumption. The shipbuilding industry in 2008 could be associated with emissions in the region of 36 million tonnes (OECD, 2010).

4.2.2 Surface Treatment Operations

Surface treatment operations take place during construction and various maintenance and repair activities. These processes include the cleaning and coating of steel, the cleaning of hulls, tanks and cargo areas, and painting, as well as paint removal. Abrasive blasting is a technique used to prepare surfaces for coating and painting. The environmental impacts of blasting can be reduced using non-silica blasting agents as well as different techniques of blasting. Coating and painting activities include the use of a number of chemicals that emit air pollutants. To reduce the build-up of marine organisms, which causes increased drag on the hull and leads to increased fuel consumption, ship hulls are treated with anti-fouling paints. These coatings save substantial amounts of fuel, leading to lower GHG emissions (OECD, 2010).

4.2.3 Scrubbers

A scrubber is an exhaust gas cleaning system that is used to remove particulates and/or gas from exhaust streams. Scrubbers traditionally use liquid to wash unwanted pollutants from the vessel's funnel. The main pollutants removed are SO_x, and particulate matter, and in some cases small amounts of NO_x and CO_2. Vessels can also be retrofitted with scrubbers, however the size and weight and cost of the equipment is of concern (Petromedia, 2015).

4.2.3.1 Open Loop Scrubber System

In the open loop system, the exhaust enters the scrubber and is sprayed using seawater in three different stages. The sulphur oxide in the exhaust reacts with the water and forms sulphuric acid. There is no need for chemicals as the natural alkalinity of the sea water neutralises the acid. Wash water is treated and monitored at the inlet and outlet (Babicz, 2015).

4.2.3.2 Closed Loop Scrubber System

In the closed loop system, the wash water is being circulated within the scrubber. Only a small bleed-off is extracted from the loop and fresh water and alkali is added. The bleed-off contains traces of oil and combustion products. Clean effluent from the treatment unit is discharged overboard or led to the effluent holding tank when overboard discharges are to be avoided. (Babicz, 2015).

4.3 Energy and Propulsion

4.3.1 Hull and Propeller optimisation

The condition of the hull is vitally important to reducing GHG emissions. Hull roughness refers to the condition of the hull, and has two main characteristics: physical roughness, which can result from mechanical damage and corrosion; and biological roughness, which is typically attributed to animal and weed fouling. The increase in roughness increases the fuel usage, thereby increasing the GHG emissions. Modern self-polishing antifouling paint systems have significantly reduced the problem of increasing roughness (MARINTEK, 2000). The efficiency of a propeller is dependent mainly on its design and dimensions. Propeller cleaning and polishing and appropriate coating may significantly increase fuel efficiency (IMO, 2009b)

4.3.2 Engines

The power needed on ships is generated through main and auxiliary engines and boilers, which are also sources of emissions on board the vessels. The main engines consist of one or several two- or four-stroke diesel engines, to produce the energy needed for the propulsion system. The auxiliary engines are used to produce the energy needed on board for electricity, pumps, cooling and heating devices, derricks, hydraulic devices, and so on (Walstrom, 2006). GHG emissions may be reduced by internal diesel engine adjustments. Some of these adjustments may include:

1. Combustion Optimisation
2. Fuel Injection Optimisation
3. Common Rail Technology
4. Turbo-charging and Charge-air After-cooling
5. Miller Cycle
6. Lubrication technology
7. Combination of internal engine measures (Bazari, 2011).

4.3.3 Fuel

While fuel is an essential component of shipping, it is also one of the largest sources of air pollution in the industry. Depending on estimates and vessel types, fuel can amount up to 40% of a ship's total operating costs (Stopford, 2009). Vessels run on a particular form of diesel known as bunker fuel, which can be described as a very dense and highly polluting residual substance from the oil refining process. Bunker fuel has a high concentration of nitrogen oxide, sulphur and particulate matter, which are all emitted into the air through the vessel's exhaust (OECD, 2010).

The marine fuel qualities available are:

1. Marine Gas Oil (MGO) – Gas oil or High Speed Diesel Oil – Sulphur content ranges from 0.9% to 1.1%
2. Marine Fuel Oil (MDO) – Diesel Fuel Oil, Diesel Oil, Bunker Diesel Oil, Marine Diesel Fuel – ranging from 60 centistoke (cSt) to 180 cSt. (Centistoke is the unit of measurement for the kinematic viscosity of fluids) (McGraw-Hill, 2003).
3. Heavy Fuel Oil or Residual Fuel Oil (HFO) – is the dominating fuel oil and is of very high viscosity. HFO has to be treated on board a vessel (MARINTEK, 2000).

GHG emissions can be reduced by switching from residual fuels to distillate fuels with lower total emissions (IMO, 2009a).

4.3.4 Biofuels

Bioenergy comes from biomass which is one of the oldest forms of energy that human beings are comfortable using. Biomass is referred to as 'fresh' carbon from plants and animals, while coal, oil and natural gas is more like 'old' carbon from plants and animals. The energy comes from carbohydrates, lipids and other compounds in the biomass.

There are four main uses for biomass.

1) Use at power stations as a coal substitute
2) Can be burned in purpose built facilities for heat or power generation
3) Can be used as a petroleum substitute
4) Used as food

Energy from biomass is usually extracted by direct combustion, gasification or digestion.

Direct combustion is where the biomass is burnt as a coal substitute or in a purpose built facility.

One of the difficulties with biomass is that it can contain up to 60% water and this reduces the amount of useful heat that may be obtained because a lot of the heat goes into boiling off all of that water. It also means that when biomass is transported, up to 60% of what is transported has no energy value.

Gasification is where the biomass is burned but not given quite enough air. In this method it forms carbon monoxide and hydrogen which is known as syngas which is short for synthesis gas. Once syngas is made from the biomass, it can used as a fuel or turned into almost any hydrocarbon chemical.

The last energy extraction process is digestion where biomass is broken down microbially in a low oxygen atmosphere. This process makes biogas which is 65-70% methane.

Biofuels are particularly susceptible to biofouling, so although compatible from a technical perspective, engine shutdown may be a consequence of any mishaps, while blending biofuels into diesel fuel. Furthermore, there is a high cost attached to using biofuels, as well as a lack of availability and production of biofuels (IMO, 2009a).

4.3.5 Liquefied Natural Gas (LNG)

Liquefied Natural Gas can be used as an alternative in the shipping industry. LNG is a clean fuel and as a result there are lower CO_2 emissions, no sulphur emissions and reduced NO_x emissions. However, here too, there are challenges with the use of this alternative fuel. The storage tank for LNG requires a large space on board a vessel and there are limited bunkering options for LNG at present (IMO, 2009a).

4.3.6 Wind

Wind power describes the process by which the wind is used to generate mechanical power and electricity. Wind turbines convert the kinetic energy from the wind into mechanical power. This mechanical power can be used for specific tasks such as pumping water, grinding grain, or converted into electricity by a generator, to power homes, businesses and industry.

In order to get the maximum energy output, it's crucial to place the wind turbines in areas with high average wind speeds and minimum turbulence. The speed of the wind generally increases with the height above ground, so turbines are mounted on tall towers in order to take advantage of faster and less turbulent winds.

Wind power is considered an intermittent energy generation source, as it relies on a natural resource which may not always be there.

4.3.6.1. Project Vindskip

Lade AS, a Norwegian company, has designed a cargo ship known as the Vindskip (Windship) that will use a combination of wind propulsion and LNG powered engines. The vessel will use a computer programme to calculate the best sailing route to exploit the available wind energy potential. The vessel is designed with high sides turning it into a wind assisted airfoil. The vessel is still in the design phase and testing phase. The cost of building a vessel like the Vindskip is unknown (Lade, 2013).

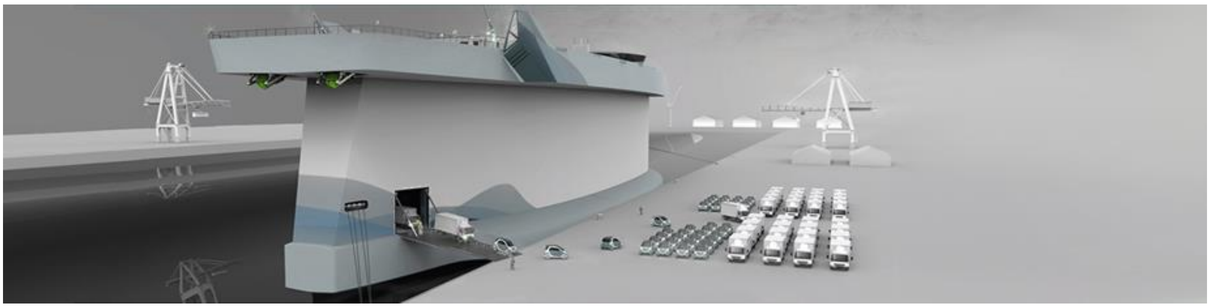

Figure 1 Vindskip designed by Lade AS Source: (Lade, 2013)

4.3.6.2. Flettner Rotor Sails

Flettner rotors were invented by engineer Anton Flettner in 1924. The rotors depend on the aerodynamic phenomenon known as the Magnus effect. When wind contacts a rotating cylinder, it flows at different relative speeds as it passes on each side. That speed difference translates into a pressure difference, creating force perpendicular to the wind direction (MAREX, 2018).

Flettner's invention has re-emerged with Norsepower, a Finnish company installing 2 rotors on a Maersk Tanker. Norsepower has improved the Flettner design by manufacturing with lightweight composite materials, full automation i.e. the rotor starts on its own whenever the wind is strong enough to deliver fuel savings. The technology will be tested and analysed on the Maersk Pelican throughout 2019 as Maersk Tankers anticipates fuel savings up to 10% and a reduction of carbon emissions of up to 20% (Smith, 2018).

4.3.7 Hydropower

Hydropower is classified as a renewable form of energy generation, forming roughly 70% of the world's renewable energy generation capacity. The energy is sourced from flowing water. The general configuration of hydropower stations includes two bodies or reservoirs of water, one higher and one lower. Water in the upper reservoir has substantial potential energy. This is converted to kinetic energy by allowing it to flow through to the lower reservoir through a turbine in a controlled way. The turbine turns the kinetic energy into mechanical energy -- which then becomes electrical energy as the turbine spins a generator.

Some of the advantages of hydropower stations are their high reliability and high efficiency. Efficiency ranges from 80-90%, meaning that 80-90% of the potential energy can be converted to electricity. Hydropower is a low emissions technology - particularly during generation and the amount of electricity actually generated can be intentionally varied by the plant's operators.

Fraunhofer Mobile Wave Crawler

The Fraunhofer system consists floating buoys deployed over the sides of a 50m vessel on hinged arms. The arms would pivot up and down when the buoys bob up and down on the waves, generating power that would be stored in the onboard battery. Some of the power would be used to propel the vessel and the rest would be released into the municipal grid system when the vessel is at port (Fraunhofer, 2018).

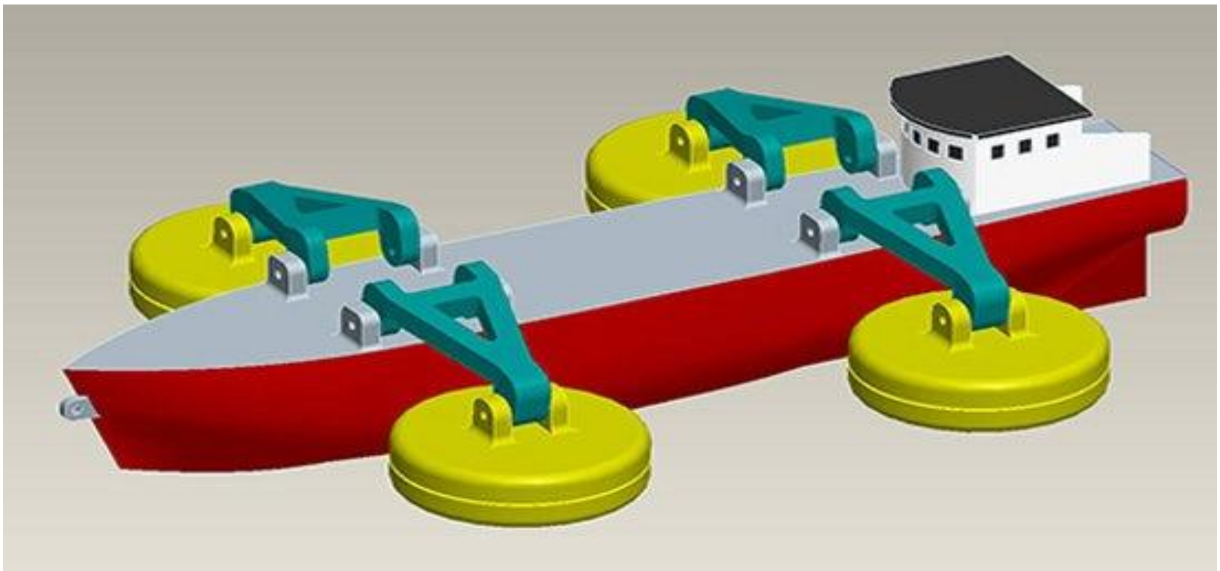

Figure 2 Fraunhofer Mobile Wave Crawler Source: (Fraunhofer, 2018)

4.3.8 Solar Energy

Solar energy comes in the form of electromagnetic radiation, which is basically a wave of heat and light radiating from the sun. There are currently several ways to use solar energy: passive use, active use, photovoltaics and concentrated solar thermal.

The best application of passive use can be seen in building infrastructure, with simple design techniques that maximise the impact of the sun. These include: building orientation, natural light (and heat) collection and thermal differences used to encourage ventilation.

Active solar heating uses the Sun combined with some moving parts, like a water pump. The most common examples of these are solar hot water systems for households and swimming pools, and basic solar cook stoves.

The most recognisable use of solar of solar energy is photovoltaics, or solar PV. This is typically seen as panels of solar PV cells, using the photovoltaic effect, to convert sunlight into electrical current.

The third is a less common, but no less powerful method, in which the solar radiation from the sun is concentrated using mirrors or reflective surfaces, to heat a thermal fluid which is then used to run a steam power cycle to generate electricity. This is known as concentrated Solar thermal.

Solar energy has no fuel cost, very low to no carbon dioxide emissions and nearly limitless potential (IPCC, 2011).

Aquarius Marine Renewable Energy (MRE) System

Eco Marine Power Co. Ltd. Has patented their wind power and solar energy system for ocean going vessels. The computer controlled integrated system will allow ships to utilise wind power with rigid but movable sails. The sails can be fitted with solar panels that have been specifically designed to be light, flexible and impact resistant to withstand the extreme conditions at sea (EMP, 2018).

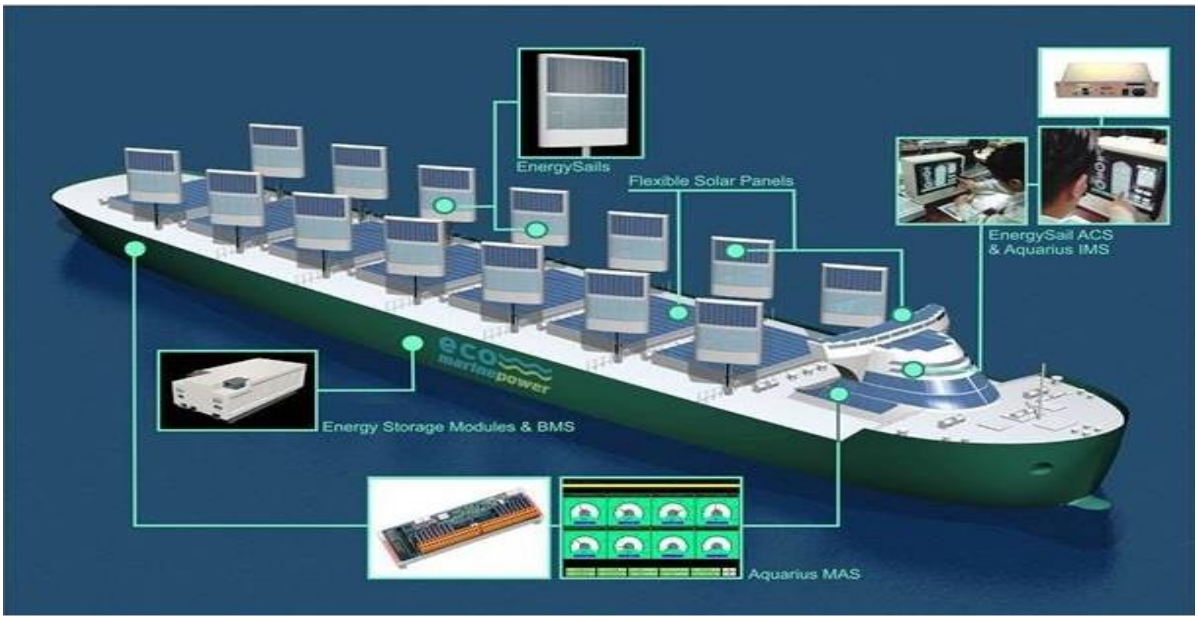

Figure 3 Aquarius Marine Renewable Energy (MRE) System Source:(EMP, 2018)

4.4 Operations

GHG emissions can be reduced by reducing the fuel consumed during the operational phase using the following categories:

1. Enhanced Technical and Operational Management: measures include enhanced weather routing, better engine maintenance, deployment of cost effective propulsion.
2. Enhanced Logistics and Fleet Planning: by combining cargoes to achieve higher utilisation rate, enhanced routing, few/shorter ballast legs and slower steaming.
3. Port related: removing restrictions on ship size so larger ships may enter the port for more efficient handling, and improving port turn around (IMO, 2009b).

4.5 Summary of Measures Based on EEDI and SEEMP

The EEDI is expected to stimulate continued innovation and technical development of all the components influencing the fuel efficiency of a ship from its design phase. SEEMP is an operational measure that establishes a mechanism to improve the energy efficiency of a ship in a cost-effective manner.

Table 3 Summary of measures based on EEDI and SEEMP, Source: (Bazari, 2011)

	EEDI reduction measure	**SEEMP related measure**
1.	Optimised hull dimensions and form	Engine tuning and monitoring
2.	Lightweight construction	Hull condition
3.	Hull coating	Propeller condition
4.	Hull air lubrication system	Reduced auxiliary power
5.	Optimisation of propeller-hull interface and flow devices	Speed reduction (operation)
6.	Contra-rotating propeller	Trim/draft
7.	Engine Efficiency improvement	Voyage execution
8.	Waste heat recovery	Weather routing
9.	Gas fuelled (LNG)	Advanced hull coating
10.	Hybrid electric power and propulsion concepts	Propeller upgrades and aft body flow devices
11.	Reducing on-board power demand (auxiliary systems and hotel loads)	
12.	Variable speed drive for pumps, fans, etc.	
13.	Wind power (sail, wind engine, etc.)	
14.	Solar power	
15.	Design speed reduction (new builds)	

4.6 Conclusion

Many of these solutions for reducing GHG emissions are implementable; however, it is necessary to note that it is far easier when in the design phase to accommodate new technologies for reducing carbon emissions. When vessels are already operational, carrying lines' options are limited to using cleaner fuels, and retrofitting scrubbers and propellers. A discussion of the cost implications of these interventions will be addressed in Chapter 7.

CHAPTER FIVE

REGULATIONS GOVERNING EMISSIONS RELATED TO SHIPS

The shipping industry is one of the most complex industries in the world. A shipping company that may be based in Denmark can order a new ship from a shipyard in South Korea, have it flagged in London and operate between Asia and Europe. Regulating such an industry takes co-ordination and co-operation from several industry bodies as well as the relevant Port states and Flag States. This is where international organisations like IMO and the MEPC come in to ensure that all nations are following the same rules.

5.1. The Broad Regulatory Environment

The International Convention for Prevention of Pollution by Ships (MARPOL) includes regulations aimed at preventing and minimising pollution from ships – both accidental pollution and that from routine operations – and currently includes six technical Annexes. The principal focus of this study is on Annexure VI, which covers the various greenhouse gas emissions from ships. These regulations have been implemented in particular geographical areas, such as the Baltic Sea, North Sea, elsewhere throughout the European Union, and on all the seaboards of North America that have been designated as Emissions Control Areas (ECAs). These areas have already implemented the new regulations whereas, worldwide, the regulations will be implemented with effect from January 2020.

5.2. MARPOL Annex VI

5.2.1. Regulation 12

This regulation applies to installations which contain ozone-depleting substances. Those installations containing hydro-chlorofluorocarbons (HCFCs) will be prohibited on ships constructed on or after 1 January 2020. HCFCs are a group of manmade compounds containing hydrogen, chlorine, fluorine and carbon, and constitute a potent source of greenhouse gas. Installations containing ozone-depleting substances other than HCFCs have been prohibited on ships constructed on or after 19 May 2005 (IMO, 2006).

5.2.2. Regulation 13

Nitrogen oxides are a collective term used to refer to nitric oxide and nitrogen dioxide. Nitric oxide is a colourless, flammable gas with a slight odour and is somewhat toxic. Nitrogen dioxide is a reddish brown, non-flammable gas with a detectable odour. In significant concentrations it is highly toxic and is a strong oxidising agent that reacts with air to form corrosive nitric acid as well as toxic organic nitrates (IMO, 2006).

Regulation 13 addresses Nitrogen Oxide emissions and applies to marine diesel engines with a power output of more than 130 kW installed on a ship, or one that undergoes a major conversion on or after 1 January 2000. The three tiers are based on the dates of installation of a diesel engine on a ship and the more recent engine installations face more stringent rules. Tier I applies to the operation of a marine diesel engine which is installed on a ship constructed on or after 1 January 2000 and prior to 1 January

2011. Operation is prohibited except when the emission of nitrogen oxides from the engine is within the required limits, e.g. 17.0g/kWh, when rated engine speed is less than 130 rpm. Ships constructed between 1 January 1990 and 1 January 2000 will apply the Tier I requirements. Tier II applies to the operation of marine diesel engines, which are installed on a ship on or after 1 January 2011, which is prohibited except when the emission of nitrogen oxides is within the required limits e.g. 14.4g/kWh when rated engine speed is less than 130 rpm. Tier III applies to the operation of marine diesel engines, which are installed on a ship constructed on or after 1 January 2016, which is prohibited except when the emission of nitrogen oxides is within the required limits, e.g. 3.4g/kWh when the rated engine speed is less than 130 rpm (MEPC65, 2013).

5.2.3. Regulation 14

This regulation provides the specifications for the emission of sulphur content of the fuel oil used on board ships for worldwide and specifications for the Emission Control Areas. These fuel oil sulphur limits (expressed in terms of % m/m – that is by mass) are subject to a series of step changes over the years.

Worldwide specifications are as follows:

1) 4.5% m/m prior to January 2012
2) 3.5% m/m on and after January 2012
3) 0.5% m/m on and after January 2020 (MEPC70, 2016)

Emission Control Areas:

The ECAs established are:

- Baltic Sea area – as defined in Annex I of MARPOL (SO_x only);
- North Sea area – as defined in Annex V of MARPOL (SO_x only);
- North American area (entered into effect 1 August 2012) – as defined in Appendix VII of Annex VI of MARPOL (SO_x, NO_x and PM); and(MEPC63, 2012)
- United States Caribbean Sea area (entered into effect 1 January 2014) – as defined in Appendix VII of Annex VI of MARPOL (SO_x, NO_x and PM) (MEPC66, 2014).

1) 1.50% m/m prior to 1 July 2010
2) 1.00% m/m on and after 1 July 2010
3) 0.10% m/m on and after 1 January 2015 (MEPC66, 2014).

5.3. Enforcing the MARPOL Annex VI Regulations

The Marine Environment Protection Committee 59/24 report, which adopted the resolution MEPC.181 (59) on 17 July 2009, provides guidelines for Port State Control (PSC) under the revised MARPOL Annex VI. PSC refers to the inspection of foreign ships in national ports to verify that the condition of the ship and its equipment comply with the requirements of international regulations such as MARPOL and that the ship is manned and operated in compliance with these rules. Many of the IMO's most important technical conventions contain provisions for ships to be inspected when they visit foreign ports, so as to ensure that they meet IMO requirements (MEPC59, 2009).

The Organisation adopted resolution A.682 (17) on Regional co-operation in the control of ships and discharges promoting the conclusion of regional agreements. If a ship is going to more than one port in a region it would be more efficient if inspections can be closely coordinated in order to focus on substandard ships. The ship will be inspected at one of the regional ports to avoid multiple inspections. The information on inspections is shared regionally and this ensures that as many ships as possible are inspected and there are no delays for unnecessary inspections. The primary responsibility for ships' standards rests with the flag State - but port State control provides a "safety net" to catch substandard ships (MEPC59, 2009).

There are nine regional agreements on port State control - Memoranda of Understanding or MoUs - have been signed: Europe and the North Atlantic (Paris MoU); Asia and the Pacific (Tokyo MoU); Latin America (Acuerdo de Viña del Mar); Caribbean (Caribbean MoU); West and Central Africa (Abuja MoU); the Black Sea region (Black Sea MoU); the Mediterranean (Mediterranean MoU); the Indian Ocean (Indian Ocean MoU); and the Riyadh MoU. The United States Coast Guard maintains the tenth PSC regime (IMO, 2017).

The Paris MoU consists of 27 member participating maritime administrations. The current members are Belgium, Bulgaria, Canada, Croatia, Cyprus, Denmark, Estonia, Finland, France, Germany, Greece, Iceland, Ireland, Italy, Latvia, Lithuania, Malta, the Netherlands, Norway, Poland, Portugal, Romania, the Russian Federation, Slovenia, Spain, Sweden and the United Kingdom. Their mission is to eliminate the operation of substandard ships through a harmonised system of port state control. (MoU, 2017) The guidelines on application of MARPOL Annex VI Regulation 18 in an emission control area (ECA) is attached as Appendix II.

Annex 6 of the MEPC 59/24 report provides basic guidance on the conduct of port state control inspections for compliance with MARPOL Annex VI. Ships are required to carry the International Air Pollution Prevention (IAPP) certificate, which is issued by the Flag state of the particular vessel. The Port State control officer (PSCO) is required to examine the IAPP certificate, as well as the Engine International Air Pollution Prevention Certificate (EIAPP), the Technical File, the Record Book of the Engine Parameters, and documentation related to measurement and monitoring method, bunker notes, etc. (MEPC59, 2009).

In cases where there is evidence that certificates required are missing, or any other substandard issues, a more detailed inspection is to be conducted. The PSCO may detain a ship should the following conditions be present:

1. Absence of valid IAPP certificate, EIAPP certificates, or Technical Files;
2. A marine diesel engine does not comply with the NOx Technical Code or relevant NOx emission limit; and
3. The sulphur content in the fuel being used on board exceeds the relevant limits.

Annex 7 of the MEPC 59/24 report provides a method to obtain a representative sample of the fuel oil delivered for use on board ships. The details of the fuel oil should be recorded by means of a bunker delivery note, which ought to be kept as proof of compliance (MEPC59, 2009).

5.3.1. North America Emissions Control Area

The North American ECA includes waters adjacent to the Pacific Coast, the Atlantic Gulf Coast and the eight main Hawaiian Islands. It extends up to Canada and the French territories. The United States Environmental Protection Agency has "unveiled an enforcement policy for how it will penalise ship owners and operators for violating new fuel sulphur limits for vessels steaming near U.S. coastlines with low emissions requirements, aiming to deter potential violations with the threat of fines up to $25,000 per infraction and to quickly resolve non-compliance claims" (EPA, 2015).

5.3.2. Europe Emissions Control Area

The Directive 2012/33/EU of the European Parliament with regards to the sulphur content of marine fuels states that a strong monitoring and enforcement regime is needed to ensure proper implementation of the Directive. Member states are required to ensure sufficiently frequent and accurate sampling of marine fuel as well as verifications of the ships' log books and bunker delivery notes. The European mechanism also provides potential sanctions as "it is also necessary for Member states to establish a system of effective, proportionate and dissuasive penalties for non-compliance" (EU, 1999).

In June 2014, the Danish Maritime Authority (DMA, 2014), presented an action plan for the efficient enforcement of sulphur emissions from ships. This Authority has a number of initiatives to enforce environmental regulation and propose administrative fines in connection with Port State Control and sanctioning of ships.

5.4. Concerns regarding the MARPOL Annex VI regulations

5.4.1 Cost of Compliance

The cost of compliance includes buying more expensive fuel, as well as investing in new technologies and vessel equipment. The impact on some short sea traffic inside ECAs may lead to routes becoming uneconomical. Furthermore, the Port State Control that undertakes the inspections and enforces the penalties would also need to provide resources to do these tasks. These costs are further discussed in Chapter 6.

5.4.2 Availability of MARPOL Compliant Fuel Oil

There have been instances where there has been a lack of availability of 0.10% sulphur mass fuel oil or insufficient quantities. When these situations arise, the procedure is for a Fuel Oil Non-Availability Report (FONAR) to be filled in due time, and with full disclosure. According to Regulation 18 of MARPOL Annex VI, the ship will be required to present a record of the actions taken to attempt to achieve compliance, and to provide evidence that it attempted to purchase compliant fuel oil in accordance with its voyage plan.

According to the Paris MoU guidelines, for a ship to be able to rely on Regulation 18's provision, it will be necessary to:

- Present a record of efforts made to source compliant fuel;
- Show evidence of an attempt to buy such fuel;
- Demonstrate efforts made to locate alternative sources;
- Notify the port state administration in the port of arrival of this situation;
- Notify the vessel's flag state of this situation;
- Provide further evidence will be the vessel's voyage plan (and how it corroborates the non-availability of compliant fuel);
- Provide contact details of fuel suppliers approached for compliant fuel; and
- Provide plans to obtain compliant fuel at the first port of call in an ECA (Paris MoU, 2017)

5.4.3 Fuel Switching Hazards

Ships moving from non-ECA areas to ECA areas burn different types of fuel. In the ECA areas, ships burn MARPOL compliant fuel. The switch from hot heavy fuel oil to comparatively cool gas oil may lead to a thermal shock in the engines. The significantly lower viscosity of the ultra-low sulphur fuel may also be a factor contributing to engine problems. The following graph provides data from Californian waters where from the period of January 2009 to January 2014, there were at least 121 loss-of-propulsion events related to fuel switching. For each vessel, this was a serious incident which led to significant liabilities (SKULD, 2014).

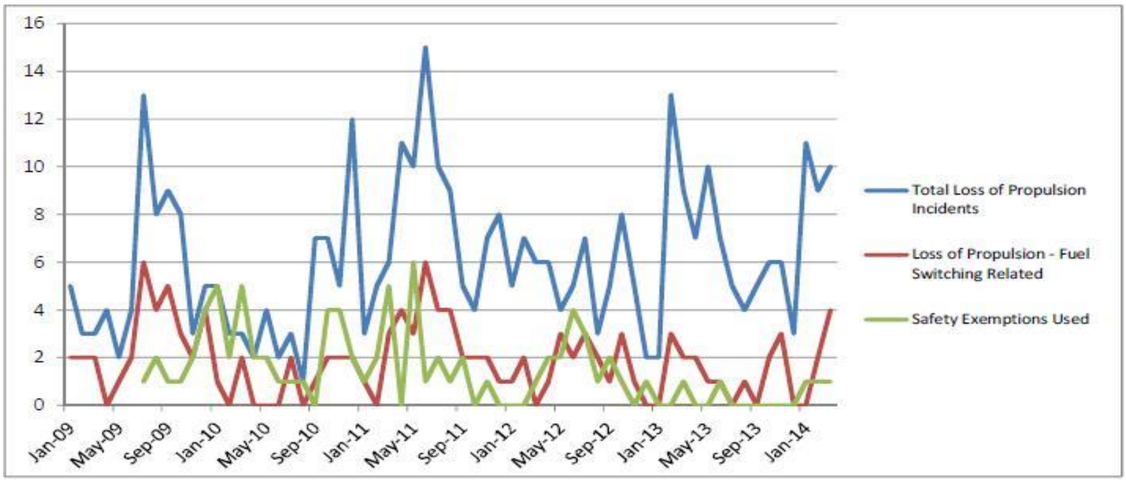

Figure 4 Data on loss of propulsion incidents in 2014, Source: (SKULD, 2014)

5.5. Conclusion

The implementation of MARPOL Annex VI requires the MEPC and industry bodies to work together to ensure that the regulations are enforced. The North American and European Emissions Control Areas allow neighbouring countries to work together to reduce emissions from vessels. The MEPC has provided guidance documents for Port State Control in these areas. Once the worldwide specifications are implemented on 1 January 2020 it will be imperative that all ports globally are prepared to monitor and enforce the regulations.

CHAPTER SIX

CASE STUDIES

Two case studies have been selected and are presented here to represent the initiatives of two shipping companies that are at the forefront of carbon emissions reduction in the shipping industry. The first company is Viking Line, a Finnish passenger and cargo line that operates in the Baltic Sea. The second company is Maersk Line, which is the biggest container shipping company in the world. Thereafter, the study will give further details on the actual costs that are incurred to reduce emissions. These costs include retrofitting, building new vessels, fuel compliance and fines for not complying with regulations.

6.1 Viking Line

Viking Line offers passenger and cargo freight services in the Baltic Sea. Their fleet consists of seven vessels: M/S Rosella, M/S Viking XPRS, M/S Mariella, M/S Gabriella, M/S Amorella, M/S Viking Grace and M/S Viking Cinderella. Viking Line pro-actively developed their environmental work for many years, such that they do more than what is required by international agreements and national laws. They have an in-house programme to reduce exhaust gas emissions through energy efficiency measures. In this programme, vessel operating staff and the Group's technical department work to introduce new fuel-efficient operating methods, install new and more energy-efficient technology, reduce the vessels' hydrodynamic resistance, and recover energy (Viking Line, 2016). The M/S Viking Grace is the most fuel efficient and environmentally friendly vessel on the Baltic, and the first passenger vessel of its size and class in the world to run on LNG.

6.2 M/S Viking Grace

The M/S Viking Grace is a cruise ferry built at STX Europe Turku Shipyard for the Finland based ferry company Viking Line. The ferry took service on 13 January 2013 and is the first large scale passenger ferry to be powered by Liquefied Natural Gas (LNG), which results in lowered GHG emissions. With its LNG powered engines, hydro-dynamically optimised hull design and soundproofing technology, the M/S Viking Grace is the greenest and quietest ferry in the Baltic Sea, as well as globally.

The vessel is powered by four Wärtsilä 8L50D engines. The new technology allows the engines to operate on LNG, Light Fuel Oil (LFO) and Heavy Fuel Oil (HFO). Switching fuel can take place seamlessly during operation without loss of power or speed.

When operating on LNG fuel, NO_x emissions are at least 85% below those specified in the MARPOL regulations. CO_2 emissions are around 25% lower than those of conventional marine engines running on diesel fuel oil; and SOx and particle emissions are negligible, at almost zero percent (Viking Line, 2016).

The author had the opportunity to visit the Viking Grace and take a trip from Turku, Finland to Stockholm, Sweden, during which she visited the engine control room and was able to examine the many methods and innovations that the M/S Viking Grace had adopted to reduce GHG emissions and all other types of pollution. The solid waste management system separates waste into the following categories: mixed waste (for partial recycling), recyclable wastes (cardboard, paper, glass, metal, cooking oil, electronics), and problem wastes. All waste is taken ashore to a certified receiving station, in compliance with the applicable regulations. All waste oil is taken ashore for recycling, and can be used as supplementary fuel during cement production. The hull is regularly cleaned by divers to reduce the drag, and thereby increasing fuel efficiency.

Figure 5 Engine Control Room of the Viking Grace, Source: Author

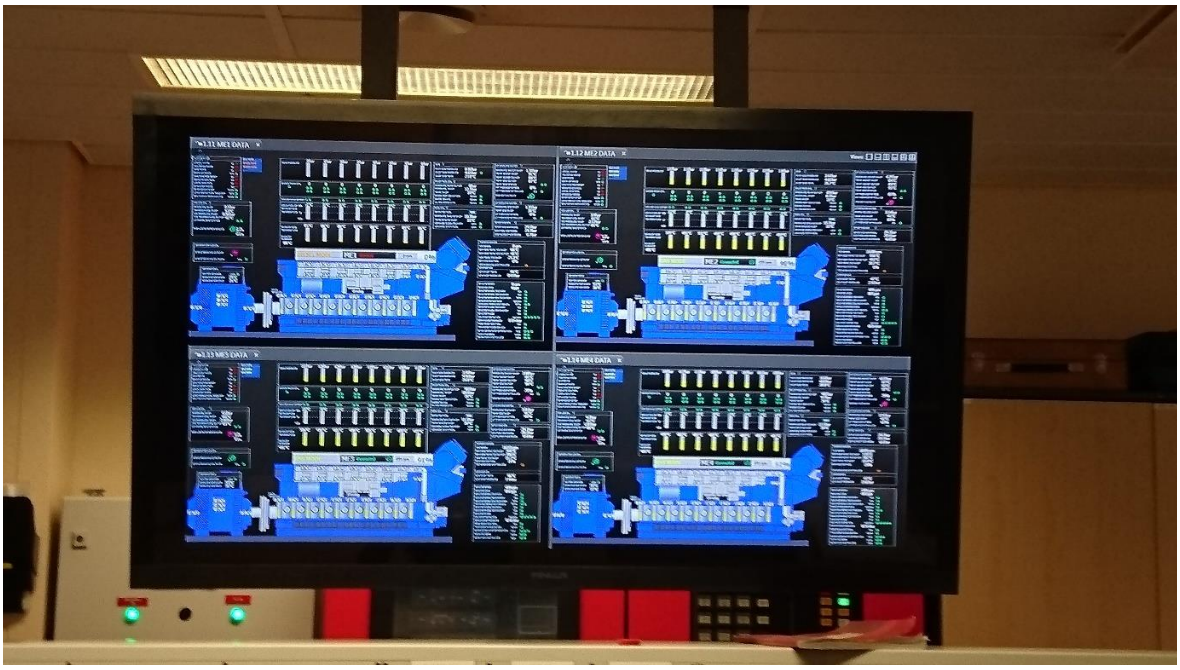

Figure 6 Engine control room screen for the 4 Wärtsilä Engines, Source: Author

6.3 Viking Lines Performance on Emissions

Viking Line notes the following: “Fuel consumption is highly proportionate to the distance travelled. It is also affected by weather, ice conditions, route planning, the vessel’s trim, speed regulations and the vessel’s electric power and energy efficiency. Preventive engine maintenance is also important to ensure a high level of operational efficiency. In 2016, the fleet’s consumption of diesel oil fell by 1.2% (992 tonnes), and LNG fell by 3.4% (520 tonnes). This reduced consumption is mainly the result of ongoing energy efficiency and savings measures, but was also affected by somewhat longer service interruptions, due to scheduled maintenance” (Viking Line, 2016).

Table 4 below is snapshot of the performance of Viking Line from 2014 to 2016 on the reduction of GHG emissions in their operations.

Table 4 Viking Line Emissions Comparison 2014-2016, Source: This study

GHG and other air emissions	**2014**	**2015**	**2016**
GHG (tonnes CO_2 equiv.)	307,853	286,797	283,109
SOx (tonnes)	433	76	75
NOx (tonnes)	3,684	3,218	3,122

6.4 Maersk Line

Maersk Line is the largest container shipping company in the world, operating out of 374 offices in 116 countries, and providing transportation in all parts of the world. It employs approximately 7100 seafarers and 23000 land-based employees. The fleet consists of 639 vessels that are deployed on every major trade lane in the world. Maersk Line is part of the AP Moller Maersk Group, a Danish company based in Copenhagen, Denmark. The company’s liner business also includes Safmarine, Seago Line, SeaLand and MCC Transport (Maersk, 2017b). In 2011, Maersk Line signed a contract with Korea’s Daewoo Shipbuilding & Marine Engineering Co. Ltd. to build 10 of the largest and most efficient container vessels called the Triple E class to be delivered between 2013 and 2015 (Maersk, 2011).

6.5 Triple E Class

The vessels were called the Triple E class to reflect the economy of scale they introduce, along with their energy efficiency and environmental improvements. The aim was to surpass industry standards for fuel efficiency and CO_2 emissions per container move. Each vessel cost USD 190 million (Maersk, 2011).

Maersk aims to reduce their CO_2 emissions by 25% by 2020 (compared to 2007 emission levels) and the technology used by the Triple E class will help reduce the company’s CO_2 emissions by 14 percent. The Triple E has two slow-running engines, and two large propellers. The result of this combination is an energy saving of four percent, compared to a one engine/one propeller design. The efficiency of the vessel is boosted further by a heat recovery system situated in the engine room that captures and reuses heat and pressure from the engine’s exhaust that would normally escape as wasted energy.

Reusing the waste heat increases power to the engine by nine percent, reducing fuel consumption by a subsequent nine percent.

6.6 Maersk Line's Performance on Environmental Indicators

Table 5 below is a consolidation of the Performance on Social, Environmental and Economic Indicator reports that are available on the Maersk website. GHG, SOx and NOx measurements have been selected to show progress (or lack thereof) made from 2011 to 2016 (Maersk, 2014, Maersk, 2015, Maersk, 2016).

In 2011, the GHG emissions from Maersk operations measured at 34,187,000 tonnes. SO_x and NO_x emissions measured at 597,000 tonnes and 858,000 tonnes respectively. In 2015, the GHG measurement was reduced to 27,973,000 tonnes, SO_x and NO_x measurements had also reduced considerably due to the measures implemented by Maersk. However, in 2016 there was an increase in all emissions measurements which can be attributed Maersk Line's capacity increase of 9,4% in 2016 (Maersk, 2017a).

Table 5 Maersk Line Emissions Comparison 2011-2014. Source: This study

GHG and other air emissions	2011	2012	2013	2014	2015	2016
GHG (1000 tonnes CO2 equiv.)	34187	31792	28014	27332	27973	30461
SOx (1000 tonnes)	597	555	473	466	458	489
NOx (1000 tonnes)	858	797	701	690	702	751

6.7 Costs of Compliance

Some of the costs of compliance include building new vessels to meet regulations, retrofitting vessels with engines and scrubbers, using bunker fuels with low sulphur emissions. The alternative would be to risk vessels being blacklisted by the PSC or being fined for non-compliance.

6.7.1 Building New Vessels that Meet Regulations:

As stated in the previous chapter, the cost of the new Maersk Triple E vessel was USD190 million for each vessel. For the 10 vessels that were ordered at that time, the total cost would consequently be USD1.9 billion. These are just 10 of the 639 vessels that Maersk owns and operates.

6.7.2 Using Retrofitted Engines/Scrubbers/Rotor Sails to Reduce GHG Emissions from Ships that are Already in the Market:

For vessels that are already in the market, the main option would be to either retrofit a scrubber or an engine. This research study has not attempted to estimate the costs of a fully-retrofitted engine, but a scrubber would cost a shipowner between USD3 million to USD 12 million (Mcqueen, 2015).

Retrofitting a rotor sail costs between €1million and €2million to install (Smith, 2018).

Table 6 Costs of Complying to MARPOL Annex VI regulations Source: This study adapted from (EPA, 2009)

Speed	**Low**	**Low**
Type of Vessel	**2500 TEU container vessel**	**6000 TEU container vessel**
Engine Power kW	**15,000**	**48,000**
Cylinders	**8**	**12**
Liters/cylinder	**650**	**1400**
Engine Speed	**110**	**100**
Retrofit Kits (Fuel Injectors) -($/engine)	$22,145	$36,496
Diffferential costs for engine modifications ($/engine)	$11,365	$12,996
Common Rail fuel injection costs for Mechanical Engines ($/engine)	$184,026	$259,710
Common Rail fuel injection costs for Electronic Engines ($/engine)	$60,018	$81,685
Diffferential costs for engine modifications for Tier II ($/engine)	$93,495	$129,061
Exhaust Gas recirculation	$158,097	$251,058
Sea Water Scrubber Costs	$862,058	$1,717,497
Fuel Switching costs (New Construction)	$55,958	$74,652
Fuel Switching Costs (Retrofits)	$76,630	$100,492

6.7.3 Using Bunker Fuels with Low Sulphur Emissions.

The Bunkerworld Index (BWI) is a weighted fuel pricing index made up of the 20 key bunkering ports: Busan, Canary Islands, Colombo, Durban, Fujairah, Gibraltar, Hong Kong, Houston, Los Angeles, New York, Off-Nigeria, Panama Canal, Piraeus, Rotterdam, Santos, Shanghai, Singapore, St Petersburg, Suez, Tokyo. These ports were selected by size with reference to their geographical importance (Bunkerworld, 2018).

a) Figure 7 and Figure 8 provide the average dollar value index for 380 cSt and 180 CSt Marine Fuel Oils respectively. The average value for 380 cSt for 2017 was $340/mt and $360/mt for 180 cSt MFO. The sulphur content of Marine Fuel Oils is less than 3%, which is much higher than the ECA requirements. These grades of fuel oil are available worldwide and the global demand for MFO is approximately 200 million tonnes per year (Draffin et al., 2012).

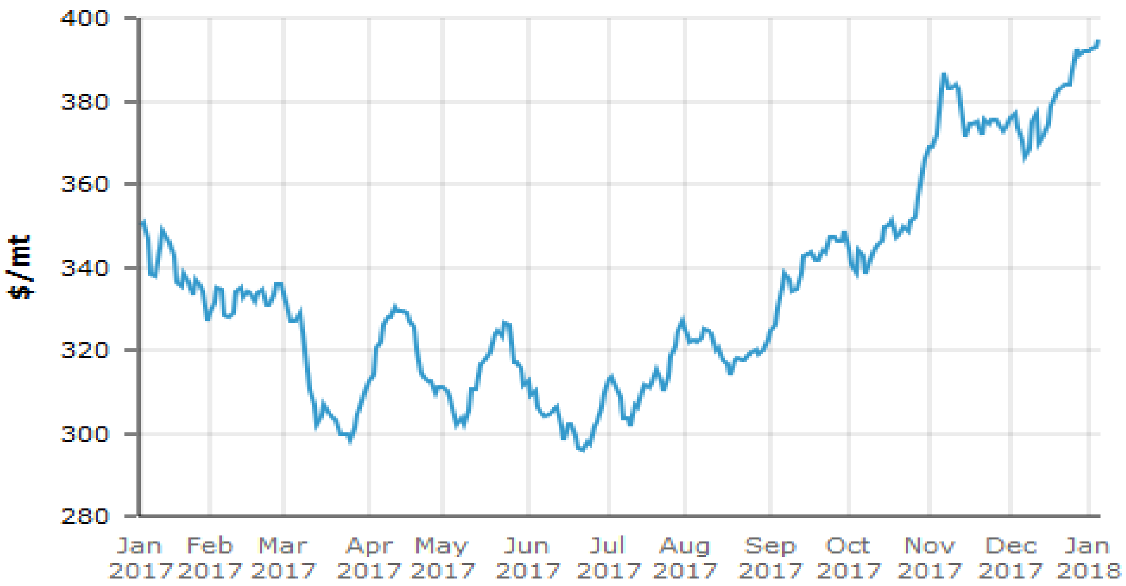

Figure 7 BW380 Average Monthly Fuel Price Jan 2017 to Jan 2018, Source: Bunkerworld

Figure 8 BW180 Average monthly fuel price Jan 2017 to Jan 2018, Source: (Bunkerworld, 2018)

b) The BW Distillate Index (DI) is an average dollar value index of Marine Diesel Oil (MDO) and Marine Gas Oil (MGO) distillate fuels. Distillate is a lighter and cleaner fuel compared to MFO and the sulphur content is between 1-1.5% and can be easily reduced to 0.1% for ECA compliance (Latarche, 2017). However, the average dollar value for BWDI in 2017 was approximately 52% more than the price of 380 cSt MFO in the same period.

Figure 9 BWDI average monthly fuel price Jan 2017 to Jan 2018, Source: (Bunkerworld, 2018)

c) The BW0.1%S Index is an average dollar value index of distillate fuels that comply with the 2015 Emissions Control Area (ECA) sulphur limit from 14 of the 20 key bunkering ports mentioned above. These fuels are also known as low sulphur fuel oils (LSFO) or ultra-low sulphur fuel oils (ULSFO). These fuels are marine fuel oils or distillates which have gone through a refining process to remove sulphur, metals and other contaminants (Latarche, 2017). The BW0.1%S Index comprises prices from the following ports and grades: Busan, Canary Islands, Fujairah, Gibraltar, Hong Kong, Houston, Los Angeles, New York, Panama Canal, Piraeus, Rotterdam, Singapore, St. Petersburg and Tokyo. The average dollar value of the 0.1%S fuel for 2017 was $520/mt.

Figure 10 BW0.1%S average monthly price Jan 2017 to Jan 2018, Source:(Bunkerworld, 2018)

d) As evidenced above, fuels with a lower sulphur content are far more expensive than the fuels with high sulphur content. Table 6 is a consolidation of the data provided in the figures above providing a comparative analysis of the dollar values of the selected fuel types. Distillates and 0.1$S fuel types cost, on average, $180/mt more than the easily available marine fuel oils. As stated earlier, the current worldwide market for residual fuel is around 200 million tonnes. This volume of fuel will have to be further processed at an increased cost to meet the emissions requirements proposed for the 2020 worldwide regulations of 0.5% sulphur content. The use of the LSFO will also require ship engines to be retrofitted.

Table 7 A comparative analysis of prices ($/mt) of the different fuel types according to BWI, Source: This study

Fuel Type	Jan-17	Feb-17	Mar-17	Apr-17	May-17	Jun-17	Jul-17	Aug-17	Sep-17	Oct-17	Nov-17	Dec-17	Jan-18
BW380	350	330	335	320	310	310	312	328	320	350	370	375	390
BW180	370	350	360	340	330	335	325	350	340	370	390	400	410
BWDI	520	510	520	500	490	470	460	500	500	540	550	570	600
BW0.1%S	520	510	520	480	480	470	450	490	500	550	550	570	605

6.8 Paying Fines and Detentions for Non-Compliance:

Within the ECA in Europe and the Baltic Sea, the Paris MoU is an agreement between 27 member states that enforces the MARPOL regulations and has specific guidelines (attached at Appendix II) for inspections and implementation. Should a vessel be inspected and not have compliant fuel, the vessel may be detained. Vessel flags are separated into “White” (low detention record), “Grey” (average performance on inspections), and “Black” (high detention record). On the “White, Grey and Black list” for 2016, a total number of 73 flags are listed: 42 on the “White List”, 19 on the “Grey List” and 12 on the “Black list” (MoU, 2017). (See Appendix III with full list for 2016 performance.) In the North American and Caribbean Emissions Control Area (ECA), The US Environmental Protection Agency (EPA) released a client alert in 2015, stating that should a client (shipowner) violate the MARPOL Annex VI emissions standards, a penalty/fine may be imposed. The penalty/fine may be up to USD 25,000 per day per violation (EPA, 2015). In 2014, the Mediterranean Shipping Company (MSC) was fined USD630,000.00 for failing to reduce its NO_x and particle matter emissions at berth at a California port.(WorldMaritime, 2018)

6.9 Conclusion

This chapter has shown that it is possible for companies to reduce emissions from ships. However, this comes from significant efforts and costs from all shipowners, charterers and role players within the industry. The industry first needs to understand the regulations and then investigate the emission-reducing options that would be most suitable for a specific type of vessel. This will also be dependent on where the ship is operating and the access to the optimal fuel.

CHAPTER SEVEN

OVERVIEW AND CONCLUSIONS

The previous chapters have provided an overview of the formation of the regulations by the IMO, the MEPC discussions over the past 20 years along with the amendments to the regulations, the options for reducing emissions on vessels during design phase or with retrofitting, the costs of these improvements along with the case studies of Maersk and Viking Lines. It is evident that the costs of adhering to the MARPOL Annex VI regulations are high and will certainly require significant investment from ship owners. This chapter will cover the ISPS Code as it is similar to the MARPOL Annex VI regulations as it was also a global regulation that was implemented in the Maritime Industry that incurred significant costs. The regulations of emissions from road vehicles will also be briefly mentioned as the costs for emissions have been passed on to the consumer. And finally, the study will discuss progress made with regard to shipping lines passing the costs of reducing emissions to the shippers/cargo owners.

7.1 ISPS Code

Similar to the MARPOL Annex VI regulations, On 1 July 2004, the 2002 amendments to the 1974 International Convention for the Safety of Life at Sea (SOLAS) and the new International Ship and Port Facility Security Code (ISPS Code) entered into force, and became mandatory for all SOLAS Member States. The SOLAS amendments and the ISPS Code impose wide-ranging obligations on governments, shipping companies, and port facilities. Implementing these obligations entails costs and potential economic implications (UNCTAD, 2007). The United Nations Conference on Trade and Development (UNCTAD) conducted a study of the costs associated with the implementation of the ISPS Code by surveying the affected parties, i.e. ports, port users, ship owners, etc. (UNCTAD, 2007).

Certain shipping lines, such as Safmarine and Maersk Line, had implemented a charge called “Carrier Security Charge…” which, they describe, refers to “…charges associated with the Carrier compliance to the ISPS code on vessel and container security measures applicable on all cargo on a container basis.” At the time of implementation, the charge was 6USD per container (Safmarine, 2005).

7.2 The Regulation of Emissions in the Motor Industry in South Africa

Currently in South Africa, vehicle manufacturers/importers are subject to carbon tax. This tax is passed on to consumers of the new vehicle, as the purchaser is the person who ultimately is responsible for the GHG emissions from the vehicle. The amount payable is between 0.6% and 4.1% of the value of the vehicle and is dependent on the emissions of the vehicle (SARS, 2010).

7.3 Have Shipping Companies Passed on any of these Costs?

In 2016, the IMF called for a carbon tax to be levied on aviation and shipping to help deliver global climate goals. A charge of USD 30 per tonne of cargo was proposed to raise approximately USD 25 billion to be used as a possible source for climate finance. This money would not go to National governments or assist shipping companies to meet their own targets for reduction of GHG emissions but will be used for “mitigation and adaption in developing economies” (IMF, 2016).

There question remains as to where the shipping industry obtains the finance to reduce their emissions. Until now, it is usually taken from their own budgets, and if the IMF goes ahead with its current plans, this will continue, putting business in the sector at risk. Shipping has always been a volatile industry and is affected by macroeconomic conditions worldwide.

After the world economic crisis in 2008, the world economic situation brightened in 2010. However, multiple risks now threatened to undermine the prospects of a sustained recovery and a stable world economy nearly a decade since the crisis, including sovereign debt problems in many developed regions, and fiscal austerity. These risks are further magnified by the extraordinary shocks that occurred in 2011, which have included natural disasters and political unrest, as well as rising and volatile energy and commodity prices. After contracting in 2009, with container freight rates as low as USD400/TEU to transport cargo from Shanghai to Europe (SSE, 2009),   international shipping experienced an upswing in demand in 2010, and recorded a positive turnaround in seaborne trade volumes especially in the dry bulk and container trade segments. The outlook remained fragile, as seaborne trade is subject to the same uncertainties and shocks that face the world economy. However, there were still new vessels being delivered from orders prior to the crisis, which further exacerbated the problems by creating an oversupply of tonnage (UNCTAD, 2011). The freight rates rose to USD1489/TEU at the end of 2013 and in March 2016 fell to a low of USD400/FFE (forty foot equivalent) for cargo from China to Europe. This further worsened the situation that the shipping lines and caused the collapse of Hanjin, a South Korean shipping line, which filed for bankruptcy in August 2016 (Petersen, 2016).

The MARPOL Annex VI regulations will continue to require ship owners to invest in modernising their fleets. Unless older tonnage is demolished, this would lead to further global overcapacity, continuing the downward pressure on freight and charter rates. The interplay between more stringent environmental regulations and low freight and charter rates should encourage the further demolition of older vessels; this will not only help reduce the oversupply in the market, but also contribute to lowering the global environmental impact of shipping (UNCTAD, 2015). This, however, does not take into consideration the fact that ship owners are in this business to make a profit, and that investments in newer vessels, which are technically within the regulation requirements, are very expensive. Shipping is a derived demand (Stopford, 2009), and for this reason, if there were no shippers/cargo owners, there would be no need for ships, thereby no GHG emissions from ships.

In 2018, Maersk Line announced their intention to become carbon neutral by 2050. They have invested over USD 1bn to investigate and implement energy efficient solutions for their fleet (WorldMaritime, 2018). Following in the wake of Maersk Line, CMA CGM, MSC, Hapag Lloyd and Ocean Network Express (ONE) have stated that they would be calculating their Bunker Adjustment Factor differently pre- and post- sulphur cap implementation. The BAF calculation will be broken down by trade lane, consumption, load factors and then multiplied by a bunker unit cost. There are differences between the BAF charges that each shipping line will be implementing. MSC have suggest a headhaul BAF of

USD248 per TEU and backhaul BAF of USD96 per TEU on the Asia-Northern Europe trade lane. On the same trade lane, Japan's Ocean Network Express has provided USD125 per TEU for the headhaul and USD100 per TEU for the backhaul (Chambers, 2019).

7.4 Conclusion

It was only very recently that shipping lines have decided to increase their charges to their customers for the costs and fines that they have incurred in reducing emissions from vessels. This has been met with considerable resistance and opposition from cargo owners, as it increases the cost of importing and exporting their shipments. The Hong Kong Shippers Councils are not in favour of more surcharges and have alluded to shipping lines profiting from these surcharges. The British International Freight Association also echoed similar sentiments saying that sulphur cap surcharges are unjustified and blatant profiteering: "While the shipping operators may say that the new BAFs are needed to cover the cost of switching to low sulphur fuels or fitting exhaust scrubbers, rises of this magnitude are unjustified and could be construed as blatant profiteering by shipping lines determined to exploit the situation." (Chambers, 2019)

This study has provided a comprehensive overview of the MARPOL Annex VI regulations and it is evident that the onus has been put on ship owners to ensure that they are complying and that they face the repercussions on non-compliance. However, in a market that is driven by a derived-demand nexus, it is not unreasonable that the shippers bear some of the cost of compliance. The carrying lines may consequently consider the implementation of mechanisms to attempt to recover some of the costs from the shippers in a manner akin to the automotive industry where the consumer pays the emissions tax. Should the shipping lines not recoup their costs, it would leave them with huge losses and further consolidation within the industry. This will not bode well for the shippers in the long run.

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