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Factors analysis: GHG emissions from international shipping

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WORLD MARITIME UNIVERSITY

Shanghai, China

Factors Analysis: GHG Emissions from International Shipping

BY

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China

A research paper submitted to the World Maritime University in partial fulfillments of the requirements for the award the degree of

MASTER OF SCIENCE

International Transportation and Logistics

2016

Declaration

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

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

Signature: Cui Weijia.

2016-08-16

Supervised by

Professor Liu Wei

World Maritime University

Acknowledgement

First and foremost, I want to express my deepest appreciation to Ms. Wen Xiyuan and Mr. Shi Xin, who are in charge of this program on behalf of Shanghai Maritime University for their great and continuous contribution and support during my master’s study.

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ABSTRACT

Title of Dissertation: **Analysis of Factors GHG Emissions from International Shipping**

Degree: **Master of Science**

The increased demand of seaborne transportation and the increasing attention to the issue of air pollution have increased interest in GHG emissions from international ships. Air pollutants such as SOx, NOx, PM (particulate matter), ozone and CO_2 seriously influence public health. The ship exhaust emissions issue is one of the significant challenges that the international shipping industry has to overcome. The aim of the International Maritime Organization (IMO) is aim to abate greenhouse gas (GHG) emissions from existing vessels by 20–50% by 2050.

Based on that background, the research paper is divided into four parts. First, the paper analyzes five main factors that may affect the GHG emissions from international shipping. Second, the research paper introduces some current approaches to mitigate ship GHG emissions and provides some potential measures that could be taken in the future in terms of the five main factors.

Third, this research paper identifies difficulties and barriers to implement each measure of emission reduction, and then offers suggestions to fix these difficulties and barriers. Lastly, the paper discusses the importance of China controlling international ship emissions and summarizes the current situation regarding China mitigating GHG emissions from international shipping. The paper concludes with the message that the entire international industry should pay more attention to combating ship exhaust emissions.

KEYWORDS: Mitigate ship GHG emissions, Ship exhaust gases, International shipping, International ships, Measures of emission reduction, China mitigating GHG emissions, Factors Analysis

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List of Abbreviations

CO_2	Carbon dioxide
EEDI	Energy Efficiency Design Index
EEOI	Energy Efficient Operational Index
ECR	Exhaust Gas Recirculation
ECA	Emission Control Area
EF	Emissions Factor
GHG	Green House Gas
GT	Gross Tonnage
HFO	Heavy Fuel Oil
HSD	High-speed Diesel (engine)
IMO	International Maritime Organization (www.imo.org)
ISO	International Organization for Standardization
LNG	Liquefied Natural Gas
MDO	Marine Diesel Oil
MGO	Marine Gas Oil
MEPC	Marine Environment Protection Committee
NO_x	Nitrogen Oxides
PM	Particulate Matter
SO_x	Sulphur Oxides
SEEMP	Shipping Energy Efficiency Management Plan
SFOC	Specific Fuel Oil Consumption
SCR	Selective Catalytic Reduction
UNCTAD	United Nations Conference of Trade and Development

Chapter 1 Introduction

1.1 Background

The rapid development of global economic could not leave international shipping industry. International trade heavily relies on international shipping which by carrying cargoes from production nation to consumption nation to complete international trading activities. At present, with 80% of the volume of world trade carried by sea, and over 90% of international trade transported by international shipping. Despite international shipping playing a key role in global economics, there are still some serious concerns regarding the environmental impacts.

With regard to the environmental performance of transport, the maritime transport mode compares favorably with other transport modes both in terms of consumption of energy and production of pollution (including air pollution) per unit of transport work performed (UNCTAD, 2009). Compared with other transport modes, maritime transport – in particular where larger ships are used – surpasses other modes of transport in terms of fuel efficiency and climate friendliness. (UNCTAD, 2009) On a per ton kilometre (km) basis and depending on ship sizes, CO_2 emissions from shipping are lower than emissions from other modes. For example, emissions from rail could be 3 to 4 times higher than emissions from tankers, while emissions from road and air transport could, respectively, be 5 to 150 times and 54 to 150 times higher.(UNCTAD, 2009) Equally, in terms of fuel consumption (kilowatt (kW)/ton/km), a container ship (3,700 twenty-foot equivalent units (TEUs)), for instance, is estimated to consume on average 77 times less energy than a freight aircraft (Boeing 747-400), about 7 times less than a heavy truck and about 3 times less than rail.(UNCTAD, 2009)

In spite of an energy-efficient mode of transport, shipping is a significant source of GHG emission because of a huge amount of demand of transport as well as is a major source of air pollution. With regard to the adverse effects of ship exhaust emissions upon the environment, it is important to mention that marine engines produce significant exhaust quantities mainly due to their sizable power and the use of low-grade fuels. (Kilic, A. and Tzannatos, E., 2014)

According to current estimate presented in the Third IMO GHG Study 2014, international shipping emitted 796 million tonnes of CO_2 in 2012, which accounts for no more than about 2.2% of the total emission volume for year. (IMO, 2015) By contrast in 2007, before the global economic downturn, international shipping is estimated to have emitted 885 million tonnes of CO_2, which represented 2.8% of global emission of CO_2 for that year. (IMO, 2015) These percentages are all the more significant when considering that shipping is the principle carrier of world trade, carry as much as 90% by volume and therefore providing a vital service to global economic development and prosperity. (IMO, 2015) That said, the mid-range forecasted scenarios presented in this Third IMO GHG Study 2014 shows that, by 2050, CO_2 emission from international shipping could grow by between 50% and 250%. Depend on future economic growth and energy developments. (IMO, 2015)

The Third IMO GHG Study2014 estimates multi-year (2007–2012) average annual totals of 20.9 million and 11.3 million tonnes for NO_x (as NO_2) and SO_x (as SO_2) from all shipping, respectively (corresponding to 6.3 million and5.6 million tonnes converted to elemental weights for nitrogen and sulphur respectively). (IMO, 2015) NO_x and SO_x play indirect roles in tropospheric ozone formation and indirect aerosol warming at regional scales. Annually, international shipping is estimated to produce approximately 18.6 million and 10.6 million tonnes of NO_x (as NO_2) and SO_x (as

SO_2) respectively; this converts to totals of 5.6 million and 5.3 million tonnes of NO_x and SO_x respectively (as elemental nitrogen and sulphur respectively). (IMO, 2015) Global NO_x and SO_x emissions from all shipping represent about 15% and 13% of global NO_x and SO_x from anthropogenic sources reported in the IPCC Fifth Assessment Report (AR5), respectively; international shipping NO_x and SO_x represent approximately 13% and 12% of global NO_x and SO_x totals respectively. (IMO,2014)

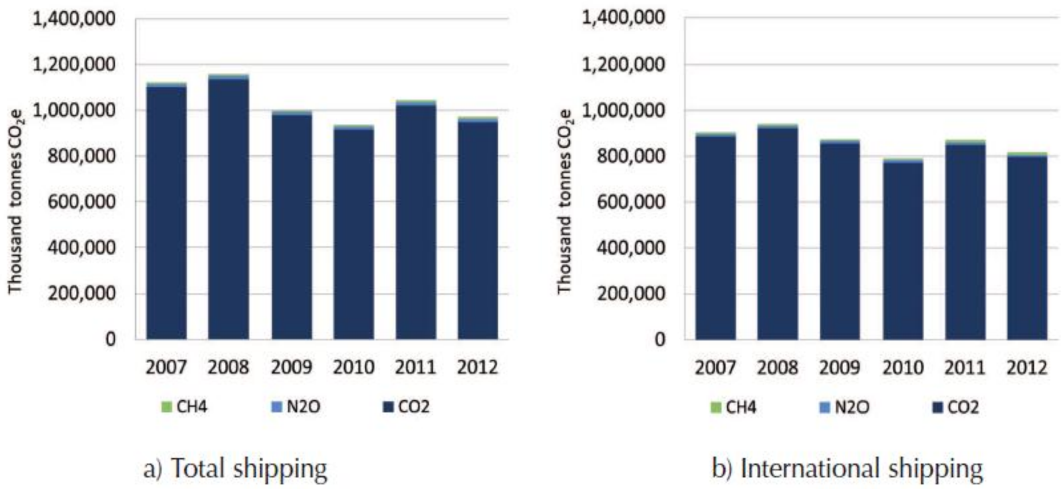

Figure 1 – Time series of bottom-up CO_2e emissions estimates for a) total shipping and b) international shipping

Source: International Maritime Organization. (2015). *Third IMO Greenhouse Gas Study 2014*. London.

As per the figure 1, a) is CO_2e emissions from total shipping, b) is CO_2e emissions only from international shipping. By reading the figure 1 and comparing the a) with the b), we could know that almost 80%~85% of CO_2e emissions from international shipping.

In recent years, with the fleetly development of cargo turnover volume of international shipping, the amount of greenhouse gases produced by international shipping is increasingly growing up year by year. GHG emissions and other relevant substances from international shipping, has gained more and more attention from the whole of society, meanwhile emissions from international shipping is really a serious issue faced by the whole society. According to the above mentioned rationale, the entire international shipping industry should pay more attention to finding main factors which affect emissions and implement effective measures to mitigate the harmful impacts on environment.

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1.2 Objectives of the Study

The first objective of the research paper is trying to find the main factors which have a great impact on emissions from international shipping. The second objective of the research paper is to summarize the current methods of controlling GHG emissions and finding feasible and effective measures that can be implemented in the future. The third objective of the research paper is to analyse the potential difficulties of taking exact measures and offering some suggestions to solve those issues. The fourth objective is introducing the importance and characteristic of China controlling GHG emissions from international shipping.

1.3 Methodology

The purposes of the research paper are finding the main factors that affect ship exhaust gases, providing feasible and effective measures to mitigate GHG emissions, and offering some suggestion to measures that go well. To achieve the mentioned purposes, the paper applies quantitative analysis method and model analysis method to find possible factors that could affect emission. As well it is expedient to apply qualitative methods, experiential summary method and literature research method to find and access the measures of mitigating GHG emissions from international shipping.

1.4 Outline of the Research Paper

Chapter 2, Literature review, aims to overview relevant academic articles and researches as well as reports about GHG emissions and other relevant substances from international shipping. **Chapter 3, The Factor to Affect GHG Emission from International Shipping**. In this Chapter, five factors are presented and analysed. **Chapter 4, Approaches to Mitigate Ship Exhaust Gases**. Based on the previous factors analysed, this chapter represents several measures for mitigating emissions, which include current measures taken and potential measures that could be implemented in the future. **Chapter 5, Barriers and Difficulties to Implement Measures of Emission Reduction.** For presenting the current and corresponding realistic situation, this chapter proposes possible and potential difficulties of implementing these measures, meanwhile it recommends some advice to solve relevant issues. **Chapter 6, the importance of China controlling international ship exhaust gases**. This chapter introduces the current situation of China controlling international ship exhaust gases, and analyses the existing problems of China developing low carbon and green shipping industry, then offers some suggestions for China to do better in regards to contributions on emission reduction of international shipping. **Conclusion 7, s**ummarizes the analysis and explains the limitations of the paper.

Chapter 2 Literature Review

As stated in the previous chapter, the GHG emissions from international shipping raised the attention from whole society. According to the Third IMO Greenhouse Gas Study 2014, over 80% of total shipping GHG emissions comes from international shipping. Maritime emissions projections show an increase in fuel use and GHG emissions in the period up to 2050, despite significant regulatory and market-driven improvements in efficiency. Depending on future economic and energy developments, our BAU scenarios project an increase of 50%–250% in the period up to 2050. (IMO, 2015, p.145) The main driver of the emissions increase is the projected rise in demand for maritime transport. (IMO, 2015, p.145), depending on future economic growth and energy developments. (IMO, 2015)

The definition of international shipping: shipping between ports of different countries, as opposed to domestic shipping. International shipping excludes military and fishing vessels. By this definition, the same ship may frequently be engaged in both international and domestic shipping operations. This is consistent with the IPCC 2006 Guidelines (Second IMO GHG Study 2009). (IMO, 2015)

The definition of domestic shipping: shipping between ports of the same country, as opposed to international shipping. Domestic shipping excludes military and fishing vessels. By this definition, the same ship may frequently be engaged in both international and domestic shipping operations. This definition is consistent with the IPCC 2006 Guidelines (Second IMO GHG Study 2009). (IMO, 2015)

Guido Emilio ROSSI and Fabio BALLINI (2013) represented that due to combustion characteristics of typical marine engines and a wide-spread use of unrefined fuel, the global fleet emits significant amounts of SO_2, NOx, particles, ozone and CO_2.Pollution emissions from vessels have a significant impact on public health and global climate changes and it is an urgent matter to reduce it. (Guido Emilio ROSSI & Fabio BALLINI, 2013, p.134)

XU Huan, LIU Wei, XU Meng-jie (2012) mention that: first, the co- integration relationship exists among them, namely, they have formed a stable, balanced, and long-term relationship; second, world seaborne trade and world GDP are Granger causation of carbon dioxide emission from international shipping. (XU Huan, LIU Wei, XU Meng-jie mentioned, 2012)

JONG-KYUN WOO* and DANIEL SEONG-HYEOK MOON (2013) Slow steaming is helpful in reducing the amount of CO_2 emissions, whereas it is not always useful to reduce the operating costs. As the voyage speed decreases, more CO_2 emissions can be reduced. (JONG-KYUN WOO and DANIEL SEONG-HYEOK MOON, 2013, p.188)

Dong Zhou (2011) mentioned that the environmental contribution from slow steaming is considerable. (Dong Zhou, 2011, p.2) Box shipping giant, A.P. Moller-Maersk reduced 9% of CO_2 emissions in 2008 compared with 2007. More significantly, every 10% of speed reduction helps to reduce 19% of CO_2 emissions per ton-mile. (UNCTAD, 2010, p. 66) (Dong Zhou, 2011, p.2)

Guido Emilio ROSSI and Fabio BALLINI (2013) state that the amount of sulfur emissions after combustion is obviously related to the amount of sulfur in the fuel. The limits to the percentage of sulfur also considerably reduce particulate emissions

(Guido Emilio ROSSI & Fabio BALLINI, 2013, p.135)

Three primary emission sources are found on ships: main engine(s), auxiliary engines and boilers. (IMO, 2015, p.102) Emissions from the main engine(s) or propulsion engine(s) (both in terms of magnitude and emissions factor) vary as a function of main engine rated power output, load factor and the engine build year. (IMO, 2015, p.102) Emissions from auxiliary engines (both in terms of magnitude and emissions factor) vary as a function of auxiliary power demand (typically changing by vessel operation mode), auxiliary engine rated power output, load factor and the engine build year. (IMO, 2015, p.102) Emissions from auxiliary boilers vary based on vessel class and operational mode. (IMO, 2015, p.103)

Sarah Mander (2016) mentioned that Maritime Organization(IMO) which in principle accepts that the shipping industry “will make its fair and proportionate contribution” to the levels of mitigation deemed necessary to reduce the likelihood of a global mean temperature rise commensurate with averting dangerous climate change (IMO, 2011) and has introduced two policies to this end, the Energy Efficiency Design Index(EEDI) applicable to new ships and the use of Ship Energy Efficiency Management Plans(SEEMP)for the existing fleet (IMO, 2014). (Sarah Mander, 2016)

Kilic,A. and Tzannatos,E (2014) mentioned that the International Maritime Organization (IMO) regulates the sulphur content of marine fuels according to sailing area and NOx emissions according to engine power. (Kilic,A. & Tzannatos,E, 2014, p.1335). At the present, there are 2 ECAs only limit SO_x emission: Baltic sea, North sea; and 2 ECAs both limit NO_x and SO_x emissions: North America, United states Caribbean Sea.

Michael Malonia, Jomon Aliyas Paulb and David M. Gligorc (2013) mentioned tht shippers have voiced significant concerns over the parity of the benefits, mainly regarding longer transit times. (Michael Malonia, Jomon Aliyas Paulb and David M. Gligorc, 2013, p.153) First and foremost, longer transit times directly increase shipper in-transit (pipeline) inventory levels (Bonney and Leach, 2010; Dupin, 2011b). Longer transit times also extend the forecast horizon, thus likely decreasing forecast accuracy and subsequently increasing safety stock needs (Bonney and Leach, 2010; Dupin, 2011b) and making just-in-time shipment volumes more difficult to estimate (Dupin, 2011b). Similarly, longer transit times create challenges with perishable and short life cycle products (like clothing and electronics) (Page, 2011). (Michael Malonia, Jomon Aliyas Paulb and David M. Gligorc, 2013, p.153)

Dr. Fabio Ballini Daniel Neumann, Prof. Jørgen Brandt, Dr. Armin Aulinger, Prof. Aykut OLCER, Dr. Volker Matthias (2015) assumed that a vessel which is equipped with a wind propulsion device uses on average 35% less power and, thus, saves 35% fuels and emits 35% less pollutants. (Dr. Fabio Ballini Daniel Neumann, Prof. Jørgen Brandt, Dr. Armin Aulinger, Prof. Aykut OLCER, Dr. Volker Matthias, 2015, p.8)

Nishatabbas Rehmatulla, Sophia Parker, Tristan Smith, Victoria Stulgis (2015)said that The abatement potential of wind technologies on ships is estimated to be around 10–60% by various sources. (Nishatabbas Rehmatulla, Sophia Parker, Tristan Smith, Victoria Stulgis, 2015, p.1) Nishatabbas Rehmatulla, Sophia Parker, Tristan Smith, Victoria Stulgis (2015) analyzed that the inhibit uptake of energy efficiency measures in shipping and provided a systematic analysis of the viability of wind technology on ships and the barriers to their implementation, both from the perspective of the technology providers and technology users(shipowner–operators). (Nishatabbas Rehmatulla, Sophia Parker, Tristan Smith, Victoria Stulgis, 2015, p.1)

A.I. Ölçer and F. Ballini (2015) mentioned that the low-sulphur limits of the Emission Control Areas (ECA) in the North Sea and Baltic Sea will depend on the choice of technologies and investment strategies that shipping companies can adopt, given as: (1) Low-sulphur fuel (MGO 0.1%); (2) LNG or bio fuels as a marine fuel; (3) Emission abatement technologies such as scrubbers. (A.I. Ölçer and F. Ballini, 2015, p.151)

Young C. Kwon said that the CO_2 abatement solutions proposed by the IMO (e.g. SEEMP Guidelines) do not give sufficient reliability to ship owners due to uncertainties of various parameters surrounding ships depending on ship type, size and age. These uncertainties prevent the ship owners from employing the CO_2 abatement solutions to their ships. (Young C. Kwon, 2011, p.10) Young C. Kwon thought that SSEMP is the general explanation of solutions without any consideration of different ship types and various operating conditions. (Young C. Kwon, 2011, p.9) In practice, not all solutions can be applicable to all ships in different operating conditions; some solutions are mutually exclusive with other solutions (IMO, 2012). (Young C. Kwon, 2011, p.9)

Guido Emilio ROSSI and Fabio BALLINI (2013) mentioned that LNG offers the ability to reduce sulfur oxide and nitrogen oxide emissions significantly (SOx<0.01%). Potentially, carbon emissions could be cut by 20 percent. SOx emissions of LNG comply with the SECA restrictions. LNG is cheaper compared to conventional fuel and this reason, combined with the strong reduction of polluting emissions, suggests an increase in the use of LNG in shipping in the near future. (Guido Emilio ROSSI & Fabio BALLINI, 2013, p.137)

Liu Xian Cheng (2012) has analyzed the current subject situation of China developing low carbon shipping industry and has offered some suggestions to help China further develop a low carbon shipping industry. (Liu Xian Cheng, 2012)

Chen Xueyin and Zhang Xiaoli (2014) analyzed that under the background of free trade zone, how China is developing a green shipping industry. They have discussed the issues faced in China and provided some advice regarding the establishment of a low carbon shipping industry. (Chen Xueyin & Zhang Xiaoli, 2014)

Liu Yannian and Ji Yulong (2015) analyzed the measures to ship reduce GHG emissions. And they provided some suggestion to ships to implement measures of controlling GHG emissions in terms of EEDI and EEOI formulas. (Liu Yannian & Ji Yulong, 2015)

Chapter 3 The Factors Affecting GHG Emission from International Shipping

The main purpose of this chapter is finding and analysing the main factors to affect GHG emission from international shipping. It may adapt the quantitative analysis method and model analysis method as well as literature research method to achieve the purpose.

3.1 International Trade Affects GHG Emissions from International Ships

International trade could not exist alone without international shipping, international trade carried by international shipping, thus both parties closely connect with each other. We assume that if international trade presents increased trend, the demand of international shipping will be increased as well. Conversely, when the international trade is shrinking, the shortage of international traded cargo would decrease the demand of international shipping.

Compared with other economic activities, the international shipping industry has special characteristics. Professor Shuo Ma has mentioned that "maritime transport is a service sector with a derived demand from trade. In other words, shipping does not create its own demand, its demand is derived from the need of trade in goods." It is easy to understand that there is no country which could produce or offer all of the necessities or commodities by itself. Thus there is the need for carrying goods from one country to another. What's more, due competitiveness in shipping transport being low cost, most international traders prefer to ship goods by sea. Therefore, international trade creates a demand for international shipping. As above mentioned, we could infer that there should be a positive correlation between the volume of international trade and international shipping, namely, international trade may be an important factor of influencing emissions from international shipping. In order to verify that international trade might be a factor that affects GHG emissions from international shipping, this research paper would quota an article written by Liu Wei which is named ‘study on the relationship among carbon emission from international shipping, world seaborne trade amounts and global economic activity’.

Liu Wei supposed that there may exist a long-term and stationary relationship among GHGs emission from international shipping, world seaborne trade and international economic. For verifying the relationship, he used the co-integration theory of econometrics and set up co-integration equation based on time series to reflect the long-term equilibrium relationship among GHGs emission from international shipping, world seaborne trade and international economics. This research paper simply explains that co-integration theory mainly explores the long-term equilibrium relationship among non-stationary economic variables, which means those economic variables are non-stationary series, but their linear combination should be stationary. In order to identify a set of non-stationary linear whether is co-integration relationship or not, the unit root test and Granger causality test as well as the Johansen test would be applied.

Liu Wei selected global GDP as indicator of measuring international economic trend, chose cargo turnover amount by international shipping as indicator of international trade, and picked up the data of CO_2 emission from international shipping which has been published by International Maritime Organization (IMO) behalf on GHG emissions of international shipping. Those three data are all collected from 1990 to 2010, as well as each of data represents annual performance. Liu Wei deployed the software of Econometric Views as a tool to set up a Co-integration equation based on three mentioned variables. This research paper simply explains how Liu Wei arrived at the Co-integration equation

Table 1 - CO_2 emissions from international shipping, word seaborne trade in ton-miles and world GDP from 1990 to 2010

Year	CE	T	GDP
1990	468	17121	21,920,792,256,960.0
1991	488	17873	22,995,566,641,243.6
1992	498	18228	24,546,395,695,297.8
1993	519	18994	24,915,078,827,178.5
1994	535	19600	26,752,109,865,946.3
1995	551	20188	29,692,894,750,906.3
1996	565	20678	30,303,289,996,658.9
1997	596	21672	30,222,356,622,951.4
1998	590	21425	30,115,107,530,226.9
1999	601	21480	31,231,321,824,407.9
2000	647	23693	32,240,383,199,090.1
2001	652	23891	32,046,348,810,620.3
2002	660	24172	33,304,640,616,151.2
2003	706	25854	37,465,967,921,629.8
2004	755	27574	42,228,984,476,590.6
2005	795	29598	45,658,316,886,272.4
2006	838	31447	49,506,293,314,880.4
2007	870	32932	55,848,896,227,304.2
2008	878	32746	61,304,541,579,435.6
2009	862	31432	58,088,277,293,607.5
2010	912	33632	63,123,887,517,709.3

Source: Liu Wei. & Xu Huan. & Xu Mengjie. (2012). Study on the relationship among carbon emission from international shipping, world seaborne trade and global economic activity. Science and Technology Management. 2014 (13).

Table 2 - The result of data processing

Year	LNCE	LNT	LNGDP
1990	6.1484683	9.7480611	30.71846

1991	6.1903154	9.7910465	30.76632
1992	6.2106001	9.8107142	30.83159
1993	6.2519039	9.8518784	30.84649
1994	6.2822667	9.8832848	30.91763
1995	6.3117348	9.9128436	31.02193
1996	6.3368257	9.9368256	31.04228
1997	6.3902407	9.9837764	31.0396
1998	6.3801225	9.9723137	31.03605
1999	6.3985949	9.9748775	31.07244
2000	6.4723463	10.072935	31.10424
2001	6.4800446	10.081257	31.0982
2002	6.4922398	10.09295	31.13672
2003	6.5596152	10.160221	31.25445
2004	6.6267177	10.224629	31.37413
2005	6.6783421	10.295462	31.45221
2006	6.7310181	10.356059	31.53312
2007	6.7684932	10.4022	31.65367
2008	6.7776466	10.396536	31.74688
2009	6.7592553	10.355582	31.69298
2010	6.81564	10.423233	31.77612

Source: Liu Wei. & Xu Huan. & Xu Mengjie. (2012). Study on the relationship among carbon emission from international shipping, world seaborne trade and global economic activity. Science and Technology Management. 2014 (13).

First, in order to avoid mistakes, data usually are transformed into Natural logarithm (shown as LN) before they are inputted into E-views. Next, they are inputted into those processed data into E-views, then a unit root test, Granger causality and Johansen test are done. Finally, the Co-integration equation is obtained as follows:

$$Lnce = 0.008982Lngdp+0.8531621Lnt+0.004036 \quad (3.1)$$

Where

Lnce is CO_2 emission from international shipping

Lngdp is GDP

Lnt is cargo turnover amount by international shipping

The result of the equation obviously shows that there is a long-term and Co-integrated relationship existing among world seaborne trade, international economic activities and CO_2 emission from international shipping. Furthermore, we can see that the elasticity coefficient of world seaborne trade is 0.85 and of international economic is 0.00898, which means world seaborne trade as one of the main factors which may increase CO_2 emissions from international shipping. According to the equation, we could know that if the per unit of world seaborne trade changes by 1%, CO_2 emissions from international shipping will change by 0.85%. The volatility of world seaborne trade could cause the change of the amount of CO_2 emissions from international shipping. However, nowadays over 90% of international trade is transported by international shipping, thus world seaborne trade closely relies on international trade. Hence, it can be said that international trade may affect emissions from international shipping.

3.2 Technical Factor

The main engine, auxiliary engine and boiler are three main technical machineries installed on ship. The main engine is the predominant propulsion equipment of a ship, which is the main dynamic source for ships moving on the sea. The auxiliary engine normally generates electricity and is a facility providing power for a ship completing daily operations. The boiler is a steam generation facility of the ship. In terms of ship fuel consumption, the fuel consumption of the main engine accounts for 87% of the vessel’s total fuel consumption, and the fuel consumption of the auxiliary engine accounts for 11% of the vessel’s total fuel consumption, and the fuel consumption of the boiler accounts for 2% of the vessel’s total fuel consumption.

Figure 2 shows annual fuel consumption broken down by ship type and machinery component. We can see that the top three of the consuming fuel are occupied by the container ship, oil tanker and dry bulk ship. We can know that the main engine plays the main role in respect of fuel consumption. For an auxiliary engine, even if it consumes less fuel than the main engine, which still takes up nearly one third of total fuel consumption of each vessel fleet. For a container vessel fleet and an oil tanker fleet, the boiler is a significant fuel consumer as well, which cannot be ignored. Due to above three machineries having direct impact on fuel consumption, they would be an influential factor affecting GHG emissions from international shipping. This is further discussed as follows:

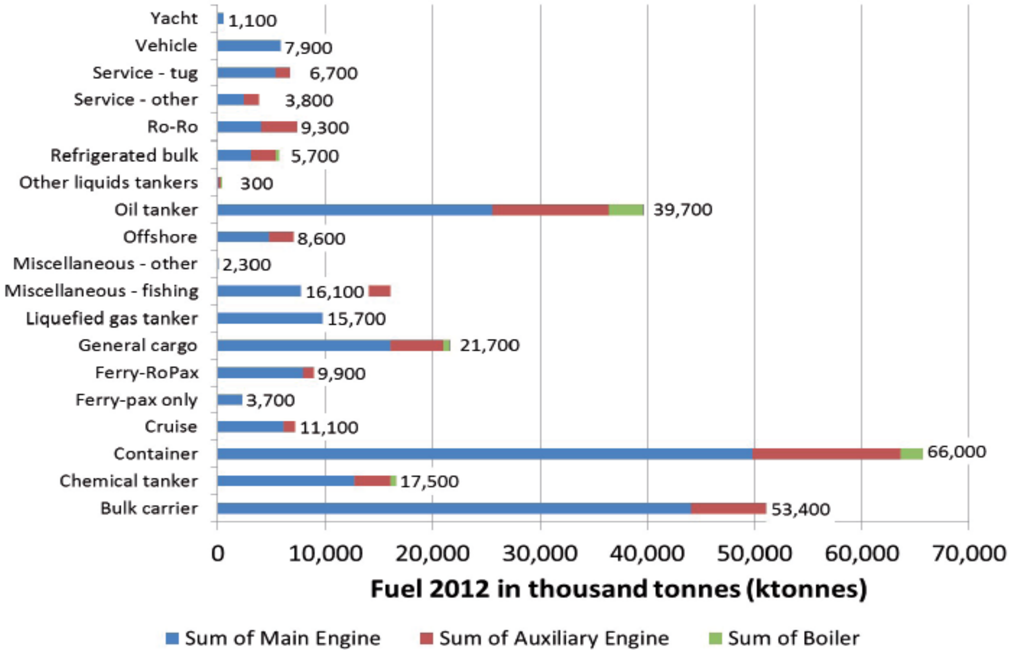

Figure 2 - Summary graph of annual fuel consumption broken down by ship type and machinery component 2012

Source: International Maritime Organization. (2015). *Third IMO Greenhouse Gas Study 2014*. London.

3.2.1 Rated Output, Load Factor and Engine Build Year of Engines

GHG emission from main engine or auxiliary engine decided by rated power output, load factor and the engine build year. (IMO, 2014)

IMO even mentioned in 3rd IMO GHG Study 2014 that “Three primary emission sources are found on ships: main engine(s), auxiliary engines and boilers.” (IMO, 2014) And it also explained that “Emission from main engines or propulsion engines vary as a function of main engine rated power output, load factor and the engine build year. Emission from auxiliary engine vary as a function of auxiliary power demand, auxiliary engine rated output, load factor and engine build year” (IMO, 2014) It means, the technical design of main engine and auxiliary engine could make sense on emissions from international shipping, and the build years or used years of main engine and auxiliary engine may be another factor affecting emission. What’s more, the technical skill of repairs and maintenances for main engines and auxiliary engines might also have effect on GHG emissions from international shipping.

3.2.2 Main Engine Types

NOx emissions vary as main engine types.

Engine type and rated power may influence the GHG emissions from international shipping**.** Table 3 shows the Specific Fuel Oil Consumption (SFOC) for different engine type. We could clearly know from table 3 that SFOC is changed by engine type, for example, SSD and MSD use same fuel HFO, the SFOC of SSD is 195g/kWh, however the SFOC of MSD is 215g/kWh, hence the SFOC for baseline emissions factors depends on engine type and rated speed of engine. Table 4 describes IMO Tier I and II SFOC assumptions for NOx baseline emissions factors. We could find from Table 4 that the same IMO Tier of main engine with different rated speed, the SFOCs are different. For instance, main engines with the same IMO Tier I, the SFOC of SSD is 195g/kWh and the SFOC of MSD is 215g/kWh. In other words, when the fuel type is constant, SFOC would change with different engine types. What's more, the IMO Tier also influences NOx emissions. The IMO Tier is classified by the build year of ship, in other words, the ship build year will affect NO_x emission. We can see in the Table 5, under the same engine speed/type and fuel, different IMO Tiers have different emission factors ($EF_{baseline}$). Such as, under SSD and HFO, compared IMO I with IMO II, the ME $EF_{baseline}$ of IMO I is 87.18 kg/tone fuel; the ME $EF_{baseline}$ of IMO II is 78.46 kg/tone fuel. In sum, Engine type, rated power of engine and IMO Tier all may influence GHG emissions from international shipping.

Table 3 – EF-related SFOCs used to convert energy-based baseline emissions factors to fuel-based

Engine type	Rated speed	Fuel	SFOC g/kWh	Source
Main/SSD	SSD	HFO	195	IVL 2004
		MGO/MDO	185	IVL 2004
Main/MSD	MSD	HFO	215	IVL 2004
		MGO/MDO	205	IVL 2004
Main/HSD	HSD	HFO	215	IVL 2004
		MGO/MDO	205	IVL 2004
Aux MSD & HSD	MSD/HSD	HFO	227	IVL 2004
		MGO/MDO	217	IVL 2004
LNG (Otto cycle)	na	LNG	116	Wartslia 2014

Source: International Maritime Organization. (2015). *Third IMO Greenhouse Gas Study 2014*. London.

Table 4 – IMO Tier I and II SFOC assumptions for NO_x baseline emissions factors

Engine type	**IMO Tier**	**Rated Speed**	**SFOC g/kWh**
Main	I	SSD	195
	I	MSD	215
	II	SSD	195
	II	MSD	215
Auxiliary	I	MSD/HSO	227
	II	MSD/HSO	227

Source: International Maritime Organization. (2015). *Third IMO Greenhouse Gas Study 2014.* London.

Notes: SSD: slow-speed diesel engines; MSD: medium-speed diesel engines; HSD: high-speed diesel engines.

Table 5 – NO_x baseline emissions factors

IMO Tier	**Engine Speed/Type**	**Fuel Type**	**SFOC ME/ Aux**	**ME $EF_{baseline}$(kg/tone fuel)**	**Aux eng $EF_{baseline}$(kg/tone fuel)**	**Reference**
0	SSD	HFO	195/na	92.82	na	ENTEC 2002
	MSD	HFO	215/227	65.12	64.76	ENTEC 2002
	HSD	HFO	na/227	na	51.10	ENTEC 2002
1	SSD	HFO	195/na	87.18	na	IMO Tier I
	MSD	HFO	215/227	60.47	57.27	IMO Tier I
	HSD	HFO	na/227	na	45.81	IMO Tier I
2	SSD	HFO	195/na	78.46	na	IMO Tier II
	MSD	HFO	215/227	52.09	49.34	IMO Tier II

	HSD	MDO	na/227	na	36.12	IMO Tier II
all	Otto	LNG	166	7.83	7.83	Kristensen, 2012
na	GT	HFO	305	20.00	na	IVL, 2004
na	STM	HFO	305	6.89	na	IVL, 2004

Source: International Maritime Organization. (2015). *Third IMO Greenhouse Gas Study 2014.* London.

Notes: GT – gas turbine; STM – steam boiler

3.2.3 Boiler

For boiler, 3rd IMO GHG Study 2014 mentioned that “Emissions from auxiliary boilers vary based on vessel class and operational mode.” (IMO, 2014) For example, tankers typically have large steam plants powered by large boilers that supply steam to the cargo pumps and in some cases heat cargo. (IMO, 2014) For most non-tanker class vessels, boilers are used to supply hot water to keep the main engine warm. (IMO, 2014) In terms of figure 2, it is easy to see that the boiler of a tanker consumes more fuel oil than container ships and dry bulk ships, because container ships and dry bulk vessels do not use boiler during open-ocean operations and they use the waste head from main engine for economizing. Relative to main engines and auxiliary engines, boilers do not consume fuel oil as much as them, but it is still one of the main fuel consumers for international ships.

In short, engines’ rated power output, load factor, build year, IMO Tiers etc. are concluded as technical factors which may influence international ships exhaust gases.

3.3 Fuel Type

Fuel type could be considered as a factor that affects GHG emissions from international ships.

There are 8 key pollutants as follows emitted from international shipping.

- Carbon dioxide (CO_2)
- Nitrogen Oxides（NO_x）
- Sulphur oxides (SO_x)
- Particulate matter(PM)
- Carbon monoxide(CO)
- Methane (CH_4)
- Nitrous oxide(N_2O)
- Non-methane volatile organic compounds(NMVOC)

This research paper will mainly dfiscuss CO_2 NO_x SO_x PM.

There are 5 types of marine fuel as followings:

- Marine HFO is heavy fuel oil;
- Intermediate fuel oil is IFO
- Marine diesel oil is MDO
- Marine gas oil is MGO
- Liquefied natural gas LNG

The key emission factors have a close connection with the fuel types such as HFO, LNG, MDO, MGO. What's more, the sulfur contained in fuel will directly influence the SO_x emissions from international ships. They can be explained with the following tables:

3.3.1 CO_2 Emission

The amount of carbon contained in the fuel will decide the amount of CO_2 emissions from international shipping. The carbon content of each fuel type is constant, and it is not influenced by engine type, rated power, duty cycle, etc. The fuel-based CO_2 emissions factors for main and auxiliary engines at slow, medium and high speeds are based on ME PC 63/23, annex 8, and include (IMO, 2014, p105):

HFO $EF_{baseline}CO_2$=3114kg CO_2/tonne fuel (3.2) (IMO, 2014, p105)

MDO/MGO $EF_{baseline}CO_2$=3206kg CO_2/tonne fuel (3.3) (IMO, 2014, p105)

LNG $EF_{baseline}CO_2$=2750kg CO_2/tonne fuel (3.4) (IMO, 2014, p105)

Where
EF is emission factor
HFO is heavy fuel oil
MDO is marine diesel oil
MGO is marine gas oil
LNG is liquefied natural gas

By comparing the above 3 equations, LNG CO_2 emission factor is the smallest among them, and the CO_2 emission factor of HFO is slightly less than MGO/MDO. If a ship combusts LNG, it will emit less CO_2 than combusting HFO or MDO. Therefore, the fuel type would affect CO_2 emissions from international ships.

3.3.2 NO_X Emission

As per table 6, table 7 and table 8, we can see that NO_x emissions change somewhat between HFO and distillate fuels. As per Table 7 and Table 8, we know that sulfur content does not change NOx emissions.

In terms of Table 6, when we compared LNG fuel with HFO and distillate fuels, the SFOC, Main engine (ME) $EF_{baseline}$ and Auxiliary Engine (AE) $EF_{baseline}$ of LNG are the lowest. It means that if the ship combusts the LNG fuel, it will emit less NO_x gases than if it combusts HFO or MGO. Hence, fuel type is a factor affecting ship exhaust gases.

Table 6 – NO_x baseline emissions factors

IMO Tier	**Engine Speed/Type**	**Fuel Type**	**SFOC ME/ Aux**	**ME $EF_{baseline}$(kg/tone fuel)**	**Aux eng $EF_{baseline}$(kg/tone fuel)**	**Reference**
0	SSD	HFO	195/na	92.82	na	ENTEC 2002
	MSD	HFO	215/227	65.12	64.76	ENTEC 2002
	HSD	HFO	na/227	na	51.10	ENTEC 2002
1	SSD	HFO	195/na	87.18	na	IMO Tier I
	MSD	HFO	215/227	60.47	57.27	IMO Tier I
	HSD	HFO	na/227	na	45.81	IMO Tier I
2	SSD	HFO	195/na	78.46	na	IMO Tier II
	MSD	HFO	215/227	52.09	49.34	IMO Tier II
	HSD	MDO	na/227	na	36.12	IMO Tier II
all	Otto	LNG	166	7.83	7.83	Kristensen, 2012
na	GT	HFO	305	20.00	na	IVL, 2004
na	STM	HFO	305	6.89	na	IVL, 2004

Source: International Maritime Organization. (2015). *Third IMO Greenhouse Gas Study 2014*. London.

Notes: GT – gas turbine; STM – steam boiler

Table 7 – NOx FCFs – HFO global sulphur averages

Engine Type	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**
HFO Sulphur%	2.42	2.37	2.60	2.61	2.65	2.51
Main SSD	1.00	1.00	1.00	1.00	1.00	1.00
Main MSD	1.00	1.00	1.00	1.00	1.00	1.00
Aux MSD	1.00	1.00	1.00	1.00	1.00	1.00
Aux HSD	1.00	1.00	1.00	1.00	1.00	1.00
GT	1.00	1.00	1.00	1.00	1.00	1.00
ST	1.00	1.00	1.00	1.00	1.00	1.00

Source: International Maritime Organization. (2015). *Third IMO Greenhouse Gas Study2014*. London.

Table 8 - NOx FCFs – MGO global sulphur averages

Engine Type	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**
MDO/MGO Sulphur%	0.15	0.15	0.15	0.15	0.14	0.14
Main SSD	0.94	0.94	0.94	0.94	0.94	0.94
Main MSD	0.94	0.94	0.94	0.94	0.94	0.94
Aux MSD	0.94	0.94	0.94	0.94	0.94	0.94
Aux HSD	0.94	0.94	0.94	0.94	0.94	0.94
GT	0.97	0.97	0.97	0.97	0.97	0.97
ST	0.95	0.95	0.95	0.95	0.95	0.95

Source: International Maritime Organization. (2015). *Third IMO Greenhouse Gas Study 2014.* London.

3.3.3 SO_x and PM Emission

In terms of table 9, table 10, table 11 and table 12, we know that the percent of sulfur content in fuel can directly influence the SO_x and PM emissions from international ships, the higher sulfur content in the fuel, the higher are the SO_x and PM emissions from international ships. Hence, the sulphur content should be the factor affects GHG emissions from international shipping.

Table 9 - SO_x FCFs – HFO global sulphur averages

Engine Type	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**
HFO Sulphur%	2.42	2.37	2.6	2.61	2.65	2.51
Main SSD	0.90	0.88	0.96	0.97	0.98	0.93
Main MSD	0.90	0.88	0.96	0.97	0.98	0.93
Aux MSD	0.90	0.88	0.96	0.97	0.98	0.93
Aux HSD	0.90	0.88	0.96	0.97	0.98	0.93
GT	0.90	0.88	0.96	0.97	0.98	0.93
ST	0.90	0.88	0.96	0.97	0.98	0.93

Source: International Maritime Organization. (2015). *Third IMO Greenhouse Gas Study 2014.* London.

Table 10 - SO_x FCFs – MGO global sulphur averages

Engine Type	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**
MDO/MGO Sulphur%	0.15	0.15	0.15	0.15	0.14	0.14
Main SSD	0.05	0.05	0.05	0.05	0.05	0.05

Main MSD	0.05	0.05	0.05	0.05	0.05	0.05
Aux MSD	0.05	0.05	0.05	0.05	0.05	0.05
Aux HSD	0.05	0.05	0.05	0.05	0.05	0.05
GT	0.05	0.05	0.05	0.05	0.05	0.05
ST	0.05	0.05	0.05	0.05	0.05	0.05

Source: International Maritime Organization. (2015). *Third IMO Greenhouse Gas Study 2014*. London.

Table 11 - PM FCFs – HFO global sulphur averages

Engine Type	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**
HFO Sulphur%	2.42	2.37	2.60	2.61	2.65	2.51
Main SSD	0.94	0.93	0.98	0.98	0.99	0.96
Main MSD	0.93	0.92	0.98	0.98	0.99	0.96
Aux MSD	0.93	0.92	0.98	0.98	0.99	0.95
Aux HSD	0.93	0.92	0.98	0.98	0.99	0.95
GT	0.91	0.89	0.97	0.97	0.98	0.94
ST	0.91	0.89	0.97	0.97	0.98	0.94

Source: International Maritime Organization. (2015). *Third IMO Greenhouse Gas Study 2014*. London.

Table 12 - PM FCFs – MGO global sulphur averages

Engine Type	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**
MDO/MGO Sulphur%	0.15	0.15	0.15	0.15	0.14	0.14
Main SSD	0.14	0.14	0.14	0.14	0.14	0.14
Main MSD	0.14	0.14	0.14	0.14	0.14	0.14
Aux MSD	0.14	0.14	0.14	0.14	0.14	0.14

Aux HSD	0.14	0.14	0.14	0.14	0.14	0.14
GT	0.13	0.13	0.13	0.13	0.12	0.12
ST	0.13	0.13	0.13	0.13	0.12	0.12

Source: International Maritime Organization. (2015). *Third IMO Greenhouse Gas Study 2014*. London.

3.3.4 Summary

With the respect to Table 13, we can see that the differences of emission factors of CO_2, CH_4 and N_2O between Marine HFO and Marine MDO is slight. Then the HFO and MDO have the same the emission factors of CO and NMVOC. Moreover, comparing the emissions factor of Marine LNG with Marine HFO and Marine MDO, we can know that the emissions factor of LNG is the smallest, which means LNG might be currently the cleanest fuel. In sum, the fuel type is one of main factors affecting emissions from international shipping.

Table 13 – Emission factors for bottom-up emissions due to the combustion of fuels

Emission species	**Marine HFO Emission factor (g/g fuel)**	**Marine MDO Emission factor (g/g fuel)**	**Marine LNG Emission factor (g/g fuel)**
CO_2	3.11400	3.20600	2.75000
CH_4	0.00006	0.00006	0.05120
N_2O	0.00016	0.00015	0.00011
NO_x Tier 0 SSD	0.09282	0.08725	0.00783
NO_x Tier 1 SSD	0.08718	0.08195	0.00783
NO_x Tier 2 SSD	0.07846	0.07375	0.00783

NO_x Tier 0 MSD	0.06512	0.06121	0.00783
NO_x Tier 1 MSD	0.06047	0.05684	0.00783
NO_x Tier 2 MSD	0.05209	0.04896	0.00783
CO	0.00277	0.00277	0.00783
NMVOC	0.00908	0.00308	0.00301

Source: International Maritime Organization. (2015). *Third IMO Greenhouse Gas Study 2014*. London.

3.4 Operational Factor

The way of operating a vessel may be a factor that affecting ship exhaust gases. Vessel operation includes vessel speed, routing design etc.

‘Full’ speed for a container ship might typically be 24 knots (generally 85–90 percent of engine capacity) (Bonney, 2010a). Reducing vessel speed to 21 knots represents ‘slow’ steaming, with 18 knots defined as ‘extra slow’ and 15 knots as ‘super slow’ (Bonney and Leach, 2010). Slower speeds generally improve vessel fuel efficiency (Rosenthal, 2010), allowing ship-owners and carriers to save on the cost of bunker.

3.4.1 Slow Steaming Reports Analysis

There is some evidence from reports that prove slow steaming could reduce ship exhaust gases.

According to the IMO report, during 2007 and 2010, the large container vessels have reduced their daily fuel consumption by 70% through sailing vessels at 60%-70% of designed speeds. By taking slow steaming strategy, the large oil tankers present reduction around 50%. Over the same time period, the whole fleet may reduce the fuel consumption by around 27%. Moreover, every 10% of speed reduction helps to reduce 19% of CO_2 emission per ton-mile. (UNCTAD, 2010, p. 66)

3.4.2 Slow Steaming Mathematical Models Analysis

Analyze the slow steaming mathematical models to qualify the reduced CO_2 emissions from slow steaming.

First of all, Michael Malonia, Jomon Aliyas Paulb and David M. Gligor have set up an environmental effects model of slow steaming. They have estimated CO_2 emissions from vessels based on a factor of 3.17 MT of emissions per MT of fuel burned (Corbett et al, 2009; International Maritime Organization, 2009). The model describes the annual carbon dioxide (CO_2) emissions (million MT) from vessels (2010 and 2015 volume), which is clear to summarize the reduction of CO_2 emissions by adopting a slow steaming strategy.

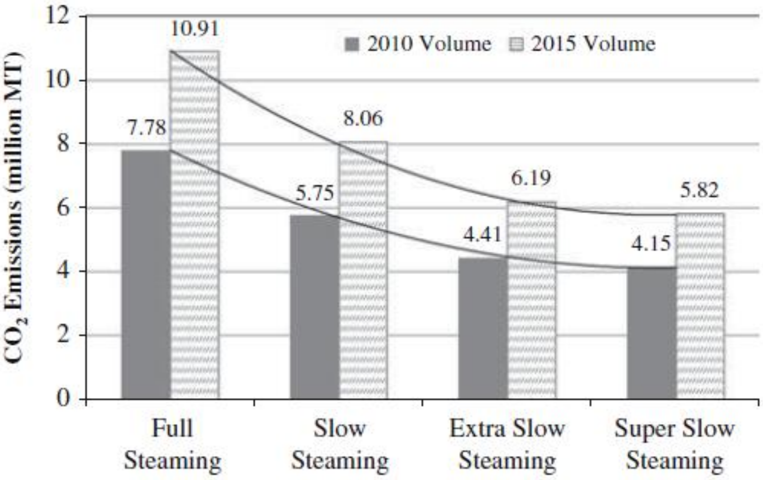

Figure 3 – Annual CO_2 emissions （million MT）from vessels (2010 and 2015 volume)

Source: Michael Malonia, Jomon Aliyas Paulb and David M. Gligorc. (2013). Slow steaming impact on ocean carriers and shippers. *Maritime Economics & Logistics, 15*(2), 151-171.

As per figure 3, for 2011 volume, slow steaming decreases by 26.1% compared to full steaming, the extra slow steaming lowers CO_2 emissions by around 43.3% compared to full steaming, and the super slow steaming roughly mitigates CO_2 emissions by 46.7% compared with full steaming. For 2015 volume, comparing full steaming and slow steaming, slow steaming decreases 2.85 million MT from full speeds, which is equal to a decrease of 26.1% from full speed. Extra slow steaming lowers annual CO_2 emissions by 43.2% (4.72 million MT) from full speed. Super slow steaming shows a decrease of 46.7% (5.09 million MT) from full speed.

Second, fuel consumption has high correlation with GHG emissions, thus the higher the fuel consumption the higher are the GHG emissions, especially CO_2 emissions. However, the amount of fuel consumption relied on condition of engine such as the engine load and engine size as well as Specific Fuel Oil Consumption (SFOC) and vessel operation speed (voyage speed). Jong-Kyun Woo & Daniel Seong-Hyeok Moon (2014) defined the annual fuel consumption on a single vessel (AFCV) as a formula:

$$AFCV = SFOCV*EP*(AVS/DVS)3*Od*^{24/106} \quad (3.5)$$

Where

AFCV is the annual fuel consumption on a single vessel (ton)
SFOCV is the specific fuel oil consumption at different voyage speed (ton/knots/day)
EP is the engine power (kW)
AVS is the changed voyage speed (10–25 knots)
DVS is the designed voyage speed (25 knots)
AVS is the average vessel size (TEU)
Od is operation day

According to the formula, there are 4 variables as follows: SFOCV, AVS, DVS, and Od. We assume that DVS, Od and EP are constant, thus the value of $(AVS/DVS)^3$ will decrease as AVC goes down. And SFOCV decided by voyage speed which is increased as speed up, thus if we want to get low value of AFCV, the AVS is the main factor which controls the final value of AFCV. Therefore, we could say slow speed could reduce the fuel consumption, at the same time it would reduce the GHG emissions from international shipping.

Jong-Kyun Woo & Daniel Seong-Hyeok Moon have argued that slow steaming is helpful in reducing the amount of CO_2 emissions. They created a simulation named System Dynamic Environmental Evaluation Model (SDEEM), which applied to simulate the net impact of slow steaming on CO_2 emissions by shifting voyage speed from 25knots to10knots. Figure 4 is the SDEEM model, which shows the relationship between the amounts of GHG（CO_2）emissions and slow steaming. In terms of the outcome of simulation (shown in Figure 4), GHG (CO_2) emissions are decreased as the voyage speed is reduced.

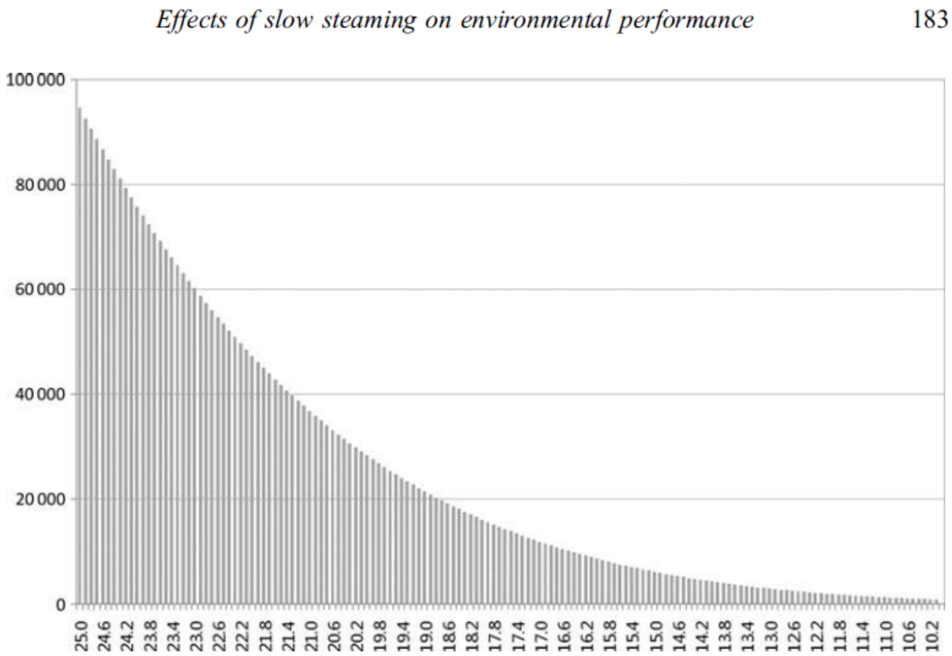

Figure 4 – Relationship between voyage speed and the amount of CO_2 emissions

Source: JONG-KYUN WOO* & Daniel, SEONG-HYEOK MOON. (2014). The effects of slow steaming on the environmental performance in liner shipping. *Maritime Policy and Management*, *41*(2), 176-191.

Third, the relationship between ship main engine power and ship speed can be depicted by the formula below:

$$P_e = \triangle^{2/3}V^3 \quad (3.6)$$

Where

P_e is main engine power

$\triangle$ is Tonnage

V is speed

According to the formula when the vessel speed is reduced by 10%, the main engine power decreases correspondingly by 28.2%, and the fuel consumption is reduced by

20.1%. Thus operating a vessel at a slow speed could decrease fuel consumption and accordingly reduce the ship's GHG emissions.

In addition, Pierre Cariou has calculated the reduction of CO_2 emissions on different trade lines which implement slow steaming strategy. In terms of his results of calculation, from 2008 to 2010, carbon emissions can probably be lowered to around 11% by implementing slow steaming strategy. The main three advantages of slow steaming are reduction in fuel consumption, controlling in GHG emissions and absorption of extra capacities (Drewry Shipping Consultancy, 2010) All in all, operational exigencies could well be a significant factor with regard to exhaust emissions from international shipping.

3.5 The Legislation and Regulation Factor

Regulation may be an influential factor in international shipping emissions since it can provide a standardized criterion for regulating the emissions from international shipping and it is also a powerful and reliable way to monitor and control emissions from international shipping. For example, MARPOL Annex VI, contains many regulations for the prevention of air pollution from ships. These regulations mainly limit and regulate the major air pollutants emitted by ships. For instance, sulphur oxides (SOx) and nitrous oxides (NOx) as well as particular matter (PM). Moreover, some countries and regions have already established Emission Control Areas (ECAs) for controlling and governing emissions from ships that enter those areas. According to the examination of ECAs, the emission reduction in ECAs exactly gets expected effect

MARPOL Annex VI was revised in 2005, the goal of which was to enhance the measures for emission limits in accordance with technical progress and practical experience. After three years, MARPOL Annex VI was revised again in 2008 and the associated NOx Technical Code 2008, which entered force on 1 July 2010. (http://www.imo.org/en/OurWork/Environment/PollutionPrevention/AirPollution/Pages/Air-Pollution.aspx)

There are several remarkable improvements and important changes in the revised MARPOL. These changes and challenges aim to increasingly mitigate major air pollutants contained in emissions from international ships. MARPOL Annex VI introduces and encourages that nations and regions set up emission control areas (ECAs) to mitigate air pollutants emissions from international shipping. Meanwhile the revised MARPOL contains further strict requirements in ECAs. This chapter highlights 3 key changes, namely, limiting SO_2 emissions, controlling NO_x emissions and establishing ECAs.

3.5.1 The First Change to SO_2 Emissions

The first change in terms of reduction of SO_2 emissions under MARPOL Annex VI, for the global ships was to reduce the sulfur content of fuel to 0.5% by 2020. By examining the Table 14, it can be seen that MARPOL controlled sulfur content to 4.5% in 2000. Up until now, it has been decreased by 1%, to 3.5% which is undoubtedly a significant improvement. The decline of sulfur content in fuel is due to MARPOL gradually improving its requirements and adopting stricter regulations.

Table 14 – MARPOL Annex VI Fuel Sulfur Limits

Date	**Sulfur Limit in fuel (%m/m)**

	SOx ECA	**Global**
2000	1.5%	4.5%
2010.07	1.0%	
2012		3.5%
2015	0.1%	
2020		0.5%

Source: The DieselNet website:

(https://www.dieselnet.com/standards/inter/imo.php?_sm_au_=iVVW7F0VS6T7PWKt)

Note: alternative date is 2025, to be decided by a review in 2018

It is now necessary to examine the two phenomena of ECA or SECA. At present there are 4 areas designated as SECAs; these are the Baltic Sea, North Sea, North America, and the United States Caribbean Sea. (See Table 15). The requirements for ECAs are more stringent than non-ECAs. The sulfur content requirement of fuel is 0.1% (or less) within SECAs from 1 January 2015. In 2000, the sulfur contained in fuel was 1.5%; up to now it has been decreased by 1.4%. It is easy to see that sulfur content of fuel keeps a declining trend. When ships sail into SECAs, they need to use fuel with a sulfur level of less than 0.1%. In another way, ships can install exhaust scrubber systems on board instead of using regulated fuel oil. Exhaust scrubber systems can achieve the same goal of limiting SO_2 emissions. As previously mentioned, controlling sulfur content in fuel oil as a measure for reducing SO_2 and PM emissions. MARPOL Annex VI makes regulations to regulate and monitor sulfur content of fuel used by international ships. According to Table 14 and Figure 5, these regulations are progressively reducing the sulfur content in fuel oil and correspondingly mitigating SO_2 and PM emissions from international shipping.

Table 15 – MARPOL Annex VI: Prevention of air pollution by ship: Emission control Area

	Emission	**In effect from**
Baltic sea	SO_x	19 May 2006
North Sea	SO_x	22 November 2007
North America	SO_x NO_x	1 August 2012
United States Caribbean Sea	SO_x NO_x	1 January 2014

Source: International Maritime Organization web site:

(http://www.imo.org/)

(http://www.imo.org/en/OurWork/Environment/PollutionPrevention/AirPollution/Pages/Air-Pollution.aspx)

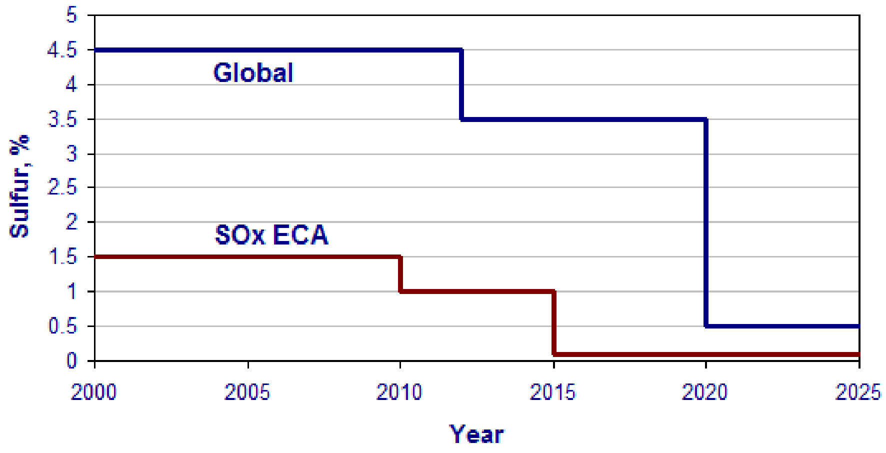

Figure 5 – MARPOL Annex VI Fuel Sulfur Limit

Source: The DieselNet website:

(https://www.dieselnet.com/standards/inter/imo.php?_sm_au_=iVVW7F0VS6T7PWKt)

3.5.2 The Second Change to NO_x Emissions

The second change is the mitigation of NO_x emissions from marine diesel engines installed on board. MARPOL Annex VI regulations now provide for engines installed on ships constructed on or after 1 January 2011 with a “Tier II” emission limit; the engines installed on a ship constructed on or after 1 January 2016 operating in NECAs (North American Emission Control Area and the U.S. Caribbean Sea Emission Control Area), with a far stricter "Tier III" emission limit; and for engines installed on a ship constructed on or after 1 January 1990 but prior to 1 January 2000, which comply with “Tier I” emission limit. (IMO,2014) (http://www.imo.org/en/OurWork/Environment/PollutionPrevention/AirPollution/Pages/Air-Pollution.aspx)

As discussed previously, NO_x emissions are mainly decided by engine type, engine age and time of engine build. MARPOL Annex VI, lists three levels of limiting NO_x emissions in light of the date of installation of the engine on vessels, which is further strictly monitored and controlled for global NO_x emissions. (See in Table 16)

Currently, there are 2 ECAs that not only limit SO_2 emissions but also limit NO_x emissions, namely North American Emission Control Area and the U.S. Caribbean Sea Emission Control Area. (See in Table 15) Vessels entering these two ECAs must comply with “Tier III” emission limits that is the strictest among the three tiers and should use fuel with sulfur levels less 0.1%. As per Figure 6, “Tier II” emission limit is applied as a global standard for controlling ship NOx emissions, which means out of ECAs the marine diesel engines installed on board must meet the Tier II requirements. There is a no doubt that “Tier II” is more stringent than “Tier I”, but there is a large and obvious gap between Tier II and Tier III. The gap means that Tier III is much stricter than Tier II; thus the effect of NOx control in ECAs would be much better than non-ECAs.

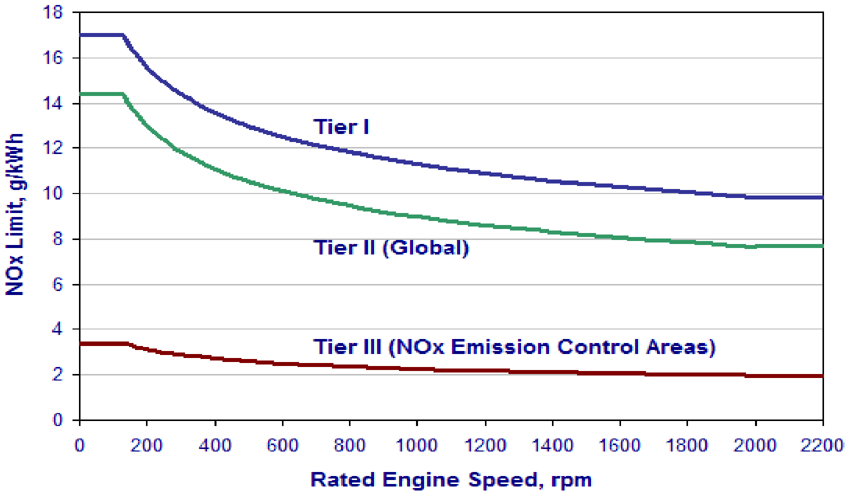

Figure 6 – MARPOL Annex VI NO_x Emission Limits

Source: The DieselNet website:

https://www.dieselnet.com/standards/inter/imo.php?_sm_au_=iVVW7F0VS6T7PWKt

Table 16 – MARPOL Annex VI NO_x Emission Limits

Tier	Date	NOx limit, g/kWh		
		n < 130	**130<= n<=2000**	**n>=2000**
Tier I	2000	17.0	$45 \cdot n^{-0.2}$	9.8
Tier II	2011	14.4	$44 \cdot n^{-0.23}$	7.7
Tier III	2016+	3.4	$45 \cdot n^{-0.2}$	1.96

Source: The DieselNet website:

(https://www.dieselnet.com/standards/inter/imo.php?_sm_au_=iVVW7F0VS6T7PWKt)

In terms of the report about North America establishing Emission Control Areas(ECA) as published by the Environmental Protection Agency (EPA), the time frame is 2020, compared with ECAs with non-ECA in North America, The amount of emissions of NO_x, PM and SO_x from ships are reduced by 3.2 million tons, 0.9 million tons and 0.2 million tons, respectively, and decreased by 23%, 74% and 86%. Therefore, we could consider that establishing ECAs and implementing relevant regulations are indeed good ways to mitigate emissions. Meanwhile it should be a factor that affects international ship exhaust gases.

3.5.3 The Third Change About Establishing ECAs

IMO made an emissions projection model in the 3rd IMO GHG Study in 2014. It designed two fuel mix scenarios, one being a high LNG/extra ECAs case, and another being a low LNG/constant ECAs case.

For the low LNG/constant ECAs case, the amount of fuel used in ECAs will not be changed because ECAs is constant. In this case, it is assumed that half of the fuel currently used in ECAs is used in ECAs that control SO_x only. It is assumed that 50% fuel is used in SECAs, and another 50% is used in ECAs where both limit SO_x and NOx emissions. (IMO, 2014, p135) In this scenario, due to the fact that no more ECAs will be set up, the demand for LNG is not high and is limited. For the high LNG/extra ECAs case, the whole world will establish more ECAs by 2030. In this case, in order to comply with regulations of ECAS, the demand for using LNG will be increased. It is instructive to view Table 13 and compare the results of two scenarios.

Table 17 shows the 2 scenarios of fuel mix. It is not difficult to find that the shares of LNG, distillates and LSHFO (low-sulfur) in high LNG/extra ECAs case are apparently higher than in a low LNG/constant ECAs case. However, HFO shares in low LNG/constant ECAs case is much larger than in high LNG/extra ECAs cases. In short, setting up more ECAs and adopting regulations have a great and direct impact on reduction of GHG emissions, because it specially requires vessel to burn more LNG to comply the regulations of ECAs. We also can say that establishing ECAs and making strict regulations may encourage and compel ships to use low sulfur fuel and cleaner fuels such as LNG, which also can reduce GHG emissions from international ships.

Table 17 – fuel mix scenarios used for emissions projection (mass%)

High LNG/extra ECAs case	LNG share	Distillates and LSHFO	HFO
2012	0%	15%	85%
2020	10%	30%	60%
2030	15%	35%	50%
2050	25%	35%	40%

Low LNG/constant ECAs case	LNG share	Distillates and LSHFO	HFO
2012	0%	15%	85%
2020	2%	25%	73%
2030	4%	25%	71%
2050	8%	25%	67%

Source: International Maritime Organization. (2015). *Third IMO Greenhouse Gas Study 2014*. London.

Additionally, since 1st January 2016, China has started to implement the policy of ECA for controlling and monitoring SO_2, NOx and PM emissions. China has chosen 3 areas as ECAs including: Pearl River Delta and the Yangtze River Delta, the Bohai Sea. In terms of the regulation of ECAs, a ship which operates in these 3 ECAs must use fuel with sulfur content less than 0.5%. Before 31st December 2019, as a result of 4 years of examination, China is aiming to implement further stringent regulations and measures. For example, vessels which operate in ECAs must use fuel with a sulfur level of less than 0.1%. According to a rough calculation, by 2020, the SO_2 and PM emissions in the three ECAs should decrease by about 65% and 30% respectively, as compared with 2015. Based on the above tables, analysis and cases, it is probable that regulations will be a factor influencing emissions from international shipping.

In short, according to above discussed, this chapter finds 5 main factors which have significant impact on emissions from international shipping.

Chapter 4 Approaches to Mitigate Ship Exhaust Gases

This chapter will mainly introduce approaches to mitigate emissions from international shipping. First, offer and analyze some current measures have already been taken. Second, introduce several potential measures which may implement in the future.

4.1 Operational Methods for Mitigating the Ship GHG Emissions

4.1.1 Speed Reduction

Ship owners and carriers have started to operate vessels at a low speed since 2007, in order to in response to the pressures of global economic recessions as well as high oil prices. Due to the depressed global economy, cargo volume in international trade had decreased and demand for shipping transport kept shrinking. It also brought the overcapacity problem to ship owners and carriers. Meanwhile, because of the gradual increase in bunker prices, the most effective way for ship-owners and carriers to save bunker costs might be slow steaming. Therefore, slow steaming strategy was initially implemented in 2007, which was not only solving the issue of overcapacity but also allowing carriers save bunker costs.

The main three advantages of slow steaming are reduction in fuel consumption, control of GHG emissions and absorption of extra capacities (Drewry Shipping Consultancy, 2010). In this paper, the discussion focuses on advantages of reducing fuel consumption and controlling GHG emissions. GHG emissions from shipping have a close connection with fuel consumption. When it comes to controlling GHG emissions, we should consider fuel consumption together with it, in other words, improving energy efficiency is a significant way to reduce GHG emissions. Notteboom and Vernimmen (2008) argue that slow steaming has a strong correlation with fuel consumption, which means slow steaming could decrease the fuel consumption of vessels. Slow steaming is the operational technique that makes the vessel to use a lower speed than the deliberately designed voyage speed (Jong-Kyun and Seong-Hyeok, 2012). Thus slow steaming directly influences the amount of GHG emissions.

Slow steaming is not a new concept for the shipping industry to mitigate GHG emissions. From 2010, most shipping companies began to utilize slow steaming as their main operational strategy to reduce operating costs, particularly bunker costs. They wanted to improve energy efficiency by operating a slow steaming strategy and save cost on bunker as well as realize the goal of mitigating GHG emissions from international shipping. For example, the Asia–North Europe route, 93% of liner services has already adopted slow steaming in 2011, and the average voyage speed was reduced from 23–25 knots in 2008 to 15–18 knots (Ultra Slow Steaming) in 2011 (Barry Rogliano Salles 2012; McCarthy 2012; Skou 2012). In addition, some of the largest shipping companies plan to reduce their voyage speed to below 15 knots on major routes, due to slow steaming being useful in mitigating the amount of GHG emissions and saving bunker costs.

So far, there have been several successful cases about shipping lines implementing slow steaming strategy. For example, Maersk line has adopted a slow steaming strategy since from 2007 and has reduced its CO_2 emissions per container-kilometer by more than 25% compared with 2007. (http://www.maerskline.com/zh-cn/new-sustainability/low-impact-shipping)

Moreover, in terms of the report on Maersk-Line, if the voyage speed is reduced by 20%, the amount of CO_2 emissions and bunker fuel consumption can be mitigated by more than 20% and 40%, respectively. According to another related report on Maersk, the company has already adopted a slow steaming strategy since 2007, which has reduced vessel speed from 20~25 knots to 15~20 knots. The strategy has decreased 40% of annual CO_2 emissions; and at the same time, has helped the company to save 40% annual bunker costs. In order to balance the shortage capacity due to slow speed of vessel, and satisfy the requirement of customers, Maersk has added one or two extra high speed vessels on each line. Even if CO_2 emission from those extra vessels is taken into account, the average CO_2 emissions per container are still less than the 2008 figures by more than 7%.

Besides, China Shipping Container Line CO. LTD (CSCL) has already cooperated with classification societies to do slow steaming trials on over 10 vessels. This lowers speeds from 24 knots to 18 knots. If vessels are operated at 18 knots, CSCL can save on bunkers around 180 thousand tons which is equal to reduction of CO_2 emissions from around 540 thousand tons. In sum, slow steaming is quite a fast and effective way of mitigating exhaust gases from ships.

4.1.2 Ship Energy Efficiency Management Plan (SEEMP)

In 2007, IMO in order to enhance the operational energy efficiency of vessel, adopted a mandatory measure called Ship Energy Efficiency Management Plan (SEEMP) which entered into force on 1st January 2013. The aim of IMO for adopting the mandatory measure is to look forward to reducing the amount of GHG emissions from international shipping based on actions from the operational perspective of ships.

4.1.2.1 Brief Introduction of SEEMP

In general, the aim of SEEMP is to guide shipping enterprises to undertake the responsibility of protecting the environment for establishing a green shipping industry. SEEMP could be a part of the company management system, which focuses on the greatest potential energy-saving procedures and system as well as completes the whole process of shipping operations. By adopting SEEMP, shipping companies may take management, technical and operational measures to achieve the goal of improving ship energy efficiency. Besides, by implementing effective measures for saving energy and applying a system and method, shipping companies could eventually increase energy efficiency of vessels, decrease GHG emissions, and improve the company profit margin as well as social interests. In other words, SEEMP actually calls on ship-owners, carriers and ship operators to perfect the whole operational structure and further optimize business structure and reduce energy consumption. The specific measures may include optimizing ship routes, effectively avoiding storms, reasonably optimizing navigation time, ensuring that vessels arrive in port punctually and narrowing the waiting time for berthing.

Shipping Energy Efficiency Management Plan (SEEMP) requires ship-owners, carriers and ship operators to make specific SEEMP arrangements for specific vessels. How do shipping companies and ship owners set up an energy efficiency management mechanism for individual ships? In fact, each SEEMP is realized by 4 steps which are detailed planning, implementing, monitoring, self-evaluation and improvement. These 4 steps perform an important role in a continuous cycle to promote energy efficiency management of ships. Moreover, the design of SEEMP was based on a “plan-do-check-act.”

Planning is the most vital stage in SEEMP. Detailed planning basically decides the present condition of vessel energy management as well as the expected improvements of a vessel. Meanwhile, the planning sector should make goals or targets for the whole cycle.

The implementing step, which actually is a system about implementing the selected measures through developing seafarers’ duties, rules on board and tasks. SEEMP requires that in the implementation sector, the selected measures should be explained and responsible crew should be named. Furthermore, SEEMP requires keep record of the performance of each selected measure and recording each issue when the measure cannot be taken.

The main work of the monitoring step is consecutively collecting data. For instance, recording the fresh water and fuel consumptions of each voyage. The data is then submitted to the company and audited by it. Moreover, it is intended that shipping companies will analyze these data to carry out self-evaluation.

The last step of the management cycle is self-evaluation and improvement, which will brings a useful and meaningful influence on the next improvement cycle. Indeed, the aim of this step is to assess the performance of selected and designed measures which are mainly about how to improve energy efficiency on board.

SEEMP applies to all ships (400 gross tonnage or above). Where ships only sail within the waters of its flag state, that is, those within its jurisdiction, the flag states should take appropriate measures to ensure that the ship meets the requirements of SEEMP within the reasonable and feasible range. SEEMP should be kept on board and remain prepared for checking anytime. The content of checking SEEMP should comply with IMO. MEPC.213(63), which should conclude:

a. the target of energy efficiency
b. the responsibilities and duties as well as roles
c. energy efficiency measures and implementation requirements;
d. monitoring system and monitoring requirements;
e. implementation schedule;
f. self-assessment and improvement requirements

4.1.2.2 Summary of SEEMP

SEEMP offers energy efficiency measures to current existing vessels, which is an overall concept and focuses on the whole industry situation, as well as provides more space for single/specific vessels carrying out optimization. SEEMP urges ships to update technology, enhance the scientific and technological skills of the ship and requires the fleet to strengthen its internal management system to reasonably reduce energy efficiency. From the operational perspective, SEEMP is beneficial to long-term development of the whole shipping industry, which not only protects the environment but also saves cost.

It should be noted that in implementing SEEMP, managers should take into account the management characteristics of the company and the ship (such as self-operating or charter out vessel etc.), and make it feasible. The energy efficiency measures should be designed in accordance with characteristics of the ship itself, the sailing area, trading type as well as the advice received from relevant industry organizations. Managers need to comprehensively consider the compatibility and flexibility of taking energy-saving measures

4.2 Technical Method for Controlling Ship Exhaust Gases

In 2007, the Marine Environment Protection Committee (MEPC) developed an Energy Efficiency Design Index (EEDI) to enhance protection of the environment from ship-source air pollution. In 2009, MEPC also recognized that EEDI must be implemented effectively to improve ship energy efficiency from a ship design perspective. EEDI thus entered into force on 1st January 2013 with a view to increasing and improving the technical energy efficiency of new-buildings. Ship owners, ship builders and ship designers are required to comply with EEDI regulations from 1st January 2013 onwards. EEDI is applicable to all new ships (400 gross tonnage or above), which is considered a vital technical measure for improving ships' energy efficiency in terms of facilities and equipment installed on board. The aim of IMO in adopting the mandatory measure is less GHG emissions from international shipping and reduction of fuel consumption of vessels. According to the EEDI, IMO requires ships built over the period 2015 to 2019, to improve the carbon efficiency of ships by 10%, vessels built during 2020 to 2024, by 20%, and vessels built after 2024, by 30%.

EEDI is an index that is used to measure CO_2 emissions of new buildings. Different ship types with different tonnages have different emission baselines, hence new buildings can control energy efficiency based on a specific emission baseline. Thus EEDI of new buildings built in the first phase (2015-2019) will be lower than the previous EEDI under the regulations. For example, for the dry bulk vessel with dead weight tonnage (DWT) of 115800, the regulation EEDI is 2.56. If there is a new-building dry bulk vessel named Star with the same DWT 115,800 and its EEDI is 2.5, then the vessel Star meets the requirement of EEDI, while if the EEDI of Star is 2.7, then the vessel cannot meet the requirement of EEDI. When shipyards or ship designers design and construct new vessel, they need to take into account the EEDI, which is a ratio of social benefit brought by shipping transport (transport volume) and the cost of environmental. In other words, it is a ratio calculated by CO_2 emissions. Ship energy consumption is simply converted to CO_2 emissions and named as A; then ship effective energy is also converted to CO_2 emissions as B. Thus the EEDI ratio is actually A to B.

EEDI can be briefly expressed by the following formula:

$$\text{EEDI}=\frac{CO2\ emissions}{transport\ \ works} \quad (4.1)$$

CO_2 emission is total carbon emission from ships, such as all the amount of CO_2 emitted by main engines, boilers and auxiliary engines combusting fuel, plus the amount of CO_2 emissions from other equipment installed on board. When the vessel adopts new energy technology, the reduced carbon emission from new energy should be deducted from the total carbon emission of the vessel. Transport works is the designed capacity of vessel (depends on ship type) times designed speed. The designed speed is 75% of the main engine rated power as well as the maximum load condition.

From the EEDI formula, it can be deduced that the higher the EEDI, the higher fuel consumption and the lower energy efficiency. EEDI offers a standard for the lowest energy efficiency for future vessels, and guides ship builders and ship owners from a design perspective to promote, inter alia, efficiency of the ship line, propeller propulsion as well as the main engine.

4.3 Make Regulations/Legislation and Establish ECAs to Control Ship GHG Emissions

As discussed in Chapter 1, IMO has already adopted mandatory regulations to limit emissions from all global fleets. Meanwhile in Northern Europe such as the Baltic Sea and North Sea areas and in North America, ECAs have been established to further control and limit the SO_2 and NO_x contained in ships’ exhausts. Aside from those mentioned above, there are other regulations that have been adopted by nations and regions to limit and reduce pollution from air emissions from ships internationally.

The regional regulations are different from mandatory regulations, which are mostly adopted by the more advanced shipping areas and most of them are voluntary. To limit and control pollution emissions from ships internationally and improve the quality of the environment, governments and port authorities formulate policies to encourage ship owners to take measures for mitigating polluting gases from exhaust emissions when vessels operate within port areas. There are some successful examples as shown below:

In North America

Some of ports in North America have realized that if vessels adopt slow-steaming measures great results can be obtained from reduction of GHG emissions. Hence Los Angeles port and Long Beach port have adopted schemes that encourage ship-owners, ship operators and masters to voluntarily operate their vessels at a slow speed. The scheme started from 2005 at Long Beach port, in terms of the requirement of the scheme, if 90% ships of a fleet meet the requirement of sailing at slow speed voluntarily, then the fleet can receive 15% discount on port charge in next year. Because the result of the scheme is better than expected, in 2009, Long Beach port enlarged the slow steaming area from 20 nautical miles outside of a port to 40 nautical miles, and give a 25% discount on port charges to shipping companies meeting the requirements. Los Angeles port began to adopt the slow steaming scheme from 2008, and provided a 15% discount on port charges to slow steaming ships. By September 2009, the discount was raised to 30%.

In Asia

The port of Singapore has implemented the “Green Port Scheme”, which focuses only on the vessel which calls at ports in Singapore. The scheme provides that if the vessel applies technology and equipment for reducing emissions or shifts to low-sulfur or clean fuel when it sails within the port areas and the technology and equipment together with low-sulfur fuel comply with the regulations of MARPOL

Annex VI, then the vessel may enjoy 15% discount on port tax.

Hong Kong has implemented the ‘Fair Winds Charter’ since 1st January 2011. The Environmental Protection Agency of the Hong Kong Special Administrative Region (HKSAR) issued a report that SO_2, NOx and PM produced by the port of Hong Kong respectively takes up 54%, 33% and 37% of the total amount of emissions, which are of the largest polluted origins in Hong Kong. In 2011, a total of 18 shipping companies including Maersk Line, CMA CGM, OOCL and COSCO etc. agreed with and signed the ‘Fair Winds Charter’. They promised that when their ocean ships called at Hong Kong, ships would, as far as possible, shift to fuel with sulfur content no higher than 0.5%. Due to the positive impact of the ‘Fair Winds Charter’ on improving the air quality of Hong Kong, the government decided to reduce half of port facilities and lights charges for the ocean ships using fuel with sulfur content but no lower than 0.5%.

Shenzhen is a famous port city in China. In 2013 September, the Shenzhen municipal government adopted a motivation policy that increases allowances to port construction shore power equipment and facilities. After 1st January 2015, if ocean ships call and operate at ports using fuel with sulfur level less 0.1%, the Shenzhen government will provide allowances to these ocean ships of up to 75% of the difference in the fuel price.

In Europe

According to a report in Lloyd’s list, the port of Antwerp has set up a plan under which vessels applying innovative technology for reducing pollution emissions within the port area, may enjoy price discounts. For example, if ship owners, operators and masters can prove that their vessels have used LNG fuel at least 24 hours before calling at Antwerp, the vessel can enjoy a 20% discount on port charges. If the vessel is shown to have installed and used a closed loop scrubber, it can get a 15% discount on port charges.

European ports take measures to promote and regulate exhaust gases from ocean going ships. The Port Authority of Rotterdam first adopted the Environmental Ship Index (ESI) held by Rightship which is a global shipping evaluation agency, to motivate ship owners to strictly control GHG emissions as well as decrease NO_x and SO_2 emissions from ships. According to the requirements of ESI, as long as shipping companies update their technical facilities and equipment such as improving engines and using clean fuels to reduce GHG emissions, and make their ships' emissions lower than the requirements of IMO regulations, the shipping companies can get discounts on port charges or get awards. As one has expert estimated, a good ESI vessel could well save 6% of port charges at Rotterdam. Due to Rotterdam obtaining good results from adopting ESI, other European ports in Norway, Germany, Belgium and Italy began to adopt ESI projects following the example of Los Angeles as the first port in North America and the Pacific area adopting ESI. Evergreen, Maersk, Yang Ming shipping etc., comprising a total of the 6 largest shipping lines in the world claimed that they were willing to join ESI scheme of Los Angeles. The port provides ships calling at Los Angeles and meeting ESI standards with bonuses of $250 to $5250. As of October 2011, 1442 ships have been registered in the ESI system, with 19 ports providing corresponding incentive measures.

4.4 The Usage of Clean Fuel and Application of New Energy.

4.4.1 The Usage of Clean Fuel

As mentioned in Chapter1, when taking into account CO_2 emissions from HFO, MDO, MGO and LNG, it is possible that LNG fuel might be the cleanest among them. Thus if ships use LNG fuel as the main bunker fuel in the future, CO_2 emissions from per tonne fuel may roughly decrease by 460 kg equaling a decrease of around 15% compared with HFO, MDO and MGO. This apparent from the following equations:

$$HFO\ EF_{baseline}CO_2=3114kg\ CO_2/tonne\ fuel$$ (4.2)(IMO, 2014, p105)

$$MDO/MGO\ EF_{baseline}CO_2=3206kg\ CO_2/tonne\ fuel$$ (4.3) (IMO, 2014, p105)

$$LNG\ EF_{baseline}CO_2=2750kg\ CO_2/tonne\ fuel$$ (4.4) (IMO, 2014, p105)

Where is
EF is emission factor
HFO is heavy fuel oil
MDO is marine diesel oil
MGO is marine gas oil
LNG is liquefied natural gas

When considering SO_2 and PM, the percentage amount of sulfur contained in fuel is the most important determinant. The higher the percentage of sulfur contained in fuels, the higher are the SO_2 and PM emissions emitted by ships. A detailed analysis is provided in Chapter 1 of this paper. However, in the opinion of this writer, if ships use LNG instead of current bunker fuels such as HFO and MGO, then the SO_2 and PM emissions may be not an issue anymore. The reason is that the residual fuel oil (HFO) and distillate fuel oil (MGO) consist of alkanes, cycloalkanes, alkenes, aromatic hydrocarbons, polycyclic aromatic hydrocarbons and a small amount of sulfur(2~60g/kg). Thus when engines combust HFO and MGO, the sulfur reacts with oxygen to produce SO_2 and PM. However, the main component of LNG fuel is methane the chemical formula of which is CH4. Through the combustion in engines there would be no SO_2 existing.

In terms of NO_x emissions, the engine type, time of engine build or engine use condition may be the deciding factors. According to IMO studies on the feasibility and use of LNG as a fuel, there are three engines which are able to burn LNG fuels. These are - four stroke otto-cycle dual fuel engines, two stroke dual fuel diesel engines and single fuel gas engines. The study said NO_x can be reduced approximately by 80% to 90% for Otto cycle processes and only reduces 10% and 20% for diesel cycle processes. (IMO, 2016, p.231) Therefore, LNG fuel may be the most ideal bunker for future ships since it contains less carbon than other oil fuels because it contains no sulfur.

At present, HFO is the major fuel combusted by ship engines. IMO requires all of ship fleets that use the residual fuel HFO with sulfur content below 3.5%. The sulfur content outside ECAs is approximately 35 times higher than the ECAs. In the designed ECAs, the vessel must shift to use distillate fuel MGO with sulfur content below 0.1%. Table 18 shows the alternatives: LNG, MGO and HFO/Scrubber compared with the traditional fuel HFO. As per Table 18, LNG earns much more ++/+ (very good) than MGO and HFO/Scrubber. It has an apparent effect on mitigating SO_2, NO_x, PM and CO_2. For HFO/Scrubber, it performs well on mitigation of SO_2 and PM, but not better than LNG. For MGO, it is only useful to reduce SO_2 emissions and performs weakly on controlling NO_x, PM and CO_2.

Table 18 – Comparing the alternatives: LNG, MGO and HFO

	Environmental features compared to the traditional HFO alternative				Factors influencing viability compared to the traditional HFO alternative		
Alternative	SO2	NOx	PM	CO_2	Cargo Capacity	Capital investments	Operating costs
LNG	++	++	++	+	Restricted	Very high	Low

MGO	+	-	-	-	Not restricted	Low	Very high
HFO/Scrubber	+	- -	+	-	Slightly restricted	High	Medium

Source: International Maritime University. (2016). S*tudies on the feasibility and use of LNG as a fuel for shipping*. London.

Notes: ++ Very good, + good, - bad, -- Very bad

In the opinion of this writer, in the future, there will be 3 available scenarios for mitigating GHG emissions from international shipping based on a fuel type perspective.

First, use MGO instead of HFO

Second, use LNG instead of HFO

Third, keep using HFO with installing technical facilities on board for abating SO_2, PM and NO_x such as installing a Selective Catalytic Reduction (SCR) or scrubber system for cleaning sulfur, fit Exhaust Gas Recirculation (ECR) for removing NO_x.

In the next few years, it will be necessary to keep decreasing the sulfur contained in bunkers which is probably the most practical and feasible measure. From the personal viewpoint of this writer, IMO or other organizations could adopt stricter regulations to further control sulfur content of fuel. For example, regulating the use of the same fuel as ECAs in non-ECAs or requiring bunker suppliers to offer 0.1% of sulfur HFO, motivating shipping companies to use 0.1% sulfur MGO instead of HFO as the dominating fuel for the shipping industry. Along with IMO gradually updating strict regulations and increasingly enhancing the management of GHG emissions, the goal of using non-sulfur fuel can be achieved in next few years. Certainly, to achieve the goal, every stakeholders of the entire shipping industry should make an effort together. Fuel refiners and bunker traders should actively improve their techniques; shipping companies should take more low sulfur and non-sulfur fuel voluntarily; shippers and cargo owners should support carriers in using non-sulfur fuel and as much as possible, cooperate with shipping companies which actively use low or non-sulfur fuel.

4.4.2 The Application of New Energy---Wind Energy and Solar Power

Applying wind energy and solar energy on board should be an effective and possible way to reduce fuel consumption and reduce ship exhaust gases in the future. Installing a wind power or solar energy system on ships may assist in main engines and auxiliary engines producing propulsion power and electricity. This would help engines save fuel, reduce consumption of burning fuel and mitigate GHG emissions from ships. So far, using a wind power system and solar energy on vessels might not be popular ways to abate GHG emissions from international ships, due to the limitations of technology. Actually, some advanced shipping countries and shipping companies have already carried out relevant trials on ships (cargo ships, ferries, cruise ships, etc.) and have gained wonderful results. We may consider that wind power and solar energy could be widely used in the shipping industry for reducing GHG emissions from international ships in the future. Some of the successful experiments that apply wind energy and solar energy on ships are set out below.

4.4.2.3 The Application of Wind Energy

Modern sailing ships apply wind energy through sails as auxiliary power to assist engines in reducing fuel consumption. In 1980, Japan successfully built the first modern ‘Sail Tanker’ in the world, named Shin Aitoku Maru, which is 1600DWT. Compared with normal tankers, Shin Aitoku Maru could save 50% of fuel consumption. After that, Japan constructed one ocean-going sailing ship and 10 coastal modern sailing ships. The largest of 11 modern sailing ships is 26,000 dwt. Research shows that the application of sail-assistance can decrease consumption of fuel and improve environmental protection. So far, modern merchant ships which apply wind power systems on board mainly use marine diesel engine as the main propulsion power and wind sail as auxiliary power. In practical operation, applying wind energy to offer power for vessels works according to the actual weather situation; thus the effect of applying wind energy might be unstable and difficult to measure.

‘Shin Aitoku Maru’

Source: http://collections.rmg.co.uk/collections/objects/66022.html

Germany innovated and built a ship named Beluga SkySails, which used wind energy by kite pulling as auxiliary propulsion power. The kite sail could fly at a 300-meter high altitude, the advantage of it being using the stable and powerful wind power in the upper atmosphere. Based on the situation of the wind, the kite sail could save 10% to 35% of fuel. In the ideal situation, the kite sail could save 50% of fuel consumption, which greatly reduces CO_2 emissions from ships.

‘Beluga SkySails’

Source: http://www.skysails.info/english/skysails-marine/skysails-propulsion-for-cargo-ships/

4.4.2.4 The Application of Solar Energy

Currently, solar energy is mostly applied to ferries, cruise boats and passenger vessels, and are less used in international merchant fleets. Because international merchant ships are much larger than ferries or cruise boats, their energy demands are far more. The present technology of applying solar energy may not be stable or mature for international merchant ships, thus it cannot be widely used on board now. However, the successful cases of applying solar energy systems on ferries, passenger vessels and cruise boats means solar energy could be applied to international merchant fleets in the future and may have a great potential to help international merchant fleets save fuel and decrease GHG emissions. Some successful cases of ferries and cruise boats applying solar energy are indicated below.

In 1997, Switzerland built a solar energy passenger vessel that was covered with a 14m^2 solar energy panel on the top as driving power, which provided no pollutant and energy saving transportation mode. In 2000, Australia built the first hybrid power passenger boat in the world, named Solar Sailor. The boat installed both a solar energy and a wind energy system. The two systems can be used together or operated separately. The boat is virtually a non-pollutant of sea and air. In 2007, Switzerland built a boat named Sun 21 with a 60m^2 solar energy panel, which used solar energy entirely to complete the trip across the Atlantic Ocean.

‘Solar Sailor’

In 2008, Japan’s Nippon Yusen Kaisha (NYK) invested 1.5 hundred million yen to build a RO-RO ship, named Auriga Leader of 60,213 tonnes. The Ro-Ro ship installed a solar energy system that constituted by 328 solar energy panels, which could yield 40kw and satisfy 6.9% lighting demand or 0.2% to 0.3% of power demand. One of the latest concepts is combining solar energy with wind energy, is the cooperation between COSCO and the Australian Solar Sailor Company to carry out an experiment that installing solar energy sails both on a dry bulk ship and a tanker. Solar energy sails may provide auxiliary power to ships and mitigate GHG emissions from ships.

‘Auriga Leader’

All in all, this chapter is based on an operational as well as a technical, legislative and alternative energy perspective. It not only introduces current measures and approaches that have been taken including slow steaming strategy, SEEMP and so on, but also offers some potential effective measures that could be taken in the future. These include application of wind and solar energy, alternative fuels, etc. In fact, realization of the above mentioned measures and approaches will meet lots of barriers and difficulties. Slow steaming, for example does have a positive impact on the environment but it also brings problems to the shipping industry which may hinder them from adopting a slow steaming strategy. In addition, other difficulties regarding LNG engines can be promoted such as how shipping companies make choices to invest money to install LNG tanks and engines on vessels. These are addressed in the next chapter

Chapter 5 Barriers and Difficulties for Implementing Measures for Emission Reduction

In this Chapter the barriers and difficulties for implementing measures for emission reduction will be addressed analytically. The writer intends to offer some suggestions and solutions to deal with the barriers and difficulties.

5.1 Barriers for Implementing Slow Steaming Scheme

There are 4 primary benefits of implementing the slow steaming scheme. First, it is a good and fast way to reduce GHG emissions from international shipping. Second, it is a direct way for ship owners, operators and shipping companies to save costs on bunkers and decrease fuel consumption. Third, slow steaming may help carriers better optimize and arrange over-capacity or idle ships during the period of a poor market. Fourth, it makes ships punctual. Through implementation of a slow steaming scheme, the occurrence of delay may be avoided. Since ships sail at slow speed, it gives more buffer time in schedules and relieves the issue of port congestion. However, every coin has two sides, slow steaming also brings some issues to the forefront like barriers for the entire shipping industry which may hinder the slow steaming scheme from being implemented smoothly.

5.1.1 Damage to Main Engine

Most people think that ship owners or carriers may save overall costs by operating ships at slow speed, but that comes at a price. Slow steaming not only brings benefits to ship owners and carriers, but also has some negative issues attached to it. Ship owners and carriers have to pay the price for saving costs through slow steaming.

Damage to the main engine is possibly the first disadvantage of slow steaming. The technical team manager of Shell Germany, Jerry Hammett has mentioned that slow steaming could save fuel, but in comparison with the full load of the engine, the pressure of the lubricating oil in theory will increase more than 3 times. Under these conditions, some of the cylinder oil cannot provide adequate protection for main engines. More than 80% of larger vessels of the world use the lubricating oil of two stroke engines which withstand the four pressures of heat, insoluble matter, acid, and humidity. Under the condition of slow steaming, due to the cylinder oil stay too long time, these pressures may be much stronger. When the engine load decreases from 90% to 30%, the time of cylinder oil staying would increase by 3 times. Obviously, although slow steaming allows ship owners and carriers to save on bunker costs, it increases engine wear and tear, and lubricating oil consumption. If this continues, ship maintenance costs will certainly increase.

5.1.2 Long Transit Time May Cause Legal Issues

“Utmost dispatch” which means carriers are required to deliver the goods to the port of destination, as soon as possible is one of the most important responsibilities contractually undertaken by ship owners. Usually, “utmost dispatch” is embodied in a bill of lading which evidences a sea carriage contract. The notion of slow steaming is not conducive to "utmost dispatch" as a term in a bill of lading, which potentially causes delay in the delivery of goods. Protection and indemnity club (P&I) warn that slow steaming could result in default of the duty of “utmost dispatch” resulting in the ship owner facing legal action for delay in delivery. Although there is no current evidence of such lawsuit involving slow steaming, some shippers take the position that ship owners and carriers should share the benefits of slow steaming with them.

5.1.3 Cause Shortage of Containers

Due to ships sailing at slow speed, the available number of containers can be a considerable problem. Slow steaming prolongs the whole transit time, reduces the effective utilization rate of transport capacity, decreases the turnover rate of the container and transportation equipment, a result of which the issue of shortage of container and equipment becomes increasingly serious. According to one relevant report, some ports are facing the situation of shortage of containers and facilities. At the same time, shippers often cannot find available containers to use because of shipping companies using the slow steaming scheme. If shipping companies wish to maintain the same service level as when they had not adopted the slow steaming scheme, shipping companies need to be equipped with more than 25% of the original number of containers. On a global scale, the extra needed containers are close to 10% to 7%. Additional input of container equipment will undoubtedly increase the operating costs of shipping companies. Meanwhile the production of containers and the process of transport as well as handling may increase carbon emissions.

5.1.4 Ship Owners Invest Extra Money in Buying New Ships

Shipping companies have to pay much more money to solve problems such as ship's delay to arrive at port or inflexible turnover of ship, which are caused by slow steaming. In order to maintain the quality of service, shipping companies may actively increase their shipping capacities and add more ships into loop or decrease the number of ports of call. Hapag-Lloyd Shipping Ltd. operated a line from Europe to the Far East, where vessel speed was decreased to 20 knots as a result of which voyage days were increased from 56 to 63 days. The company used the money saved to purchase a new ship, added it to the line to increase the total number of ships in the line to 9. In addition, “Grand Alliance" put in 2 vessels, making the total number of ships to 35. The number of ships increased from the original 33 ships now to 35. “The new world alliance” is also enlarging its ship capacity from 31 vessels to 34 vessels. The CMA - CKYH alliance has invested in a new ship in the loop as well.

5.1.5 Ship Owners Pay Additional Money for Feeder Services or Excess Services

In addition to increasing capacity, shipping companies are decreasing the number of ports of call to ensure that ships arrive at port on time. Furthermore, some shipping companies take measures such as exchanging container slots with each other. For example, Maersk and Evergreen, instead of reducing the number of ports of call, they exchange container slots. Although this method can maintain the voyage time unchanged and there is no need to increase additional investment in buying new ships, shipping companies pay more for feeder services or excess services. Whether it is to increase investments in ships, reduce the number of ports of call, or increase feeder services, all these 3 methods could potentially increase carbon emissions and operating costs.

5.1.6 Bring Pressure on Supply Chain Inventory

Slow steaming causes the time of transporting cargo to be much longer than before, due to shipping being one sector of the entire supply chain. Thus slow steaming has a significant impact on inventory or storage. Initially, slow steaming can accelerate the consumption of inventory making it difficult for shippers to fill their goods shelves. At the same time, shippers and consignors cannot order cargo from raw material producers, or cargo owners and consignees cannot supply goods to retailers on time. After that, shippers, consignees, consignors and cargo owners have to increase storage to adapt to the slow steaming strategy. In addition, the slow steaming strategy prolongs transit time which may cause information delay. As a result, the shipper cannot precisely predict the demand for inventory and blindly increases it, which is not only a waste of money but also lack efficiency. In the view of this writer, shippers, cargo owners and consignors should adopt a JIT (Just in time) strategy to manage their businesses.

Furthermore, the slow steaming strategy creates container shortage so that shippers sometimes have to pay more to obtain available containers and facilities. Thus, it can be said that slow steaming increases the freight rate intangibly. Both the increase in inventory and the change in the mode of transport may lead to increase in the cost of the supply chain and the amount of carbon dioxide emissions. From this point of view, whether slow steaming really relieves the negative impact of environment is questionable.

5.1.7 Adverse to Perishable goods and Stylish Commodities

Due to slow steaming prolonging the total transit time, it is not good for perishable goods such as fruits, vegetables, seafood, seasonal food products and style-oriented commodities such as clothing, apparel and other consumer items. One the one hand, extended transit time can cause deterioration in food products which can cause a direct loss to cargo owners. On the other hand, the prolonged transit time may lead to stylish clothing and other seasonal products going out of style or the season being over, which could directly impact cargo owners' and retailers' interests. Hence, for this issue, it is suggested that cargo owners buy cargo insurance and adjust the lead time to produce products as well as optimize the whole supply chain and logistics.

5.1.8 Summary and Brief Advice on Slow Steaming Schemes

The real reason for shipping companies implementing a slow steaming strategy is economic pressure which is not actually an environmental factor. Most shipping companies adopt a slow steaming strategy due to the high bunker costs. By reference to a relevant market report and obtaining some viewpoints from shipping experts, this chapter summarizes some situations that may make shipping companies give up implementing a slow steaming strategy. The rationale for doing so would include expensive bunker prices, lack of prosperity in the shipping market; freight rates and inventory costs rising. The above-mentioned situations may make shipping companies lose their enthusiasm for implementing a slow steaming strategy. Therefore, whether or not slow steaming can be implemented will not be a conclusive matter for a long time. Much will depend on the tendency of bunker prices and the market condition. If the entire shipping market takes a good turn or bunker prices go down, government and other authorities should adopt policies to encourage and monitor shipping companies to keep implementing slow steaming strategy, such as putting pressure on them by levying a carbon tax. So far, the whole effect of implementing slow steaming has been good, but more attention needs to be paid to the problems brought about by the slow steaming strategy.

5.2 The Weaknesses of SEEMP

As discussed, Ship Energy Efficiency Management Plan (SEEMP) as a management tool for shipping companies enhances ship energy efficiency and optimizes energy consumption in operation. As an operational measure, SEEMP helps ship owners and carriers to increase fuel efficiency, optimize voyages and reduce GHG emissions from ships. In theory, SEEMP is an excellent device for assisting and guiding the entire shipping industry to achieve the goal of abating GHG emissions in operation. However, in practice SEEMP has certain weaknesses. Young C. Kwon (2011) has expressed the view that SSEMP is simply a general explanation of solutions without any consideration of different ship types and various operating conditions. (Young C. Kwon, 2011, p.9)

5.2.1 Lack Monitoring from Public Societies

To make SEEMP work, 4 steps must be followed, namely, detailed planning, implementing, monitoring, self-evaluation and improvement. The first step is planning which includes identifying goals and targets. These could be designed in any form; so could the standard for monitoring SEEMP, examples of which are annual fuel consumption or Energy Efficiency Operational Index (EEOI). These designed goals and standards are only indicators for shipping companies and ship owners for carrying out internal management and self-improvement. It must be emphasized that goal setting is voluntary; in other words, the designed goals are not to be published for the public. This means shipping companies and the ships themselves do not need to accept inspection and monitoring by external entities such as customers and shippers. It is the opinion of this writer that if shipping companies and ships do not need to publish their goals for public information and not accept outside monitoring, SEEMP would be considered to be lacking in reliability and practicality. If outside entities are not able to know what the goals are and whether these goals have been achieved, then the real purpose of SEEMP will be defeated. Shipping companies and ship owners should make their goals public. Customers have the right to check the achievements of the goals. Public exposure of them will make SEEMP far more effective. Shippers are no doubt keenly interested in the SEEMP of carriers, but it is virtually impossible to trace SEEMP information from the websites of shipping companies and classification societies.

5.2.2 Lacks Strict Inspection.

According to the IMO regulations, international merchant ships must keep International Energy Efficiency Certificate (IEEC) and SEEMP on board. IEEC and SEEMP should be kept on ships at all times to enable classification societies and relevant national and international authorities to inspect them. Both SEEMP and IEEC are issued by classification societies. The verification of SEEMP and the process of issuing IEEC has some shortcomings. First, obtaining SEEMP is the prerequisite for obtaining IEEC. The latter is effective for an extended period; usually ship owners do not need to get new ones. Unless the ship is no longer in service, has been dismantled for recycling, or has changed flag, the ship owner is required to submit and verify the SEEMP to obtain a new IEEC. This begs the question - who would check and verify the SEEMP if the ship is still in service, not dismantled or does not change flag. Although some classification societies do inspect SEEMP every two or three years, it is not a compulsory requirement and is often not sufficiently strict in the way it is done.

5.2.3 Lack of Stringent Monitoring Standards

The third step of SEEMP is monitoring, which is an important factor for continuous improvement. The main task of monitoring is checking the set targets and designed goals to ascertain whether or not they have been accomplished. Shipping companies and carriers can apply any Key Performance Indicators (KPIs) and measurements to judge their performance. However, there is no uniform or strict standard for shipping companies and carriers to which they can refer. Some companies are of the view that SEEMP is designed for each individual vessel, and a container ship and a dry bulk ship cannot use the same SEEMP because they have different modes of operation in transportation, different voyage routes and operational characteristics. It is thus impossible to use a uniform standard to measure the achievement of goals and targets. Young C. Kwon has stated that SEEMP Guidelines do not provide sufficient reliability to ship owners due to uncertainties of various parameters surrounding ships depending on ship type, size and age. These uncertainties prevent shipowners from employing the CO_2 abatement solutions to their ships. (Young C. Kwon, 2011, p.10)

In addition, shipping companies and ship owners do not need to publish goals and targets of SEEMP for public information. Since the relevant public cannot know and is unable to check the outcome of SEEMP, its effectiveness is questionable. In this regard, the writer offers some suggestions from a personal viewpoint. Classification societies could prescribe certain compulsory KPIs or measurements for their fleets. They can classify ships according to the type, voyage route, etc., and design uniform standards for vessels in the same classification. For instance, they can have uniform design standards for panamax dry bulk vessels that operate on the same route or in the same loop; or set uniform KPIs for 13,000 TEU container vessels to measure daily CO_2 emissions and fuel consumptions.

5.2.4 Compulsory Use of EEOI

In the opinion of this writer, the use of the Energy Efficient Operational Index (EEOI) should be compulsory for all ships engaged in international shipping. The present status of EEOI is that ship owners and operators apply EEOI only on a voluntary basis so that EEOI is nothing more than a benchmark or monitoring tool contained in SEEMP. The current IMO guidelines can only motivate ship owners and operators to use EEOI but not to compel them. In fact, EEOI is a quite a useful and clear monitoring tool for ship owners and operators for assessing the performance of operating ships, especially performance relating to saving of fuel energy. First, EEOI can be applied to any ship types of international mechant fleets. Second, EEOI value can reflect the effect of installing a new engine or an efficient propeller, which could also quantify the amount of CO_2 emissions from ships. EEOI value could mirror the variations of emission change effectuated by operations, such as ship speed changes due to bad weather or changes in routing based on weather reports.

EEOI can be simply expressed by the following formulas:

$$\text{EEOI} = \frac{\text{actual CO2 emission}}{performed\ \ transport\ \ work} \quad (4.5) \quad \text{Or EEOI} = \frac{MCO2}{Mcargo * D} \quad (4.6)$$

Where

Mco_2 is the total carbon emission from ship during each voyage

Mcargo is the total TEUs of cargo or total tonnage of cargo.

D is the distance of transport work in nautical miles

MCO_2 decided by total fuel consumptuon to each type of fuel as well as carbon to CO_2 conversion factor for the fuel(s)

EEOI also could be described as

$$\text{EEOI} = \frac{\sum FCi \times Cn}{Mcargo \times D} \quad (4.7)$$

Where

i is fuel type

FCi is the total fuel consumption during each voyage

C_{Fi} is CO_2 emission facor

The above fomulae indicate that the smaller the EEOI value, the greater is the fuel efficiency of the ship, and that a reduction in the CO_2 emission can can have a direct impact on energy efficiency of the ship. Hence, EEOI is an excellent tool for monitoring the performance of ship SEEMP.

5.2.5 Suggestions Based on EEOI

First, ship owners and operators should use shore power as much as possible when ships are operating in port areas. When a ship sails in the port area, it could stop working its engines and shift to use of shore power for reducing CO_2 emissions from engine fuel combustion. According to the above formulae, reduction of FC_i can reduce the value of EEOI.

Second, clean or high quality fuels should be used. Ships could use more LNG, biofuels or wind power etc. As mentioned earlier, the CO_2 emissions factor of LNG is the smallest compared with HFO and MDO. According to the formulae, CO_2 emission factors would decrease EEOI value directly and improve ship energy efficiency.

Third, shipping companies can improve their management level of ship transportation. In terms of the EEOI formula, if the value of Mcargo (the total TEUs of cargo or total tonnage of cargo) becomes greater, the EEOI value will be decreased. In other words, increasing cargo dead weight could enhance the energy efficiency of the ship and reduce the CO_2 emissions as well. Thus, managers of shipping companies should reasonably organize transport routes at the management level and decrease no-load ratio of ships to abate GHG emissions.

Last but not least, the full load ratio of a ship should be improved. Ship owners should combine to form large-scale and high-efficiency logistics systems. To increase the full load ratio of ships, ship owners can enlarge transport distances within a reasonable range. According to the EEOI formula, as the transport distance increases, the EEOI value will be decreased. As a result, the energy efficiency of ships will be increased and CO_2 emission will be controlled effectively.

5.3 Advice Based on EEDI

EEDI offers a standard for the lowest energy efficiency for future vessels. It is hoped that the EEDI value can be as low as possible within a safe and reasonable range.

$$\text{EEDI} = \frac{EnginePower \ * SFC * Cf}{Capacity \ * speed} \quad (4.8)$$

Where

SFC is specific huel consumption

Cf is CO_2 emission factor

According to the parameters contained in the EEDI formula, some suggestions are offered with regard to better EEDI development and further enhancement of management of ship GHG emissions.

First, the ship shape and ship line should be optimized. This has a direct influence on the ship's resistance which in turn has a positive effect on the fuel consumption of the main engines. Second, the wind resistance of the superstructures on deck should be reduced. If the total area of the superstructures on deck is large, the wind resistance will be increased when the ship operates in heavy wind conditions, which in turn will increase the fuel consumption of the ship. Third, the design of the propeller should be optimized. This will decrease the SFC. In terms of the EEDI formula, with the decrease of SFC, the EEDI value will also decrease. Thus, optimisation of propeller design will increase the fuel consumption of the ship and reduce GHG emissions. Fourth, the management of ballast water must be optimized. Because the DWT of the vessel is constant, ballast water may decrease the cargo capacity of the vessel. In terms of the EEDI formula, therefore, the less the cargo capacity of the vessel, the higher is the value of the EEDI. Hence, increasing the cargo capacity is quite important for enhancing the energy efficiency of the vessel. Recently, some ship designers have innovated a non-ballast water technique that could greatly improve cargo capacity and reduce GHG emissions.

Fifth, the propulsion system on the ship must be improved which will increase the efficiency of the main engines. Engine power is the molecule as shown in the EEDI formula. Thus if the propulsion system is updated it will increase the efficiency of the main engines. If the value of engine power is reduced, the EEDI value will become smaller. Sixth, new energy that is different from traditional energy such as coal and fossil oil should be used. Rather, solar energy, wind energy, biofuel etc. should be used. As the CO_2 emission factor is the molecule as shown in the EEDI formula, the smaller the value of Cf, the smaller will be the EEDI value. Hence, activily using new energy instead of traditional energy fuel will significantly enhance ship energy efficiency and decrease CO_2 emissions.

Last but not least, waste heat from ship exhaust gases should be recovered. During the operation of the ship's main engine, which generates a large amount of exhaust gases, 30% of heat energy is taken away. If the ship owner rationalizes the use the heat energy of exhaust gases, such as transferring waste heat into electricity power and use it on ships, then the ship will further realize the goal of energy saving and emission reduction.

5.4 The Barriers to Use New Clean Energy

As discussed in Chapter 4, there are 3 senarios for mitigating GHG emissions by using alternative fuel types. It is deemed useful at this juncture to revisit these 3 scenarios.

Use of MGO with 0.1% or less Sulphur instead of HFO

Use of LNG instead of HFO

Maintain use of HFO together with installing technical facilities on board for abating SO_2, PM and NO_x.

5.4.1 The Difficulties of Using MGO with 0.1% or Less Sulphur Instead of HFO

For the first scenario, MGO with 0.1% or less sulfur should be used instead of HFO. The advantages of this scenario are that ship owners do not need to invest much more money to reconstruct ships or retrofit tanks and engines of existing ships; and current bunker suppliers or bunker traders need not change their practices for the provision of HFO and MGO to customers. Moreover, bunker suppliers do not need to pay extra money to modify barges and other facilities for delivering MGO. However, to implement the scenario of using MGO instead of HFO, there are some difficulties that need to be overcome.

First, from a point of view of economizing on operational cost, it would be significantly increased since the MGO price is roughly twice that of HFO. Ship owners may be not willing to pay more money on bunker costs. Especially in light of the current state of the shipping market, no ship owner would be inclined to pay a higher price to use MGO. Second, using MGO fuel only solves the issue of SO_x and PM emission. NOx, CO_2 and other GHG will continue to exist in ships' exhaust gases. Furthermore, ships using MGO will emit the same amount of NOx, CO_2 and other GHG as ships using HFO. Thus, to remove the NOx and other GHG emissions, ship owners have to install SCR and EGR when using MGO as the main bunker fuel. The total cost of installing SCR and EGR is not cheap for ship owners.

So far, only MGO fuel is used in ECAs for complying with the requirements of ECAs. Ship operators should switch from heated HFO to cooled MGO when preparing to sail into ECAs. Another concern is that the operation of switching fuels, if done for extended periods, is likely to damage the engines. Ship owners will then have to change the other lubricants with expensive price tags. Thus the engine maintenance cost and lubrication oil cost will be significantly increased.

Moreover, the supply of regulated MGO fuel may be not available and enough to meet the demand of global fleet. Proshanto K. Mukherjee and Mark Brownrigg (2013) mentioned that it is difficult to offer the enough fuel with less 0.5% sulphur to global fleet by 2020, the 0.5% global regulation will be delayed by 5 years until 2025. (Proshanto K. Mukherjee and Mark Brownrigg, 2013). The reason for causing the barrier is that bunker supplier and refiner are not willing to pay extra money to improve the capacity for producing fuel with less 0.5% sulfur. In terms of the analysis, the extra investment may be up to 95 billion dollars. Therefore, if it is possible, the local or regional governments can provide funding support to those bunker suppliers and refiners for encouraging them to increase capability to produce the qualified and standardized fuel.

5.4.2 The Difficulties of Using LNG Instead of HFO

For the second scenario, LNG instead of HFO should be used. The positive aspects of using LNG are that SO_x, PM and NO_x emissions can all be removed from ships' exhaust gases together and the bunker costs will decrease because the LNG price is relatively inexpensive compared with HFO and MGO prices. Ships using LNG as bunker fuel not only meets the requirements of SECAs and NECAs, but also realizes emission reduction outside of ECAs. However, there still exists some barriers if LNG is used instead of HFO.

First, is the problem of gas leaks. For using LNG as bunker fuel, ship owners must install dual fuel engines on ships. As of now, the technique of dual fuel engines is not sufficiently reliable and mature. Methane is likely to leak in the engine when the dual fuel engine is in operation, which may damage the engine and create unsafe conditions. In addition, LNG and fuel oil will produce acidic substances at high temperatures as the dual fuel engine combusts them together, which will the corrode engines. It is clear to see that dual fuel engines are more difficult to maintain and repair than single fuel engines. Dual fuel engines usually stop work once every two or three months for maintenance which may have a negative influence on the usual business of ship owners. If the maintenance time is the peak time for shipping cargo, then ship owners will lose income from carriage of goods.

Next, using LNG will reduce the cargo capacity of the ship. The tanks for storing LNG fuel need much more space than storing fuel oil such as HFO and MGO, which may decrease the cargo capacity of ship. In other words, if LNG is used as bunker fuel, existing ships will have to reconstruct their tanks for keeping an adequate amount of LNG fuel. Loss of original cargo capacity, which requires ship owners to invest additional money on reconstruction of tanks and loss of money due to the shrinking of cargo capacity. Moreover, due to the operation of dual fuel engines is more complicated than marine diesel engines, the existing crew might be not be able to operate dual fuel engines well enough. Thus ship owners will have to expend more time and money to train new crews for operating dual fuel well.

Although LNG fuel has been sucessfully used as the main propulsion fuel on LNG transportation LNG tankers, using LNG in general transportation ships such as container ships and dry bulk ships still have many limitations due to the character of LNG. For example, using LNG may lead to poor endurance ability of a ship. According to current statistical data, , the best ship endurance ability for using LNG fuel is only 22 days over a distance of 10,000 nautical miles, which cannot meet the requirements of ocean-going transportation. If by using fuel oil, the normal ship endurance ability is increased to at least 42 days for a distance of 18,000 nautical miles, ships using LNG fuel as propulsion power may be able to satisfy the requirement of ocean going transportation. Furthermore, ships cannot take on board adequate amounts of LNG fuels due to the complicated system of LNG tanks. If ships try to keep enough LNG fuel, it will take up more shipboard space and decrease the cargo capacity of the ship.

The primary reason for poor endurance ability of a ship is the difficulty in arranging tanks and equipment for LNG storage on board. Tanks for fuel oil storage are easy to arrange and design on ships in which installation is flexible. Due to the shape of LNG tanks is a matter of geometry, even if the volume of an LNG tank is smaller than an HFO tank, LNG tanks are not easy and flexible to be installed. In particular, for dry bulk ships, if LNG tanks are installed around holds, they will impede cargo handling; if LNG tanks are installed around accommodation spaces on board, safety will be a major concern. These limitations do not enable general cargo ships to take on board sufficient amounts of LNG fuel to meet voyage demands. For non-LNG vessels, the reliability and stability of the main propulsion system are quite important factors.

The supply of LNG fuel is not an easy matter. Bunker suppliers and companies need to invest huge amounts of money to construct LNG supply infrastructures. At present, HFO fuel being relatively inexpensive, the market-driven prices may inhibit the development of LNG fuel. Bunker suppliers may not voluntarily invest extra money to build LNG supply infrastructures.

5.4.3 The Difficulties of Using HFO with Installing Technical Facilities on Board

For the last scenario, it is advisable to keep using HFO together with installing technical facilities on board for abating SO_2, PM and NO_x, which can avoid certain problems. For example, ship owners need not think about retrofitting tanks and changing engines. They can continue to use high sulfur HFO thereby keeping bunker costs down. There are two considerations if this scenario is adopted. First, is the problem of capital. Installing scrubber systems on board undoubtedly requires ship owners to spend more money. Second, currently, there is no port that can receive and clean the waste generated by scrubber system, and there is no port planning to invest money on build infrastructure for receiving and disposing scrubber wastes. Even though the scrubber system is available for use, how the waste produced by the scrubber system is to be disposed, is apparent an issue that has not yet been resolved.

5.4.4 Concern of Cargo capacity

For the scenario where LNG is used instead of HFO and the scenario where HFO is used together with installation of a Scrubber, cargo capacity could be a concern to ship owners. Table 19 compares these 3 scenarios from the perspectives of cargo capacity, capital investment and operational costs. It can be observed that where LNG is used, it directly restricts cargo capacity. Use of HFO with scrubber will have a slight restriction on cargo capacity. In so far as ship owners are concerned, none is willing to pay more money, or install tanks and engines. Meanwhile money is lost due to decrease in cargo capacity. There is no benefit to ship owners. Hence it makes ship owners lose enthusiasm to implement these scenarios in practical terms.

Table 19 – Comparing the alternatives: LNG, MGO and HFO

	Factors influencing viability compared to the traditional HFO alternative		
Alternative	Cargo Capacity	Capital investments	Operating costs
LNG	Restricted	Very high	Low
MGO	Not restricted	Low	Very high
HFO/Scrubber	Slightly restricted	High	Medium

Source: Own presentation based on International Maritime Organization. (2016). S*tudies on the feasibility and use of LNG as a fuel for shipping*. London.

5.4.5 Capital Cost Problem

In the opinion of this writer, capital cost is a non-negligible barrier for implementing these 3 scenarios. It can be roughly estimated that total capital cost of implementing these scenarios should include capital investments and operational costs. As per Table 20, it is observed that capital investments and operational costs of the three scenarios together with, the total cost of each scenario is an additional and expensive cost for ship owners. Table 20 is established based on investment cost and offers 5 optional strategies. In terms of Table 20, it is clear that the cost of using MGO with scrubber system is the highest among the 5 strategies. The investment of continuous use of HFO with scrubber system is the cheapest, but it is only slightly cheaper than the other 3 LNG strategies. The cost of each strategy is not a small figure for ship owners. Thus whether the strategies can be implemented depends on whether owners are willing to spend money to promote the development of a green shipping industry. Some shipping companies and ship owners may complain that it is unfair if only they invest money on the scrubber system, LNG tanks and engines. They peruse the relevant fair market and expect to see a uniform standard for the development of a green shipping industry.

Table – 20 Indicative investment costs for optional compliance strategies

Compliance strategy	Retrofit	New builds
MGO – engine conversion, SCR and EGR	180,000 USD + 75 USD/kW	140,000 USD + 63 USD/kW
HFO and scrubber – scrubber and SCR	600 USD/kW	2 200 USD/kW*
LNG four stroke dual fuel -LNG tanks etc.	800 USD/kW	1 600 USD/ kW *
LNG two stroke dual fuel -LNG tanks etc.	700 USD/kW	1 500 USD/ kW *
LNG four stroke spark ignition -LNG tanks etc	800 USD/kW	1 600 USD/ kW *

Source: International Maritime Organization. (2016). S*tudies on the feasibility and use of LNG as a fuel for shipping*. London.
Note: *including engine, generators, etc.

It is suggested that classification societies, international organizations and regional authorities set up a uniform standard and give some allowance for persuading ship owners and shipping companies to develop a green shipping industry.

5.5 The Barriers of Applying New Energy

5.5.1 Technical Barrier of Wind Power Application

Bad weather is considered as the first technical barrier for installing wind power facilities and systems on ships. Wind power technology cannot keep stability and reliability when ships suffer extreme weather conditions at sea, such as storms. In case of heavy winds brought about by rough weather conditions or where the wind speed is over 200 knots, wind power systems have to be closed. Wind speed and power are uncertain and difficult to predict, which also raises a safety concern.

5.5.1.1 Ship Owner Concerns

Ship owners are primarily worried about structural integrity and stability of ship and cargo handling when ships encounter foul weather. The concerns of ship owners can be regarded as second barriers. Wind power systems can be installed directly on existing ships, which may bring new forces on the ship's hull. Ship owners will consider ships according to whether they can withstand new forces. Wind power technologies may hinder cargo handling (loading and unloading). Especially for dry bulk vessels, the deck does not have enough space for wind assistance technology and such technologies can restrict the workings of ships' gantry cranes. It may hinder cargo handling by port cranes as well. Furthermore, if a wind assistance system is installed, ship owners will spend additional money to train crews to meet the requirements of operating the system.

5.5.1.2 Cost Risk

Shipping companies may not be willing to invest money in wind assistance technologies. The reason is quite simple. The investment cannot yield the expected return. Hidden cost is also like a big investment. There are 3 main hidden costs. The first is installation costs. Second is the cost of reduction in cargo capacity since wind assistance systems may take up to the original cargo capacity of ships. Third is the cost of production disruption which occurs when ship owners temporarily stop operating ships to install wind power systems. If the shipping market is good at that time, the disruption may be a really expensive opportunity cost. Besides, a wind assistance technology producer states that if ship owners want to use all of the advantages of wind power, they should change original voyage routes. However, if ship owners change the route for better use of wind power, they will miss good business opportunities. The saved bunker cost from using wind power may be lower than the cost of business loss. This opportunity cost may be a good excuse for ship owners not accepting wind power technologies. Combined with the current market situation, the bunker price has dropped since 2014 and the shipping market is not very good now. Thus, ship owners have not much interest in wind assistance technology.

5.5.2 Technical Barrier of Solar Power Application

So far, installing solar energy assistance technology on ships is mostly for providing electricity for ships. Solar energy assistance technology lacks stability. It is not easy to collect solar energy as it depends on the actual weather condition and sea area. If the weather is cloudy or the vessel sails around Northern Europe where there is lack of sunshine in the winter, the solar energy assistance technology will be useless. Even if the problem of collecting solar energy can be resolved, solar energy storage will be another concern. Electricity generated by solar energy system is just not adequate for ocean going ships.

In addition, the investment cost of installing solar energy storage facilities and energy assistance technologies on ships is expensive for ship owners. The investment cannot yield the expected return for ship owners. What is more, since the solar energy technology is not reliable enough, solar energy storage facilities and energy assistance technology need to be maintained frequently; hence maintenance cost is a hidden cost for ship owners. In sum, taking into consideration the disadvantages of using solar energy technology, it is unlikely that ship owners will accept it in the short term.

5.6 The Weaknesses of ECAs

ECAs require ships using fuel with sulfur content less than 0.1%. If ships do not comply with the requirement, they will have to pay penalties. For ships which mainly transport cargo around non-ECAs and sail in ECAs occasionally, ships would rather pay the penalties than spend more money buying regulated fuel oil or install equipment to use LNG. This seems to be a drawback of ECAs.

Besides, Proshanto K. Mukherjee and Mark Brownrigg (2013) mentioned that Dutch authorities released figures for 2010 showing that 46% of ships failed to meet sulphur standards within the North Sea SECA. (Proshanto K. Mukherjee and Mark Brownrigg, 2013) The reason for ships failing to meet requirement is that fuel quality is below standard, rather than that ship owners intentionally do not comply with the regulations. Hence, even if the explicit regulation of SECA is existing, the objective factor will also hinder ship owners to comply with.

Comparing ECAs standards with global standards, it is obvious that global standards are less strict than ECAs. IMO should accelerate the adoption of high level regulations regarding ship emission reductions. Times have changed no doubt; the center of the shipping industry has started to move from Europe to Asia, but the regulations for ship emissions are not strict in Asia. European countries place greater emphasis on the importance of reducing emissions from international shipping. In the North Sea and Baltic Sea, ECAs with strict regulations have been established, whereas in Asia which mostly consists of developing countries, which pay little attention to the issue of emission reduction and lack awareness of the importance of adopting regulations for emission reduction, IMO could guide and persuade these countries to further control emission reduction from shipping, and make strict regulations for the global shipping industry.

Chapter 6 The importance of China Controlling GHG emissions from International Shipping.

6.1 China's importance in international shipping industry.

Today, China is the largest developing country, the largest exporting country, and a crucial importing country in the world, which is significant to international trade and economics. The commodities that are exported by China are mostly carried by international ships; and the goods that are imported by China are mostly transported by international ships as well. Hence, there is no doubt that China is playing an important role to the entire shipping industry.

A report from Chinese Port (http://www.chineseport.cn/) shows the throughput ranking of global container ports in 2015. There are 7 Chinese ports entering the top 10, which include Shanghai ports, Ningbo-Zhoushan port, Qingdao port, Tianjin port, Guangzhou port, Tangshang Port, and Suzhou Port. According to the news from China Economic Net (http://en.ce.cn/), The Chinese-owned shipping fleet is up to

160 million DWT, which is the 3rd largest ship fleet in the world. Moreover, China is the top 3 both in the world ship building industry and world ship scrap industry. Due to that China takes a significant position in the whole international shipping industry, hence the actions and initiatives taken by China to control international ship exhaust gases have a remarkable impact on emission reduction efforts in international shipping.

6.2 The Efforts Made by China in Controlling International Ship Exhaust Gases.

Firstly, China is establishing ECAs. Since 1st January 2016, ECAs have entered into force. Ships must strictly implement the existing international conventions and comply with Chinese law requirements for controlling sulfur oxides, particulate matter and nitrogen oxide emissions. If ships operate at the core ports of ECAs, during the time of ships calling at berths, ships will switch to using fuel with 0.5% sulfur or less

After 1st January 2017, if ships operate in the core ports of ECAs, during the time of ships calling at port (except 1 hour after ship departures and 1 hour before ship departures port), ships will switch to using fuel with 0.5% sulfur or less

After 1st January 2018, if ships operate at all of ports of ECAs, during the time of ships calling at port, ships will switch to using fuel with 0.5% sulfur or less.

After 1st January 2019, once ships enter ECAs, ships will switch to using fuel with 0.5% sulfur or less. Before 31st December 2019, the performance of implementing ECAs will be accessed, and government will confirm whether future action will be taken as follows:

- Once ships enter ECAs, ships will switch to using fuel with 0.1% sulfur or less.
- Enlarge the ECAs control area in geographically
- Take other strict actions to further control ship exhaust emissions
- Ships may take action of connecting shore power, use clean energy, install tail gas treatment, or take other equivalent methods which could meet the requirement of ECAs.

Second, ports construct shore power infrastructure. Shanghai port, Shenzhen port, Qingdao port, Tianjin port and so on, are actively establishing shore power infrastructure. The aim of these ports establishing shore power infrastructure is offering shore power to berth ships. When the ship operates at berth, the ship could shut engines up and connect shore power to complete the cargo handling and daily operation. It greatly reduces ship fuel consumption and mitigates international ship exhaust gases in port.

It is worth mentioning that Tianjin port has already finished the construction of low voltage shore power infrastructure, and realized that all of ships which operate at berth could fully use shore power instead of engines combusting fuels. The shore power infrastructure of other Chinese ports is under experiment or construction phases.

6.3 The Existing Problems with China's Governance of International Ship Exhaust Gases.

In the long term, due to the Chinese government and Chinese operators lacking clear reorganization of the concept of developing a low carbon and green shipping industry, and lacking awareness of marine environmental protection, the Chinese shipping industry has not established an overall concept for developing a low carbon and green shipping industry. It causes China lacking the complete concept of controlling GHG emissions from international shipping as well. As reported in some China shipping enterprise reports and articles from China shipping experts, in this Chapter the author summarizes 5 limitations restricting China from developing a low carbon and green shipping industry

6.3.1 Unclear Concept of Low Carbon Shipping Industry.

Since reform and opening up in 1978, China has started to enter into the global marker and welcomed foreigners to do business in the Chinese market. The shipping industry is an international industry; thus it has started to develop in China since 1978, which has led to the development of the Chinese shipping industry is fairly late and the concept of developing low carbon shipping is strange for China. Because the shipping development started late in China, people are not very familiar with marine technology and do not have deep understanding and knowledge of shipping. Thus the Chinese shipping industry has neglected the issue of ship exhaust gases over a long period. In other words, the Chinese shipping industry has only focused on rapid development and has ignored the issue of shipping exhaust emissions reduction in the past.

Due to China not having sufficient shipping knowledge, it brings barriers to the development of a low-carbon shipping industry. First, it is difficult for the shipping industry to make scientific and reasonable methods to develop a low carbon and green shipping industry. Second, each shipping department and shipping company only focuses on short term interests and ignores the long term social benefits of environmental protection

6.3.2 Incomplete Legislation and Regulations

Since the 1990s, even though China has adopted many relevant policies for controlling environmental pollution, these policies have rarely referred to development of low carbon and green shipping industry. For example, there is no exclusive legislation clearly dividing the responsibility of emission reductions between ship owner and charter.

In addition, the complete business of international shipping contains many processes. Each process has more than one department to manage. Thus usually there are multiple departments in place to manage and monitor the same process in China, which makes the shipping business complicated and has an adverse impact on the development of low carbon shipping industry. China is a nation with a total of 34 provincial administrative regions, each regional government making its own plan about developing low carbon shipping industry and only considers its own short term benefit. It is really hard to balance and unify management in China, which leads to imbalance and the unsustainable development of low carbon shipping. That is the main reason why China's shipping industry lacks integrated development of low carbon and green.

Furthermore, China is the biggest developing country in the world. Some senior Chinese scholars think that the concept of environmental protection and economic development are mutually inconsistent in China, As a country, China has not been able to adopt policies and regulations for controlling ships' exhaust gases like western developed countries. Promoting the concept of developing the shipping industry in this way is not easy in China.

6.3.3 Poor Shipping Technical Level.

The current trend of global development has been transforming from “high carbon economy” to a “low carbon economy”. A low carbon shipping industry is closely connected to low carbon technology; developing a low carbon shipping industry cannot be separated from the control and application of green technology. The technology of improving energy efficiency is fundamental to the development of a low carbon shipping industry. However, in China, the current investigative ability of shipping technology and the application of shipping technology are far lower than the specific requirements of low carbon shipping. Energy saving technology cannot be well used on Chinese ships. Chinese shipping activities lack management proficiency in terms of such things as automation, information and intelligence. China is the 3rd largest shipbuilding country in the world, but when Chinese shipbuilding technology is compared with counterparts in developed countries such as Japan and Korea, Chinese shipbuilding technology is rather inferior. Shipping technology in China is not comprehensive enough to be able to dispose of ship waste and exhaust gases.

6.3.4 Overall Development of the Shipping Industry Lagging Behind.

Although China as a shipping country is big in the world, the overall competitiveness of the Chinese shipping industry is not strong. Thus there exists a gap between the Chinese shipping industry and those of the advanced European countries. China's backwardness in the development of low carbon shipping mainly reveals that the modernization of China's shipping infrastructure is relatively low. Most Chinese shipping enterprises are still using old concepts to operate and manage ships.

6.3.5 Chinese Shipping Industry’s Lack of Professional Shipping Talent

At present, most people who work in the Chinese shipping industry almost did not receive any professional shipping education and training. In particular, the majority of shipping managers in China hold majors in computer science or finance. China lacks professional shipping education institutions. At present in China there are only 2 professional maritime universities; one is Shanghai Maritime University, and the other is Dalian Maritime University. In addition, China lacks proper training schools for training of qualified seafarers. Contemporary ships are becoming increasingly complex and diversified, which makes requirements and standards for the crew much stricter than before. Qualified seafarers are helpful for developing a low carbon shipping industry since seafarers can help to reduce GHG emissions by rational and professional operation.

6.4 Suggestions for China Governing International Ship Exhaust Gases.

In recent years, the Chinese government has started to pay attention to developing low carbon and a green shipping industry. As global climate change and serious marine pollution is moving at an accelerated pace, some of China's scholars have begun to change their minds, and are gradually paying more attention to developing a Chinese and international low-carbon shipping industry.

6.4.1 Multi-parties Jointly Establishing Development of Low Carbon Shipping

The Chinese government may encourage and guide China's shipbuilding enterprises to be more innovative in terms of shipping technology, and motivate them to design and produce low energy consumption, high energy efficiency and low operational cost vessels, which could greatly reduce the adverse impacts on air pollution. China

Classification Society is responsible for monitoring the whole process of building ships. Chinese shipping companies could pay more attention to setting up modernized international shipping fleets, and can offer advice to their new building vessels based on transportation demand. The Government can adopt policies or provide methods for motivating shipping companies and shipbuilding enterprises to expend more effort towards the development of a low carbon shipping industry, and assistance in the growth of China's low carbon and green shipping industry.

6.4.2 Establishment of Overall Reliable Regulations and Legislation

Regulations and legislation play important roles in China's development of a low carbon and green shipping industry. Government and related shipping management departments should intensify regulations and management, accelerate the establishment of relevant legislation for development of a low carbon shipping industry, regulate the establishment of a standardized legislation system, and ensure that China can rely on sound legislation for the orderly development of a low carbon and green shipping industry.

6.4.3 Cultivation and Development of Professional Shipping Talent

Professional shipping talent is significant for China establishing a low carbon and green shipping industry, which ensures that the development process avoids barriers as much as possible. On the one hand, shipping enterprises could expend adequate effort to attract high quality talent and cultivate hi-tech home-grown shipping talent. On the other hand, China should pay attention to the construction of shipping education institutions including academies and universities, and increase investment in training and developing shipping talent to further establish a diversified and multi-level education system for the shipping industry. This would be a determinant factor for the improvement of the management level in the Chinese shipping industry.

In China shipping education institutions should combine research with teaching and actively cultivate professional shipping talents as well as apply research results to practical operations. China should attach importance to people who are proficient in shipping policies and legislation and are knowledgeable in shipping finance and economics. In addition, China's shipping institutions and universities should actively communicate and cooperate with advanced shipping countries to develop highly qualified shipping managers, who can offer good support for developing a low carbon and green shipping industry.

6.4.4 Development of Advanced Shipping Technology and Intensification of Application of Green Technology

Green shipping technology underpins green shipping industry. The development of green shipping technology can greatly save energy and reduce energy consumption as well as abate ship exhaust gases, which paves the road to the development of green shipping. China should improve ship designs and eliminate old vessels. Improvement of ship design can include: optimization of hull, improvement of propulsion equipment to increase the efficiency of engines.

The Chinese government could strictly control emissions of ship exhaust gases by intensifying the application of green technology. For instance, they could advise shipping companies to use fuel with low sulfur content, encourage ship owners to install Tier III engines for reducing NOx emissions; inspire ship owners to install scrubber systems on board for cleaning ship exhaust gases and also motivate ports to develop infrastructure for receiving and disposing of wastes produced by scrubber systems.

6.4.5 Use New Energy

The Government should encourage shipping companies to use new energy. For example, it could encourage shipping companies to actively install wind assistance technologies and solar energy systems on ships and give these companies some allowances and incentives; motivate ship owners to use LNG as main bunker fuel and inspire ship owners retrofit LNG engines and tanks by giving monetary benefits or reducing taxes.

6.4.6 Adoption of Slow Steaming Strategy.

Chinese ships should be encouraged to continuously adopt slow steaming strategies, particularly in cases of operation of large vessels at a safe and low speed. Slow steaming is the fastest and the most effective way of reducing the fuel consumption of existing ships and mitigate current ship exhaust gases. In addition, China should foster the development of a shipping industry cluster, and accelerate the updating of the shipping industry, which will undoubtedly have a positive impact on the development of a low carbon and green shipping industry.

Chapter 7 Conclusion

The ship exhaust gases issue is one of the significant challenges that the whole international shipping industry has to face. Due to the gradual increase of seaborne trade and the constantly growing demand of ship transportation, the entire international industry should pay more attention to combat the ship exhaust emission issue.

7.1 Main Findings

First, this research paper finds and analyzes five main factors that may affect GHG emissions from international shipping.

Second, the research paper introduces some current approaches to mitigate ship GHG emissions and provides some potential measures that could be taken in the future in terms of the five main factors.

Third, this research paper finds difficulties and barriers to implement each measure of emission reduction, and then offers some suggestions to fix these difficulties and barriers.

Last, the paper states the importance of China controlling international ship emissions and summarizes the current situation regarding China’s mitigation of GHG emissions from international shipping

7.2 Limitations of the Research Paper

The paper probably lacks the practical experiences and analyses that can add value to the proposition. On the one hand, the paper only analyzes the main factors that effect on GHG emissions from international shipping in theory, but does not carry out proper trials in realistic situations. On the other hand, the measures and the identified barriers are obtained from related literature. Since the author did not participate in the whole process of implementing measures, the outcomes as presented may not be sufficiently reliable. In addition, the author cannot offer suggestions with respect to all measures mentioned because she did not actually participate in the process of the practical work, but has nevertheless pointed out the barriers and difficulties that may be faced in the course of implementing the measures without making any concrete personal suggestions.

7.3 Summary

Based on the discussion of this topic, society as a whole should treat the problem of ship exhaust emissions seriously. The biggest barrier to implementing reduction measures is the problem of cost. Since reducing emissions from ships is an expensive proposition, ship owners and shipping enterprises should spend more to mitigate emissions. However, few are willing to pay that price, which hinders ship owners from implementing the emission reduction measures. In the opinion of this author, uniform and standardized regulations issued by IMO or other international bodies should be relatively reliable. Uniform standards will influence and even compel ship owners to comply with them. Ship owners must comply with such regulations without fail. Eventually the problem of cost will disappear. In addition, it is better to establish a fair shipping market. Therefore, stringent regulations are urgently required. The IMO and other international bodies should accelerate the process by making stringent regulations of uniform application. Meanwhile, regional governments and local authorities can offer funding support to shipping enterprises and ship owner to facilitate the implementing of measures for the reduction of exhaust emissions from ships.

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