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MSc. NAVIGATION AND MARITIME TRANSPORT

DISSERTATION

LOW CARBON SHIPPING – AN ANALYSIS OF THE EFECTIVENESS OF 'SLOW STEAMING' ON MERCHANT SHIPS

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After five months of work, I conclude my dissertation dedicating these words to the most significant people during this period.

Along the writing process of the thesis, I have come across different difficulties that I have been able to overcome with the help and support of my sister Julene, my family and friends. For this and much more, thank you.

I am grateful to my best friend, Iga Cierpiał for always being there for me despite the distance, for sharing with me information upon which this dissertation is partially based, and because we both entered the world of sustainable maritime transport after attending *Green Shipping* lectures in Norway together.

Special thanks to Capt. Prof. Michael Vahs for supporting the most technical part of this project and encouraging me to keep going full speed ahead.

And last but certainly not least, thanks especially once again to the director of this dissertation, Dr. Itsaso Ibáñez for her commitment, willingness, backing and trust placed in me.

ABSTRACT

This dissertation purports to analyse the effectiveness of the 'Slow Steaming' technique on merchant ships, determining its economic and environmental impact. To this effect, databases such as Scopus and WoS (Web of Science) have been consulted in order to collect the necessary bibliography to carry out the project at hand. After the research, it has been observed that slowing down could turn into a commonplace practice nowadays on vessels due to its main benefits: the reduction in fuel consumption and the lowering of CO_2 and overall greenhouse gas emissions. Through the analysis of alternatives, it has been demonstrated that the 'Slow Steaming' is the most feasible sustainable alternative currently, albeit it cannot be considered a long-term application due to the main consequences it entails: the lengthening of voyage duration and the need to cover the generated lack of cargo capacity by putting more vessels into service. Therefore, it is concluded that it is a temporary action to be taken during the process of development and implementation of new 'Green Shipping' technologies.

Keywords: slow steaming, speed reduction, emissions, green shipping, fuel consumption

LABURPENA

Master amaierako lan honen bitartez, 'Slow Steaming'-ak merkantzia-ontzietan duen eraginkortasuna aztertu nahi da, teknika honen ingurumen-eragina eta inpaktu ekonomikoa determinatuz. Horretarako, datu-baseetara jo izan da, Scopus eta WoS (Web of Science) batik bat, proiektu hau burutzeko beharrekoa den bibliografia jasotzeko helburuarekin. Ikerketaren ondoren, itsasontzien abiaduraren murrizketa gaur egun praktika arrunt batean bilakatu daitekela frogatu ahal izan da bere onura nagusiak direla medio: erregai kontsumoaren jaitsiera eta bai CO_2 nahiz gainerako berotegi-efektu gas emisioen murrizpena. Hala ere, nahiz eta alternatiba desberdinen analisiaren bitartez 'Slow Steaming'-a aukera jasangarri egingarrientzat frogatu, aukera honek ez du aplikaziorik epe luzera honek eragiten dituen ondorio nagusiak direla bide: itsas bidaien luzapena eta honek sorrarazten duen karga kapazitate hutsunea itsasontzi gehiagorekin betetzeko beharra. Horregatik, itsas-garraio jasangarriaren baitan dauden teknologia berriak garatu eta ezartzen diren bitartean aplikatu daitekeen aldi baterako neurria dela ondorioztatu da.

Hitz gakoak: slow steaming, abiadura murrizketa, emisioak, itsas-garraio jasangarria, erregai kontsumoa

RESUMEN

A través de este trabajo fin de máster se pretende analizar la eficacia de la técnica del 'Slow Steaming' en los buques mercantes, determinando su impacto económico y medioambiental. Para ello han sido consultadas bases de datos como Scopus y WoS (Web of Science) con el fin de recoger la bibliografía necesaria para llevar a cabo el proyecto. Tras la investigación, se ha observado que la reducción de velocidad de los barcos puede convertirse en una práctica común hoy en día debido a sus principales beneficios: la reducción en consumo de combustible y la disminución de emisiones de CO_2 y gases de efecto invernadero en general. Sin embargo, a pesar de que mediante el análisis de diferentes opciones se haya contemplado el 'Slow Steaming' como la alternativa sostenible más factible actualmente, no puede aplicarse a largo plazo debido a las principales consecuencias que acarrea: el incremento de duración de las travesías y la subsiguiente necesidad de cubrir la falta de capacidad de carga generada con más buques. Por ello, se concluye que se trata de una medida temporal a aplicar durante el proceso de desarrollo e implementación de nuevas tecnologías en el ámbito del transporte marítimo sostenible.

Palabras clave: slow steaming, ajuste de velocidad, emisiones, transporte marítimo sostenible, consumo de combustible

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GLOSSARY OF ABBREVIATIONS AND ACRONYMS

CO_2	Carbon dioxide
DWT	Dead-weight tonnage
ECA	Emission Control Area
EEDI	Energy Efficiency Design Index
EU	European Union
GHG	Greenhouse Gas
GloMEEP	Global Maritime Energy Efficiency Partnership
ICCT	International Council of Clean Transportation
IEA	International Energy Agency
IMO	International Maritime Organization
kW	Kilowatts
kWh	Kilowatt-hour
LNG	Liquefied Natural Gas
LPG	Liquefied Petroleum Gas
MARPOL	International Convention for the Prevention of Pollution from Ships 73/78 (IMO)
MCR	Maximum Continuous Rate
MEPC	Marine Environment Protection Committee
N_2O	Nitrous dioxide
NO_X	Nitrogen oxides
PM	Particulate Matter
SDGs	Sustainable Development Goals
SEEMP	Ship Energy Efficiency Management Plan

SFOC	Specific Fuel Oil Consumption
SO_X	Sulphur oxides
T	Tonnes
TEU	Twenty-foot equivalent unit
TTL	Total
UN	Untied Nations
UNFCCC	United Nations Framework Convention on Climate Change

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INTRODUCTION

INTRODUCTION

Currently, the protection of the environment is the order of the day, included in the maritime sector. The CO_2 emissions produced by the world fleet amount to 2.6% (932 million tonnes) of global emissions (Comer et al., 2017). The new legislations for the maritime industry regulate greenhouse gases emitted by ships, aiming to cut them by 50% by the year 2050 (IMO, 2018). As a result of this problem, a new concept of navigation has been developed: the 'Green Shipping'. This new and more sustainable way of maritime transport puts into practice the various methods respectful of the environment that have been created. However, many of them are at an early stage: they are currently being studied, or they will be tested soon to monitor their results and, therefore, analyse their viability.

However, there are still more rudimentary alternatives, which are not necessarily less efficient; this is the case of the 'slow steaming' or reduction of the speed of ships. The present work contemplates all the characteristics, advantages and disadvantages of this technique, offering, in the end, a comprehensive and general vision about the practice in question, providing new conclusions about the effectiveness of its application.

OBJECTIVES

The interest in this topic arises during my stay as an Erasmus student in Haugesund (Norway), in particular, in *Green Shipping* classes, a subject taught by professors Dr. Marcus Bentin, Eng. Freerk Meyer, Dr. Eng. Jann Strybny and Capt. Michael Vahs. Their lectures about many different sides of the green shipping helped me to broaden horizons and inspired me to work on projects about sustainable maritime transport, taking the present dissertation as a sample.

With respect to the specific objective of this dissertation, it mainly intends to analyse the effectiveness of the slow steaming technique on merchant ships from an environmental point of view. In this way, this green alternative as well as its energy, economic and environmental impact can become widespread.

Similarly, it purports to differentiate the advantages and disadvantages of slowing down, establishing consequences that derive from its application. It also tries to collate the different 'Low Carbon Shipping' alternatives under development, analysing the competitiveness and viability of the slow steaming.

Therefore, the dissertation at hand is done in the interest of knowing and covering all possible fields (results, impact, consequences and effects on the maritime industry), expanding the knowledge about this alternative to the scope of any vessel and, therefore, contributing to its application in more ships to turn the maritime transport into a more sustainable practice.

Hence, we present this original work as the final step to get the MSc. degree in Navigation and Maritime Transport.

METHODOLOGY

For the overall elaboration of this document, a bibliographic review has been carried out in order to investigate the publications about the Green Shipping and Low Carbon Shipping in depth, as well as on the slow steaming in particular.

Regarding the sources of information, secondary sources (articles, books and nautical publications) have been mainly consulted, as it will be explained in more detail in the review of the state of the art. Primary sources have also been accessed for this purpose, such as different official research institutions (for example the International Council on Clean Transportation, ICCT, or the Det Norske Veritas Classification Society, DNV GL), and conventions and resolutions of the International Maritime Organization (IMO), a specialized body of the United Nations responsible for safety and security of navigation and the prevention of sea pollution by ships.

Moreover, pursuing to show both the environmental and economic impact of the slow steaming, publications regarding speed and fuel consumption relationship have been consulted and an example of calculation is given to illustrate its effect to the reader. In addition, to get a truthful and reliable result and since slow steaming effects are not equal for every ship, four real ship-based scenarios have been suggested, in which true data of their propulsion systems and a habitual route for each case are provided and the impact of three speed reduction rates is assayed. Besides, for the calculation, several formulae have been consulted in order to choose the most appropriate ones.

Likewise, we have count on the help of Captain and Professor Michael Vahs, who has supervised and supported the technical part of this dissertation. He has been working on several Low Carbon Shipping projects, such as “Low Emission Ship with SkySails”, “E-Ship 1” and “MariGREEN”, among others, and he currently leads the “Green Sailer” project, consisting in the development of an innovative sail cargo ship for coastal shipping and island supply based on the vision of a 'zero emission ship', funded by the European Union (European Regional Development Fund).

STATE OF THE ART

Speed reduction or the so-called slow steaming made a space of itself in the maritime industry out of necessity, due to the economic situation prevailing in the 70s. At that time, it did not arouse any interest beyond the money saving that slower navigation entails, so there is no great theoretical foundation on this issue relating to that epoch.

Currently, the opposite is happening. During the last decade, there have been several studies that have raised the possibility of rescuing this ancient and rudimentary practice and apply it aboard ships with a completely different purpose: the reduction of CO_2 emissions (among other greenhouse gases) stemming from the maritime sector. Since this question is of total interest for the development of this dissertation, numerous articles have been consulted, such as Cariou (2011), Corbett et al. (2009), Lee et al. (2015), Mallidis et al. (2018) and Maloni et al. (2013) among others.

Besides the speed reduction, the green shipping in general has been addressed. In aiming for gathering data about this new sustainable initiative, more additional scientific articles have been looked up (Smith et al, 2016; Kontovas, 2014; Cames et al., 2015), highlighting one of the most multidisciplinary scientific magazines worldwide, *Nature* (Wang, 2016; Tollefson, 2018).

In addition, to dig into the green shipping and pursuing to carry out a complete and reality-conformed study, we have researched about those environmentally friendly alternatives with more future projection. Among the sources consulted, we can distinguish among brochures (Magma Structures BP, 2014; SkySails, nd; DYKSTRA Naval Architects, nd), magazine articles (De Marco et al. 2016; Carrington, 2017), audio-visual content (Argitech, 2015; Wind Hybrid Coaster, 2015) and also reports of classification societies (e.g. Chryssakis et al., 2017).

About the most technical part concerning the power and speed relationship as well as the calculation of fuel consumption and CO_2 emissions, several papers have been looked up in aiming for getting the most appropriate formulas. Eventually, equations chosen by Corbett et al. (2009) have been selected, while some data are based on assumptions by Cariou (2011), Jalkanen et al. (2011), Saputra et al. (2015) and DNV GL (2016).

Regarding the overview exposed in the first chapter, we have carried out a thorough collection of data concerning global warming, greenhouse gas emissions, and air pollution. On the one hand, general information from the World Health Organization (WHO, 2014), the Intergovernmental Panel on Climate Change (IPCC, 2014), the National Aeronautics and Space Administration (NASA, 2015), the International Energy Agency (IEA, 2016) and the United Nations (UN, 2015; UN, 2018; UN, 2019) has been collected. On the other hand, focusing on the maritime sector and its environmental footprint, well-known organizations' reports have been the most helpful and objective publications, e.g., Smith et al. (2015), Comer et al. (2017), Endresen et al. (2018), the International Chamber of Shipping (ICS, 2018), and the United Nations Conference on Trade and Development (UNCTAD, 2018). Nonetheless, some additional articles by Corbett et al. (2009), Cames et al. (2015) and Mander (2017) have been accessed. In addition, we have employed online content from verified websites such as the European Commission (EC, 2019), the European Environment Agency (EEA, 2017) and the Global Maritime Energy Efficiency Partnerships (GloMEEP, nd), which is mainly executed by the International Maritime Organization (IMO), funded by the Global Environment Facility (GEF) and implemented by the United Nations Developing Programme (UNDP). To finish, papers of different conventions such as the International Convention for the Prevention of Pollution from Ships (MARPOL 73/78) and the United Nations Framework Convention on Climate Change (UNFCCC) have been handled to address the legislative section.

Based on this bibliography, an original dissertation has been carried out, since such a paper that analyses the competitiveness of the slow steaming in comparison to that many promising sustainable solutions has not been found. In addition, all the works that have hitherto been assayed approached this issue from an economic prism mainly. On the contrary, in our case, we have worked from a primarily environmental point of view on the grounds that we consider that we are facing an alarming need to protect our planet for which economic interests should remain in the background. Therefore, in this way, a new and more complete approach to this topic is provided.

STRUCTURE

In order to fulfil the aforementioned objectives, the project is made up of four main sections. To begin with, so that the reader understands the content of the dissertation, a wide background is provided, displaying data from general issues such as global warming, air pollution and current world fleet's features, to information regarding maritime sector's contribution to those environmental problems and actions taken to curb the devastating effects of shipping.

The second section consists of the analysis of the most promising green alternatives at this moment, which will be the bedrock for the upcoming discussion.

Once the sustainable solutions are introduced, the dissertation focuses on one of those green options, the slow steaming, which is the motor for this master's thesis. Along this third section, its impact in different scopes is assayed, as well as its main advantages and disadvantages.

The fourth section is destined to discuss the theoretical foundations displayed in the previous two parts (low carbon alternatives and slow steaming) for the purpose of determining the effectiveness and viability of the speed reduction compared to newer and more sophisticated technologies.

Finally, the work concludes with a list of conclusions derived from the previous discussion, culminating the study on the impact of the application of the slow steaming in the global merchant fleet.

CHAPTER 1
BACKGROUND

1. BACKGROUND

1.1 CLIMATE CHANGE AND GREENHOUSE GASES (GHGS)

Greenhouse gases conform the essential barrier to keep some of the sun's warmth when it is reflected back into the space, resulting indispensable to preserve life on Earth. These heat-trapping gases can occur naturally, from volcanic activities for instance, but as a result of anthropogenic activities such as the industrialization, the clearing of forests, large scale agriculture and massive fossil fuel burning, greenhouse gas concentration in the air has risen to never seen level. Moreover, this human effect on climate change and global warming is likely to increase, since the greater the population and its liveliness are, the higher the amount of GHGs emissions will be.

There are some basic well-established scientific links (United Nations, 2019):

- The concentration of GHGs in the earth's atmosphere is directly linked to the average global temperature on Earth;
- The concentration has been rising steadily, and mean global temperatures along with it, since the time of the Industrial Revolution;
- The most abundant GHG, accounting for about two-thirds of GHGs, is carbon dioxide (CO_2), is largely the product of burning fossil fuels.

The United Nations (UN) is in fact in the forefront of the effort to promote and raise worldwide environmental awareness. As a consequence, many international agreements on climate and environmental issues have been signed, such as the United Nations Framework Convention on Climate Change in 1992, the Kyoto Protocol in 1997 or the Paris Agreement, adopted by world leaders in 2015[1].

Actually, on 1 January 2016, the 17 Sustainable Development Goals (SDGs) of the 2030 Agenda for Sustainable Development officially came into force. The 13th SDG: Climate Action, in particular, is expected to mobilize efforts to tackle climate change. However,

[1] The Paris Agreement entered into force on 4 November 2016, thirty days after the date on which at least 55 Parties to the Convention accounting in total for at least an estimated 55 % of the total global greenhouse gas emissions have deposited their instruments of ratification, acceptance, approval or accession with the Depositary.

the annual reports that review progress in the implementation of the 2030 Agenda conclude that urgent and accelerated action is needed as "The year 2017 was one of the three warmest on record and was 1.1 degrees Celsius above the pre-industrial period [...] The world continues to experience rising sea levels, extreme weather conditions and increasing concentrations of greenhouse gases" (United Nations, 2018, p.10).

There is a factual confirmation that the presence of carbon dioxide (CO_2) and other greenhouse gases (GHGs) in the atmosphere does nothing but grow, reaching unprecedent alarming data. Because of the effect of these heat-trapping gases, among other pollutants, the earth surface temperature is also rising. As part of an event-chain, the global warming entails further consequences: melting ice block in Arctic and Greenland and sea level rise. As a matter of fact, latest NASA estimations revealed that sea level grew 23 centimetres since 1880 and it is likely to keep rising. Figure 1.1 provides the progressive increase of the sea level from 1980 and, as it can be deduced from the graphic, its tendency will remain upwards.

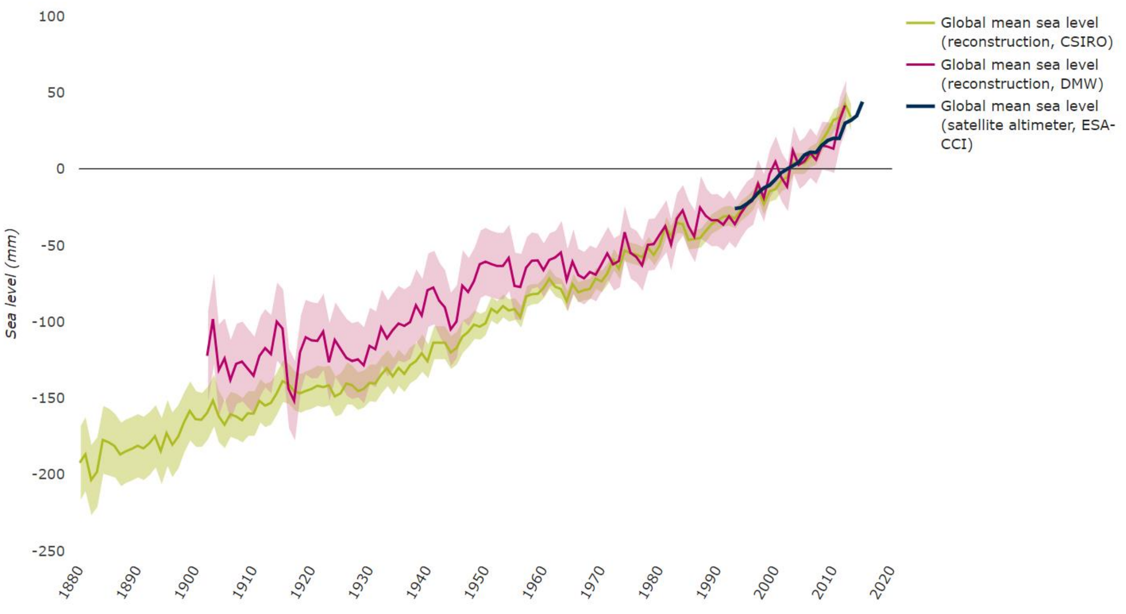

Figure 1.1. Observed change in global mean sea level[2] (EEA, 2017)

Given the current GHG concentration data, the Intergovernmental Panel on Climate Change (IPCC), body set up by the World Meteorological Organization (WMO) and United Nations Environment to provide an objective source of scientific information, in its Fifth Assessment Report found that almost half of the 2°C limit set by the Paris

[2] Figure 1.1 depicts the rise in global mean sea level from 1880 to 2015 based on three sources: Commonwealth Scientific and Industrial Research Organisation (CSIRO), Universität Siegen and European Space Agency (ESA). All values are relative to the average level of the period 1993-2012, during which the three datasets overlap.

Agreement was already reached by 2011, since the average global temperature increased by 0.85°C (IPCC, 2014). This publication also assesses the sea level rise and its causes, and, to this regard, it mulled over a future scenario at which the average sea level is expected to rise from 24 to 30 cm by 2065 and from 40 to 63 cm by 2100, calculated with respect to the 1986–2005 period.

Once the real and unavoidable climate change problem has been depicted, throughout this first section of Chapter 1, we will analyze the greenhouse gases in order to provide a complete overview on this topic.

About the different kind of GHGs in particular, they are made up of the following substances (NASA, 2015):

- Water vapour (H_2O). It is the most abundant and it blocks heat from escaping; consequently, more water is evaporated, as part of a closed loop.
- Carbon dioxide (CO_2). It is all around us naturally, as part of our breathing, volcano eruptions, and so on. Nevertheless, it is the major contributor to human-caused global warming, as a result of the current massive fossil fuel burning and depletion. In fact, in the words of the physicist and meteorologist Luis Balairón for the documentary by Gorritiberea, A. & Hilario, A. (2010), "warming has been observed since the mid-19th century and much of that warming, more than half a degree, occurred between 1850 and 1970. The other half-degree has occurred in the last 40-50 years".
- Nitrous oxide (N_2O). It damages the ozone layer and it is a powerful GHG. The N_2O is mainly produced by the use of organic fertilizers, fossil fuel combustion, factories, nitric acid production and biomass burning.
- Methane (CH_4). In addition to CO_2, scientists state that it is the second biggest contributor to human-caused global heating (albeit it also has its origin in natural processes), despite is its much lower abundancy in the atmosphere.
- Chlorofluorocarbons (CFCs). These compounds are totally generated by the industrial activity but, since they entail high risk to ozone layer destruction, they are largely regulated.

In addition to those pollutants, there exist more relevant substances that imply significant hazard for the earth and its inhabitants (IEA, 2016):

- Sulphur oxides (SO_X), in particular SO_2. Fossil fuels contain sulphur and if not removed, these compounds are emitted to the atmosphere after combustion.

- Nitrogen oxides (NO_X). They stem from high-temperature combustion, mainly in transport and power generation.
- Particulate Matter (PM). It is a mix of solid/liquid organic and inorganic pollutant substances which are linked to major detrimental health impacts, black carbon for example.
- Volatile organic compounds (VOCs). They come from the evaporation of chemicals, solvents and fuels. They are also associated with a range of negative health effects.
- Ammonia (NH_3). It is released in relation to agricultural and waste management activities; the main ammonia-related issue comes from its chemical reaction with oxides of nitrogen and sulphur, generating harmful particles.
- Carbon monoxide (CO). This toxic gas comes from incomplete combustion of fossil fuels.

Figure 1.2 shows that even though there are multiple heat-trapping and pollutant substances in the atmosphere, total annual anthropogenic GHG emissions are mainly composed of four substances: CO_2 from fossil fuel burning and industrial activity and CO_2 from forestry and other land use, methane (CH_4), nitrous oxide (N_2O) and fluorinated gases (F-gases such as hydrofluorocarbons, perfluorocarbons and sulphur hexafluoride).

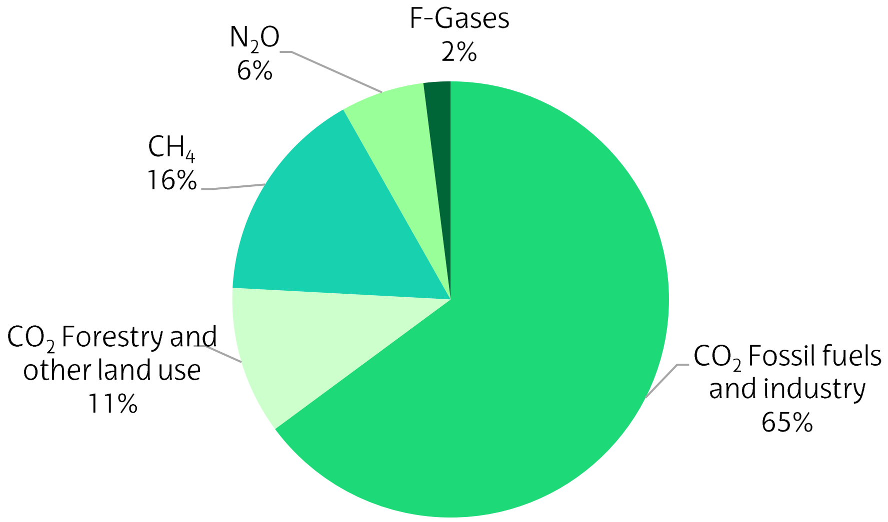

Figure 1.2. Total annual anthropogenic GHG emissions by groups of gases (Author based on data from IPCC, 2014)

It is undeniable that the presence of CO_2 in the atmosphere has surged reaching unacceptable limits (it accounts for the 76% of the GHGs according to IPCC, 2014); hence the immediate need to take action to reduce the carbon footprint generated by humans.

Besides those aforementioned frightening forecast scenarios regarding global warming and sea level rise, there are other upsetting effects deriving from atmospheric pollution. The World Health Organization (2014) revealed that one in eight of total global deaths are caused by air pollution; furthermore, the toxicity of the air also increases the chances to develop lung cancer, stroke, chronic obstructive pulmonary disease, and acute lower respiratory infections in children, among other risks.

1.2 GREENHOUSE GASES AND THE SHIPPING INDUSTRY

With regard to the maritime sector, as it is widely known, the shipping industry covers the 90% of world trade (International Chamber of Shipping, 2018) and its impact on air pollution cannot be set aside. Table 1.1 gathers the main global fleet data according to latest UNCTAD report published in 2018, which currently consists of 94,171 vessels, with a combined tonnage of 1.92 billion dwt; as to vessel types, dry bulk carriers account for the largest percentage of dead-weight tonnage (42.5%), followed by oil tankers (29.2%) and containerships (13.1%).

Table 1.1. Share of global fleet dwt by vessel type (Author based on data from UNCTAD, 2018)

Vessel type	Share of dwt	Share of dwt (%)
Oil tankers	561,079	29.2
General cargo carriers	74,458	3.9
Dry bulk carriers	818,612	42.5
Containerships	252,825	13.1
Gas tankers	64,317	3.3
Chemical tankers	44,597	2.3
Offshore vessels	78,228	4.1
Ferries and passenger ships	6,075	0.3
Other	23,811	1.2
Total global fleet	**1,924,002**	**100**

Once maritime industry's magnitude is highlighted, its contribution to global air pollution must be assayed. IMO's last Greenhouse Gas Study issued in 2015 reveals that the main expelled substances by ships' exhaust gases are the CO_2, the N_2O, the CH_4, the NO_X, the SO_X, and PM.

Figure 1.3 clearly displays the magnitude of CO_2 emissions, compared to sulphur and nitrogen oxide gases. As for CO_2e indicator, it corresponds to an equivalent representing the addition of CO_2, CH_4, N_2O and other GHG emissions and it is used to show their impact all together, since the amounts are too low to refer to them individually.

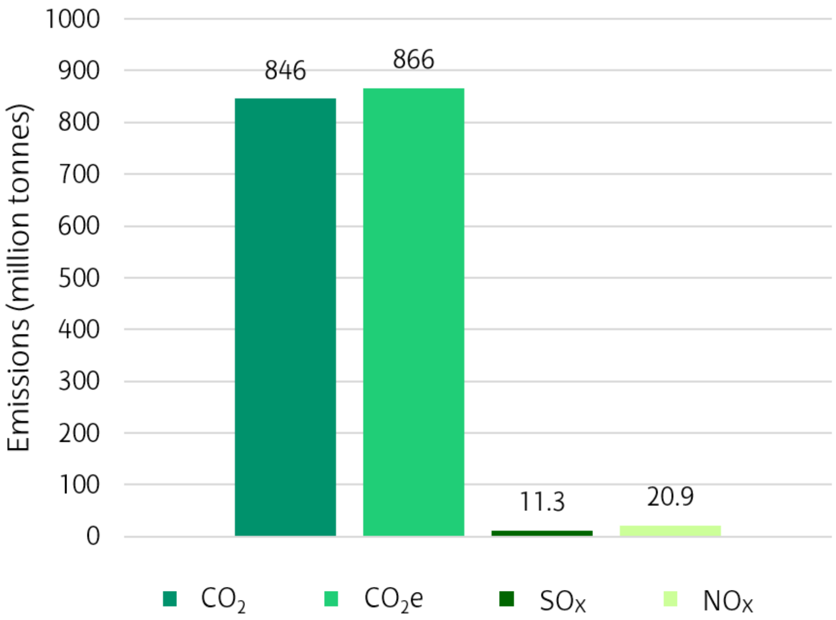

Figure 1.3. Shipping emissions by substance type in 2012 (Author based on data from Smith et al., 2015)

Therefore, it is evident that CO_2 is the most common of the greenhouse gases, and it is likewise the most emitted substance by ships, we need to address this matter in particular. On this basis, this dissertation will shed light on the impact of the maritime sector on this pollutant, as well as on diverse solutions to tackle the vast rise of CO_2 in the atmosphere.

In fact, as seen in Table 1.2, CO_2 emissions from ships account for 2.6% of the global emissions amount, emitting almost 1 million tonnes of CO_2 (Comer et al., 2017). Moreover, even though the shipping carbon footprint does not follow a constant pattern, the emissions are expected to increase as international trade by sea is to grow. In fact, Smith et al. (2015) estimate that ship CO_2 emissions will increase 50%–250% from 2012 to 2050 and according to Cames et al. (2015), "without further action, the international shipping sector could account for 17% of global CO_2 emissions in 2050".

Table 1.2. Shipping CO_2 emissions, 2007–2015 (Author based on data from Comer et al., 2017)

	3rd IMO GHG Study (million tonnes)						ICCT (million tonnes)		
Source	2007	2008	2009	2010	2011	2012	2013	2014	2015
Global CO_2 emissions	**31,959**	**32,133**	**31,822**	**33,661**	**34,726**	**34,968**	**35,572**	**36,084**	**36,062**
International shipping	881	916	858	773	853	805	801	813	812
Domestic shipping	133	139	75	83	110	87	73	78	78
Fishing	86	80	44	58	58	51	36	39	42
TTL shipping	**1,100**	**1,135**	**977**	**914**	**1,021**	**942**	**910**	**930**	**932**
% of global	3.5%	3.5%	3.1%	2.7%	2.9%	2.6%	2.5%	2.6%	2.6%

1.3 ANALYSIS OF THE CONTRIBUTION OF TO GLOBAL CO_2 EMISSIONS

The contribution of the maritime sector to global CO_2 emissions can be analysed in several ways. In this section, the impact will be assayed according to shipping modality, vessel type and operation mode.

Regarding shipping modality, as shown in Figure 1.4, in 2015, international shipping activity accounted for the majority (87.1%) of the shipping CO_2 emissions; domestic shipping accounted for the 8.4% of the emissions and fishing accounted for 4.5%. Therefore, the main source of the carbon footprint generated by the maritime sector is international shipping, which is the assayed field in this dissertation.

Figure 1.4. Evolution of contribution of the three main shipping modalities (Author based on data from Comer et al., 2017)

As for the type of ship, containerships are the biggest emitting source covering the 23% of the CO_2 emitted to the atmosphere, despite their relatively small number, about 4% of the global registered fleet -in vessels number- (Comer et al., 2017). Bulk carriers and oil tankers also generate large amounts of emissions into the atmosphere (see figure 1.5), which, together with containerships, cover the 84% of global fleet's dead-weight tonnage.

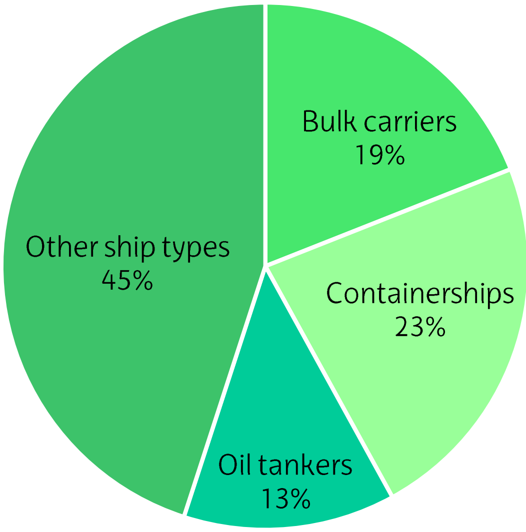

Figure 1.5. Average percent share of CO_2 emissions by ship class, 2013–2015 (own preparation based on Comer et al., 2017)

At this point, it is essential to briefly introduce the relationship between air pollution and fuel consumption, and Corbett et al. (2009) made a clear statement on this matter:

> international shipping [emissions] [...] are function of the carbon content of the fuel, energy density and combustion efficiency. Marine fuels are a petroleum by-product with well-understood carbon content, and large marine diesel combustion converts nearly all carbon to CO_2 [...]; this relationship allows fuel consumption to be used to calculate CO_2 emission rates. (p. 594)

On these grounds, fuel consumption evolution must be remarked. As for now, total fuel consumption (domestic shipping and fishing included) increased from 291 to 298 million tonnes (+2.4%) from 2013 to 2015 and it is expected an increase of 250% by 2050 as a result of the undeniable growth of international shipping; LNG use is also expected to rise, albeit it represents only the 2% of fuel sources (Comer et al., 2017).

Finally, in order to analyse how operating mode affects CO_2 emissions, the amount of fuel burnt during those activities will be used. Figure 1.6 shows that in average, ships consume most, 84%, when cruising (at a speed of more than 5 knots); around 15% while stationary (0 knot); and only 1% while manoeuvring (1-5 knots).

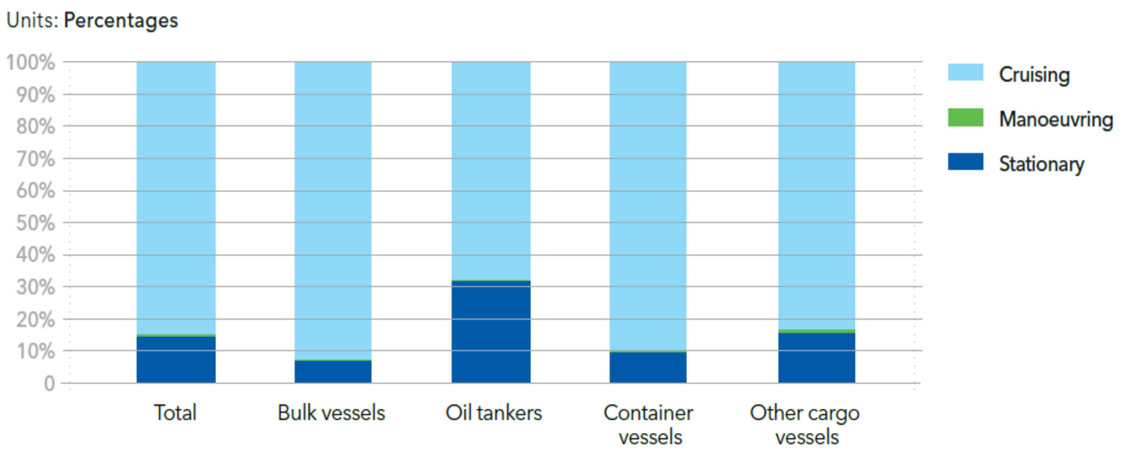

Figure 1.6. Share of fuel used in each operation mode in 2017 by cargo vessel segment (Endresen et al., 2018)

Having considered all points above, it is more than evident that actions need to be taken to tackle air pollution, and more precisely, CO_2 emission concentration in the atmosphere. As a result, so that global warming's devastating forecast does not come true, international institutions and organizations have promulgated legislation on this matter.

1.4 EXISTING IMO REGULATIONS TO REDUCE GREENHOUSE GAS (GHG) EMISSIONS FROM SHIPS

As well as for any issue related to the maritime sector, the International Maritime Organization (IMO) is responsible for regulating greenhouse gas emissions produced by global fleet. However, existing legislation is scarce; as Mander (2017) pointed out, "compared to other parts of the global economy, the shipping industry is subject to little regulatory pressure to reduce its carbon emissions". In a work published in the prestigious magazine *Nature*, Wang (2016) also wrote on this subject:

> Shipping policies must be applied worldwide to be effective. Shipping and aviation emissions are not addressed by global climate-change agreements, including the deal made in Paris last December. The International Maritime Organization (IMO), which regulates international shipping, is engaging – slowly. (p. 276)

Apart from MARPOL Annex VI, which basically controls the prevention of air pollution from ships by limiting the air pollutants contained in exhaust gas and introducing emission control areas (ECAs) to further reduce the emissions in designated zones, there is only one IMO regulation demanding improvements in ship energy efficiency: the Energy Efficiency Design Index (EEDI). This policy was made mandatory after the amendments to MARPOL Annex VI entered in force on 1 January 2013. In order to monitor, report and verify actual information gathered on board the existing fleet, the IMO also issued two other IMO regulations: the Ship Energy Efficiency Management Plan (SEEMP) and the Fuel Consumption Data Collection System (DCS), the latter coming into force with the amendments to MARPOL Annex VI on 1 March 2018.

Among those requirements established on the EEDI, new ships of over 400 gross tonnage are to emit less CO_2 per nautical mile navigated. Ships built between 2015 and 2019 are required to be 10% more efficient than a baseline of ships built between 1999 and 2009. Subsequently, ships built between 2020 and 2024 must be 20% more efficient, and those built in 2025 or later must be 30% more efficient than the baseline (Comer et al., 2017). According to Lee Adamson (2017), at that time IMO's Head of Public Information Services, "in simpler terms, the more efficient vessels are, the less fuel they burn, so the emissions go down accordingly".

Under the energy-efficiency regulations, existing ships now must arrange a new management plan, considering voyage plan changes, improving ship's hydrodynamics, introducing new technical solutions, fitting a new propeller and so on.

The main problem of the EEDI is that it is only applied to new vessels; therefore, GHG emissions cannot be reduced in a short term. As a result, the EEDI alone is not enough to reverse the trend of increasing CO_2 and GHG emissions from ships (Smith et al., 2016).

1.5 OTHER REGULATIONS

Besides IMO, which is responsible for almost all the international maritime matters, there are other organizations that have promulgated legislation in order to cut CO_2 (and other pollutants) emissions, albeit they have been put forward mostly in a general scope.

On the one hand, as mentioned above, the United Nations Framework Convention on Climate Change (UNFCCC), which was held in 1992, is the main international treaty on this topic. Its ultimate objective, as it is written in the Convention's paper (1992), "is to achieve […] stabilization of greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system".

After this treaty, in pursuit of binding UNFCCC signatories to stabilize greenhouse gas emissions (whilst the Convention only encourages them to do so), the Kyoto Protocol was ratified in 1997 by 192 countries.

Finally, in December 2015, all UNFCCC parties signed the Paris Agreement that specifies a global action plan to put the world on track to avoid dangerous climate change by limiting global warming to well below 2°C above pre-industrial levels and pursuing efforts to limit it to 1.5°C (UN, 2015). However, it does not directly address the maritime sector's contribution to air pollution. Additionally, the agreement gives the States the right to propose specific measures to comply with the objectives set, albeit so far, no significant advances have been produced; in fact, they worsened as stated in the Annual Monitoring Reports of the SDGs of the 2030 Agenda for Sustainable Development. Indeed, the latest SDGs Report by the United Nations (2018) urged Parties to act against the global warming, declaring that increasing concentrations of greenhouse gases call for urgent and accelerated action by countries as they implement their commitments to the Paris Agreement on Climate Change (United Nations, 2018).

On the other hand, the European Union and small island states are pushing for more aggressive action on greenhouse-gas reductions (Tollefson, 2018). In fact, in 2005 the European Union launched the first and biggest International CO_2 allowance system in use to date (Mo Zhu et al., 2018). It is EU's main tool purported to reduce greenhouse gas emissions. The system works by stablishing a cap on overall emissions and according to the European Commission (2019 b) "within this limit, companies can buy and sell emission allowances as needed. This 'cap-and-trade' approach gives companies the flexibility they need to cut their emissions in the most cost-effective way". However, shipping industry is not part of this project at the moment, albeit it is expected to be included on the third stage of the strategy that is already taking place (2013-2020).

1.6 STRATEGIES TO REDUCE GHGS FROM SHIPS

Given that it is estimated that within 30 years fuel consumption will increase between 50% and 250% due to the transportation volume, more than 170 governments have converged on a plan to curb greenhouse-gas emissions from the shipping industry, filling a gap left by the 2015 Paris climate agreement (Tollefson, 2018): the strategy to combat GHG emissions from ships. This roadmap, the IMO Resolution MEPC 304 (72) 'Initial IMO Strategy on Reduction of GHG Emissions from Ships', has been initially delivered in April 2018, but a final strategy will be adopted in 2023, as established in the former document.

The initial strategy sets out the identified 'levels of ambition', depending on what goals and what deadlines the states are willing to commit to. Therefore, the actions adopted in this paper can be classified into three groups: short-, mid- and long-term measures (see Annex 1). Anyway, this roadmap seeks to reduce CO_2 emissions by at least 40% by 2030, pursuing efforts towards 70% by 2050, comparing to 2008 (IMO, 2018).

Furthermore, when it comes to reducing emissions from maritime sector, the European Commission set out a strategy to tackle CO_2 and other GHGs. It consists of three consecutive steps: monitoring, reporting and verification of CO_2 emissions from large ships over 5,000 gross tonnage loading or unloading cargo or passengers at ports in the European Economic Area (EEA)[3]; the enactment of greenhouse gas reduction targets for the maritime transport sector; and further mid and long term measures, including the introduction of the 'cap-and-trade' system to the maritime industry (European Commission, 2019 c).

In addition, three more strategies have been set by the European Commission: the 2020 climate & energy package, the 2030 climate & energy framework and the 2050 long-term strategy. All of them basically aim to cut greenhouse gases (40% below 1990 levels), improve energy efficiency systems and foster renewable energy sources (European Commission, 2019 a), however, not exclusively in the maritime sector but in a general scope this time.

On the whole, with the aim of finding the best sustainable solution to meet the demanding expectations of the IMO, this dissertation will address different green alternatives, paying special attention to the best and most viable option to face the alarming CO_2 presence in the atmosphere, which is, relying in our research, the slow steaming alternative.

[3] EU Regulation 2015/757, in force from 1 January 2018.

CHAPTER 2
LOW CARBON SHIPPING

2. LOW CARBON SHIPPING

The shipping industry cannot be set aside when it comes to combating air pollution and GHG emissions to the atmosphere since more than 2% of global emissions are produced by vessels (IMO, 2015). Yet, even though many international agreements on climate and environmental issues have been signed (see Chapter 1), there has been little progress in the shipping industry. However, it seems that the introduction of new environmentally friendly technologies in this sector is increasingly becoming a common practice to reduce the environmental footprint of ship propulsion systems. As Wang (2016) stated in *Nature*, "the future is green shipping: efficient marine transport with minimal health and ecological damage [...] cleaner practices are needed". However, he added that "achieving this will require heroic efforts by the industry and its engineers in collaboration with regulators, port authorities and communities", so it will be a hard duty to attain the cooperation of all the stakeholders.

Although it is a challenging task, the low carbon shipping seeks to tackle the alarming amount of emissions of CO_2 by employing current green alternatives. In this section, the main sustainable solutions are analysed, namely the windship technology, energy efficiency measures, alternative fuels and speed reduction or slow steaming.

2.1 WINDSHIP TECHNOLOGY

Wind is powerful, unlimited and free; that is why wind propulsion is a well proven energy source for ships and it is used to reduce fuel consumption and thereby pollutant emissions. Systems that turn wind into profit are becoming increasingly popular, namely the Kite Sail, the Dyna Rig and the Flettner Rotor. Yet, wind propulsion is an alternative at an early stage.

2.1.1 Kite Sail

The kite sail system is based on a large and aerodynamic towing kite that, in optimal wind conditions, can equal up to 2,000 kW of propulsion power (SkySails, n.d.). As seen in Section 1, fuel consumption is dependent on ship's speed, and so do fuel savings. Employing this technology, the thrust provided by the kite sail makes up for the main engine's rate reduction, hence decreasing fuel consumption as showing in Figure 2.1. In fact, it can be cut generating savings up to 10-15% (SkySails, n.d.).

By way of example, the German shipping company Wessels has been the first to invest and bet on this technology: the system has been installed on two multi-purpose cargo ships of its fleet, the *Theseus* and the *Michael A*, and two more Wessels vessels are expected to be retrofitted with kite sails. Both of them have been monitored in order to gather data of the use of the sails; the results obtained from the *Theseus*, which navigates at 11,5 knots at full speed ahead, are shown in the Figure 2.1. For instance, when these vessels fitted with kite sails navigate close to full speed ahead, fuel consumption can be lowered up to 100 kilograms per hour; yet, fuel saving benefits are scarce if the ships halve their maximum speed, point at which the maximum profit is a reduction of 25 kilograms per hour.

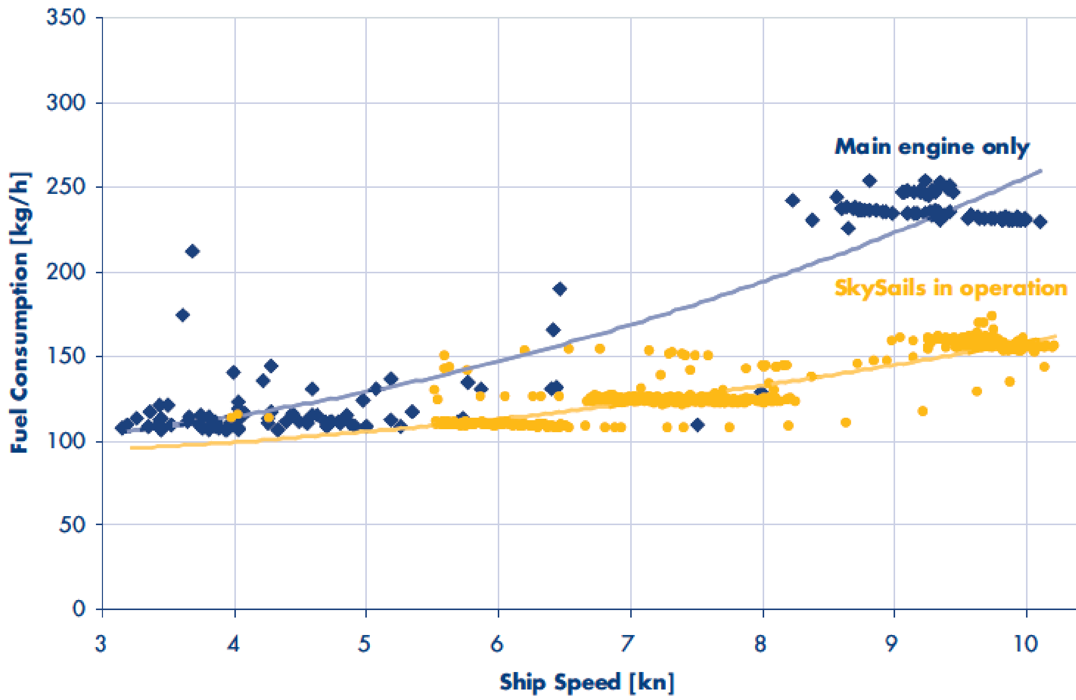

Figure 2.1. Comparison of fuel consumption with/without kite sail (SkySails, n.d.)

The kite works in the air ahead of the ship, making her move forward. The tractive force is transferred to the vessel through a resistant towing rope that allows to prevail the strongest wind tends (see Figure 2.2 and Figure 2.3). Regarding its components, the equipment is entirely rigged in the bow deck; therefore, there is no reduction of cargo space and it does not impair the passage nor loading and unloading operations as the kite is fold and stowed before calling at ports.

Figure 2.2. Kite sail rope on the *Theseus* (SkySails, n.d.)

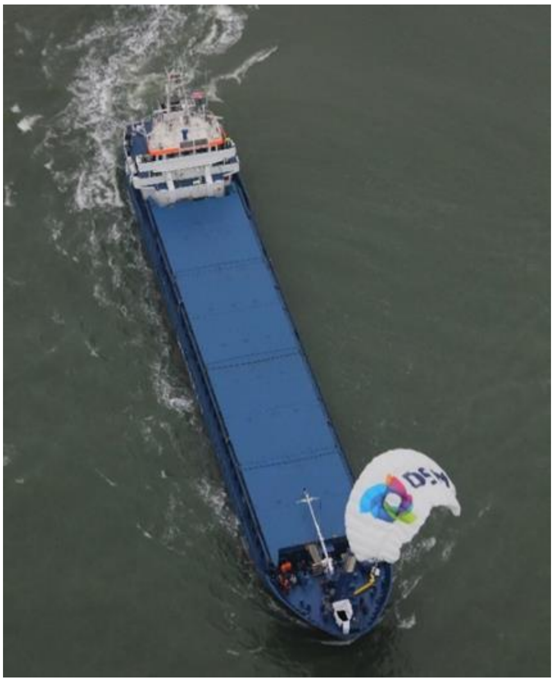

Figure 2.3. The *Theseus* sailing with kite sail (SkySails, n.d.)

About the price, this kite-based technology cost is estimated at $660,000 - $3,300,000 (Kirschbaum, 2007).

As for the operative aspect, the system is almost fully automatically controlled from the bridge; just a few actions on the foredeck are required. When it is up in the air, an autopilot software ensures that the kite flies according to the current wind circumstances so that its propulsion is optimized.

According to SkySails (n.d.), "the IMO estimates that up to 100 million tonnes of climate damaging carbon emissions can be eliminated worldwide every year with the help of SkySails [kite sails] technology alone". However, it turns out to be a slight amount bearing in mind that merchant ships emit almost a billion tonnes of carbon pollutants a year.

Kite sails act sustainably as their use can reduce shipborne CO_2 emissions while it lowers the output of other greenhouse gases, but, as mentioned, a maximum of 10-15% of fuel reduction is achieved in the best meteorological conditions. In addition, they can only be raised when the wind is powerful enough so that the kite is lifted and sustained and its use is effective. Besides, although the sail is suspended in optimal conditions, the intensity of the wind is very variable, which might generate substantial ship's speed losses due to the irregularity of its thrust and, consequently, casting doubts on the vessel's reliability of delivery times.

2.1.2 DynaRig

The idea of DynaRig was created in the 1960s as a potential fuel saving alternative, as well as an additional propulsion system for ships. However, this technology has not been developed until 2000, when this system was selected to be installed in the sailing yacht *Maltese Falcon* (see Figure 2.4). One of the most important factors of the success of the DynaRig is the material, the carbon fibre and composite, which provide the system with a lightweight structure, high strength and resistance (Magma Structures BP, 2014).

Regarding the operational aspect, the sails are set individually, using automated mechanisms and the masts are free-standing and rotating.

The system has proved to be so reliable and easy to sail that the *Maltese Falcon* is considered one of the greenest superyachts afloat. In the main, she has the capability to rely on the performance of sailing, minimising the fuel consumption (Magma Structures BP, 2014). However, according to the statements of the yatch's first owner Tom Perkins in an interview for CBS (2007), the DynaRig system totalled more than $80 million.

Figure 2.4. The *Maltese Falcon* (Dykstra Naval Architects, n.d.)

DynaRig has been implemented in sailing vessels or yachts hitherto, but its installation on board merchant ship is currently being studied and developed. In fact, an ecoliner called *Wasp* (see Figure 2.5) is presently being designed by Dykstra Naval Architects. The ship is equipped with a hybrid propulsion system based on DynaRig sails and a propeller. As the architects explained, the ship can keep her schedule reliability thanks to the main engine while the sails contribute to navigate in the most efficient way. According to

Argitech (2015), "calculations have shown a 35% saving of fuel or even more under favourable conditions".

Figure 2.5. *WASP* Ecoliner (Dykstra Naval Architects, n.d.)

2.1.3 Flettner Rotor

The Flettner rotor is a spinning cylinder patented in the 1920s, though the system has not reached success hitherto. Those spinning sails are considered as rotating columns fixed to the ship's deck. When these columns interact with wind, they provide forward thrust, harnessing the Magnus Force[4] (Figure 2.6). The air flow accelerates on one side and decelerates on the opposite side as a result of the spinning cylinder. This difference in the speed of the air flow results into a pressure difference, which creates a lift force that is perpendicular to the wind flow direction.

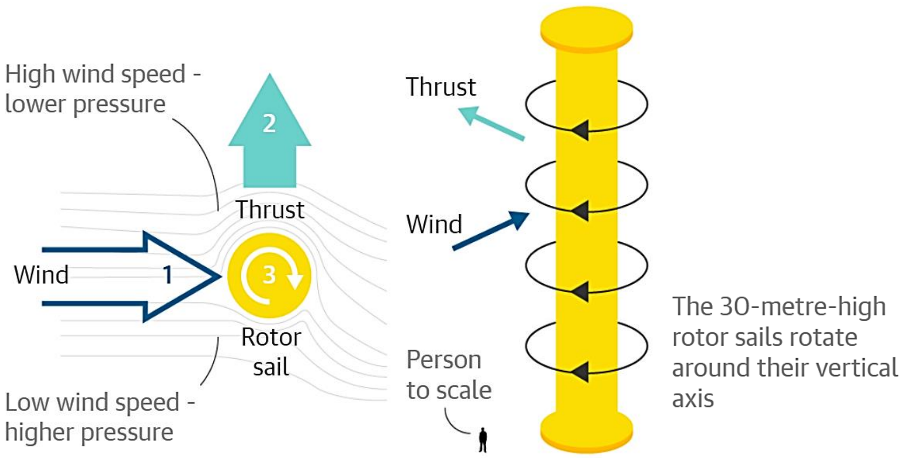

Figure 2.6. Working principle of Flettner Rotor (The Guardian, 2017)

[4] The force exerted on a rapidly spinning cylinder or sphere moving through air or another fluid in a direction at an angle to the axis of spin.

About the wind conditions, rotor sails are generally effective if the wind is moving faster than 10 knots and is blowing across the ship's bow at an angle of at least 20° (The Guardian, 2017).

The system can be used as a windship propulsion technology onboard ships by placing these cylinders on the weather deck[5] of the vessel and by rotating it around its main vertical axis. An electric drive system is used to turn the rotor sail. Its thrust allows a ship's engines to be significantly throttled back, cutting fuel consumption on global shipping routes by an estimated 7-10% (Carrington, 2017). However, as GloMEEP (n.d.) stated, reductions of up to 35% have been reported, but, generally speaking, this level of reduction potential is currently considered out of reach.

Modern Flettner rotors are currently in use aboard the E-Ship 1 (see Figure 2.7), a R&D project consisting on the development, build and evaluation of an outstanding innovative Wind Hybrid Ship, performed by ENERCON with support of Hochschule Emden/Leer.

Figure 2.7. *E-Ship 1* with Flettner Rotors on her deck (Marine Insight, 2013).

Besides this project, there are certain shipping companies betting on this alternative technology, e.g. Maersk Tankers has installed two 30-metre tall rotor sails onboard the product tanker vessel Maersk Pelican and testing period has already begun (Ugilt, 2018).

[5] A ship's uppermost deck open to the weather, which has no overhead protection.

As mentioned above, the use of Flettner rotors on board is very simple and it can be an appropriate answer to the problem of saving fuel and emissions, while providing the required power to maintain a constant and suitable cruising speed to fit for the prearranged voyage time.

Nonetheless, besides these benefits, the are significant disadvantages. First, Flettner rotor installation has a big impact on stability of the ship. Therefore, their implantation must be exhaustively studied, and the rotors would probably had to be rigged on board new vessels. The cranes and other machinery used for cargo handling can also be a hazard for these columns, whilst the latter can also hamper loading and unloading operations in port. Furthermore, the costs of their production and the consequent installation on deck are also questionably affordable. The range of price for a Flettner rotor is $400,000 to $950,000 depending on the model of the rotor and, for a typical delivery with multiple rotor sails, the bill increases starting from $1,000,000 up to $3,000,000 (GloMEEP, n.d.).

2.2 ENERGY EFFICIENCY MEASURES

Shipping must fulfil its obligation to reduce GHG emissions and, therefore, the efficiency of the global fleet needs to be further improved in order to achieve significant GHG reductions (Chryssakis et al., 2017).

Through its regulations (see section 1.3), besides other alternatives, the IMO seeks to foster technical solution in order to improve the operational energy efficiency and, therefore, optimize fuel consumption and reduce GHG emissions to the atmosphere.

Some of the energy efficiency measures have been grouped by Chryssakis et al. (2017) for simplicity into the following categories:

- **Machinery**: includes optimisation of auxiliary systems, engine performance optimisation, engine de-rating, exhaust gas boilers on auxiliary engines, variable engine speed, shaft generators, efficient lighting system and variable frequency drives, etc.
- **Hydrodynamics**: hull cleaning, hull coating, hull form optimisation, hull modifications, propulsion efficiency devices, propeller efficiency and propeller retrofit.
- **Operational**: autopilot optimisation, trim/draft optimisation, weather routing, etc.

Scrubbers, air pollution control devices that can be used to remove some particulates and/or gases from industrial exhaust streams, have also been suggested as a technical means for mitigating pollutant gases. Its main advantage consists in the fact that it is a cost-effective way for large ships to comply with low sulphur standards. However, installing scrubbers locks vessels into using HFO as fuel, increasing fuel consumption by 5% (Chryssakis et al., 2017), hence boosting the emission of GHGs. Therefore, further solutions would be needed so that these gases were lowered. In addition, the cost of fitting a scrubber system in a new building ship is estimated at $2,700,000, whereas the refitting cost is around $4,300,000 (Drewry, 2018).

The former study has also calculated the potential fuel saving for each energy efficiency measure. As it is shown in the Table 2.1, the most profitable action is the cold ironing or shore connection (30-70%); however, it can only be applied to auxiliaries while in port, bearing in mind that it is tried to reduce the laytime as much as possible. In the second place, hull form and hydrodynamics are displayed as most efficient technical solutions. Results around 20% of savings are significant, but these arrangements can only be made on new construction vessels. As a result, they are not applicable on the current existing fleet. Still, shipowners, naval architects and shipyards must consider these measures to build future energy-efficient ships. Lastly, we have the implementation of operational measures (e.g. optimization of navigation and steering systems, weather routing) and hybridization as a last minimally beneficial option (15% maximum). The former does not imply complication to some extent, unlike the latter, which involves large changes in the ship's propulsion system if it is not fitted with hybrid equipment from her launching. Within the operational measures, weather routing is one of the energy efficiency measures that could significantly help a vessel to reduce CO_2 emissions by improving her route depending on weather conditions. It can be costless if it was carried out by the deck officers; however, nowadays there are several resources that provide the bridge officers with many facilities in order to make navigation safer, cost-efficient and the most important at this moment, sustainable; the only disadvantage is that this service requires disbursement if it is wanted to avoid an increase in workload of the deck officers.

StormGeo is a tool that offer a route optimization system. In this way, the program calculates the routes and the required charts, creating a new voyage plan basing on the reigning weather circumstances. Per Olof Schroeder, StormGeo's CEO, stated that in 2018, this company helped its customers "to a saving of 1 million metric tonnes of fuel [...] and an atmospheric reduction of 4 million tonnes of CO_2" (VPO, 2019 b).

Table 2.1. List of energy efficiency measures and their expected impact (Author based on data from Chryssakis et al., 2017).

ENERGY EFFICIENCY	FUEL SAVINGS	
	MAIN ENGINE	AUXILIARIES
Hull Form – New buildings	12-17%	-
Hydrodynamics	13-20%	-
Machinery improvements	4-8%	12-23%
Waste Heat Recovery	0-8%	-
Hybridization	3-15%	
Operational measures	3-11%	-
Cold Ironing	-	30-70%

2.3 ALTERNATIVE FUELS

Currently there is a wide variety of fuel options (see Table 2.2) to be used on ships; some of them are already being consumed by marine engines, while others are still been developed or are restricted because of their price (hydrogen), low availability, ethical issues or limitation to certain types of vessels. For example, electrification, stored energy (batteries) or solar panels can only be applied on small crafts in order to be productive as a main energy source or nuclear propulsion is mainly used on submarines or war ships.

LNG and LPG are the most well-known and available fuels at the moment. The former is the most suitable alternative at the very moment to take the place of the HFO, but the truth of the matter is that the use of the LNG as fuel source accounts for only 2%. In addition, methanol is at the same development stage as the LPG and for instance, it is being used as fuel source onboard the *Stena Germanica*, worlds first-ever methanol powered vessel (Lloyd's Register, 2015). Their use can contribute to lower SO_X, NO_X CO_2 and PM emissions in a quite successful way and according to Ship Technology (2015) the conversion cost $25,500,000.

Even so, there are some risky issues that may hinder their employment (Endresen, 2018):

- High energy content in the tanks
- Explosion hazard in case of leakage

- Extremely low temperature (-163°C)
- Arrangement of the system
- Inexperience crew; different kind of fuel to handle

As well as with kite propulsion technology, the Wessels Shipping Company has converted its *Wes Amelie* into a fully LNG-propelled containership, process that has lasted two years since the project was first approved.

Besides the German company, there are a few enterprises that have replaced the HFO by this environmentally-friendly fuel or, at least, combined both by means of a dual fuel engine[6] such as United European Car Carriers (*Auto ECO, Auto Energy*) or Viking Line (*Viking Grace*), among others. Gas tankers (e.g. Knutsen OAS Shipping) also use the boil-off gas from the cargo tanks as part of their fuel source in order to propel the vessel; in this way, they burn less HFO, reducing carbon and other pollutants footprint.

As for the mitigation of the overall reduction of GHGs, as shown in Table 2.2, they can contribute with a lowering of 20% as a maximum.

Table 2.2. List of alternative fuels and their expected impact (Author based on data from Chryssakis et al., 2017).

FUEL OPTION	GHG EMISSIONS CHANGE
HFO with scrubbers	+5%
LNG	-20%
LPG	-17%
Methanol (from Natural Gas)	+5%
Biodiesel	-50%
Biomethanol	-50%
LGB (Liquefied Biogas)	-90%
Electricity from renewables	-50% to -20%
Hydrogen	Depending on H_2 production
Nuclear	-99%

In short, these sustainable marine fuels can actually be available within the next two decades, but their use would become widespread gently, with the exception of LNG.

[6] Engines that can be operated on natural gas as well as fuel oil.

Still, the conversion of a propulsion system and fuel storage in order to burn a different kind of energy source is likely to imply high investments, deterring shipowners to support the employment of this environmentally friendly fuel.

2.4 SPEED REDUCTION OR SLOW STEAMING

Speed reduction is considered separately from other operational or energy efficiency options because of its nature and future consequences.

In fact, IMO, on its last issued roadmap to mitigate GHG emissions from ships, has suggested that this technique is a short-term measure (see Annex 1). Furthermore, it is claimed to be the alternative with the highest potential for offering realistic fuel savings (Chryssakis et al., 2017). Accordingly, the impact of slow steaming will be thoroughly studied in the next chapter.

2.5 MERGING ALTERNATIVES

The future is about the combination of green alternatives. As mentioned above, the effectiveness of the energy efficiency measures can be boosted if they were mixed with other sustainable solutions such as the windship technology or the slow steaming itself.

However, it is not the only example. Flettner rotor system, even though it is still at an early stage, is feasible and it is becoming widespread and known by big shipping companies such as Maersk. Lately, Hyundai Heavy Industries (HHI) has joined the Danish shipping company initiative and has ordered a Very Large Crude Carrier (VLCC) ecotanker (VPO, 2019 a). Figure 2.8 shows the prototype design of this eco-friendly oil tanker; she consists of four spinning cylinders on the main deck where free deck area is available, two on the port side and two on the starboard side; LNG tanks for combustion are also rigged on the weather deck.

According to VPO (2019 a) "the vessel will be capable of using a combination of volatile organic compounds (VOC) mixed with LNG as fuel and Norsepower's rotor sail solution for wind-assisted propulsion". By her recovery system, the ship can use the vaporized gas from the cargo she carries to burn it by her propulsion system. In addition to the previous statement, regarding the rotor, the publication also affirmed that it has been confirmed that their fuel-saving potential is about 5-7 percent; but, in this case, these positive savings translated to a CO_2 emission cut will be incremented by the use of these greener alternative fuels.

Figure 2.8. HHI ecotanker (VPO, 2019)

CHAPTER 3
THE SLOW STEAMING

3. THE SLOW STEAMING

The slow steaming has been previously defined as the technique consisting in the reduction of merchant ships' speed. In rough outlines, a direct relationship can be established between fuel consumption and velocity, since the power of the main engine of the ship is directly proportional to her speed; in other words, as the ship slows down, her power demand falls even more rapidly. Nevertheless, this statement is not utterly true, since the fuel consumption depends on other factors that will be mentioned later on.

Due to the high oil prices and global economic recession around 2007, vessels started to navigate at lower speeds, though the slow steaming was first implemented in the 1970s in response to the reigning oil crisis. Therefore, it is not an innovative green alternative, but a both rudimentary and effective technique directly applicable onboard with the purpose of improving fuel efficiency and lowering carbon emissions to the air. In fact, as mentioned in the previous section, this technique is currently being boosted by IMO, albeit the amount of available ship capacity and the increase of fuel prices have also fostered the slow steaming solution.

It is true that during periods of low freight rates, which generally are cyclical, the speed reduction has been used to compensate the reduced money income that occurs when total expenditure is greater than the earnings from the freight. As a result, there are companies that resort to slower velocity to lower the bunker costs. This practice is called economic or optimal speed and is employed for a single purpose, which is to obtain economic benefits, forgetting other factors such as the sustainability of the environment. Therefore, it is just about an occasional resource that takes place in times of recession.

Certain leading shipping companies such as Maersk, the world's largest container shipping company, or Orient Overseas Container Line (OOCL), the eighth largest one, are betting on speed reduction. On the one hand, Maersk came up with the slow steaming idea more than a decade ago, and in the near future all Maersk vessels may be involved: in 2008, Maersk carried out an experiment consisting in steaming out several ships. As far as the company did not notice any engine damages and proved that slow steaming is a safe practice nowadays (Maersk, 2012), it would make sense that it could be extended among all the vessels operated by this firm. In fact, the Head of Maersk Ship Engineering Ole Grå Jakobsen (2012) stated that "going fast is definitely not an option" and in view of the successful results of the test he added that "it is an acceptable way of operating engines". Lajos Holmslykke (2012), Maersk Line's Senior Project Leader also declared that "it is a project that has an impact like this globally and not only in our company". On the other hand, OOCL has applied the slow steaming to 90% of its Euro-Asia routes and 60% of its Trans-Pacific routes (Lee et al., 2015).

Depending on the magnitude of the reduction, the practice is called by different names: slow steaming, (10-20% of lowering), extra slow steaming, (20-30% of lowering) and super slow steaming (for reductions greater than 30%). Even though all of them can be carried out in the same way, the impact on states and stakeholders must be borne in mind when considering the implementation of green alternatives (IMO, 2018). Therefore, this work will not take into account speed reductions greater than 20%, that is, the extra and super slow steaming, since they would greatly break the balance in the maritime industry due to the excessive increase in the duration of the journeys[7].

However, as mentioned above, in addition to speed variation, the fuel consumption depends mainly on the engine load, that is, the power, and on draft and displacement parameters (Andersen et al., 2005): the bigger they are, the more the vessel will consume. Other factors such as hull cleaning conditions and harsh weather circumstances may affect. Consequently, the fuel consumption is not equal for every vessel.

The next sections contain the procedures and results of the research carried out on this field which consists in the study of the impact that slow steaming entails on different areas, namely: the environment, the economy, the merchant fleet and trade, and the stakeholders.

As the effects of the speed reduction are not equal for every vessel since fuel consumption depends on more factors, four different vessel types were chosen for the analysis of the environmental impact of the slow steaming technique (see Table 3.1). The first vessel is the most pollutant vessel type at this moment, the containership; the second one is about the second less eco-friendly vessel type, the car carrier; the third scenario belongs to third most emitting ship, the oil tanker; and the fourth type is an average car carrier. In this way, with four vessels possessing different characteristics such as displacement and engine power output, the impact of the slow steaming can be assessed in a more comprehensive way. As for the speed adjustment rate, the same

[7] For more information about results obtained from different speed reductions consult Maloni et al., 2013.

reduction has been applied on the three situations: 10% and 15% rates, equivalent to the conventional slow steaming, and 20% rate, which corresponds to the border with the extra slow steaming.

Table 3.1. Chosen scenarios to assay the slow steaming effects

Vessel type[8]	Design speed (kn)	Slow steaming speed (kn)	Main engine (kW)	Auxiliary engine (kW)	DWT (tonnes)
Containership	24	21.6	47,430	8,500	110,800
		20.4			
		19.2			
Bulk carrier	16	14.4	7,800	2,040	52,434
		13.6			
		12.8			
Oil tanker	15	13.5	15,310	1,370	156,400
		12.75			
		12			
Car carrier	20	18	16,800	5,800	6,670
		17			
		16			

Trough calculations (see Annex 1), the effect of different slow steaming speeds on different ships is assayed. In addition, since these vessels' routes vary, each ship has been allocated a voyage-type (see table 3.2): the containership covers a long distance route that joins Eastern Asia with Western North America; the oil tanker that connects Saudi Arabia with Japan; about the bulk carrier, she navigates a shorter distance, from Northern Europe to Northern Africa; and finally, a short sea shipping route had to be studied, carried out in this case by the car carrier. Hence, the obtained results will be more accurate and realistic.

It must be pointed out that, as it will be shown later, the fuel consumption is directly proportional to the navigated distance (see equation [5]); therefore, if any of these chosen vessels changes her route length, the fuel consumption and the corresponding carbon emissions will be proportional to the results collected in this dissertation.

However, the results obtained in Annex 1 can guide on the effectiveness of this practice and, based on these data, other different scenarios can be assessed.

[8] Data correspond to real operating vessels (*MSC ANTONELLA* from Mediterranean Shipping Company (MSC), *MONTE URBASA* from Ibaizabal Tankers, *STAR DELTA* from Stark Bulk and *AUTOSUN* from United European Car Carriers (UECC)).

Table 3.2. Selected routes and distances for each vessel

	Route	Distance (nm)	Voyage type
Containership	Busan (KR) – Long Beach (EEUU)	5,230	Long distance voyage
Bulk carrier	Antwerp (BE) – Casablanca (MA)	1,391	Medium distance voyage
Oil tanker	Ras Tanura (SAU) – Yokohama (JP)	6,593	Long distance voyage
Car carrier	Pasaia (ES) – Bristol (UK)	600	Short sea shipping voyage

3.1 ENVIRONMENTAL IMPACT STUDY

As explained in Chapter 1, GHGs and, in particular, CO_2 emissions are generated by the ship's fuel burning, and fuel consumption of the main engines depends on the power provided, which, in turn, only depends on the vessel's speed.

It is widely accepted that a vessel's engine power and the vessel's speed are related by a cubic relationship, the so-called cubic law. Broadly speaking, it can be calculated in the following way, basing on Newtonian mechanics:

$$P = F \cdot v \quad [1]$$

where *P* is the power (kW), *F* is a force (N) and *v* is the velocity (kn).

Assuming that the resistance that the environment (sea and air) opposes to the ship's movement is a force, we can get the formula below:

$$P = R \cdot v \quad [2]$$

where the power (*P*) is the product of the multiplication of resistance (*R*) and speed (*v*).

In turn, in fluid dynamics, this resistance or drag force is proportional to the ship's squared speed[9]:

$$R = k \cdot v^2 \quad [3]$$

[9] Drag force complete expression is $F_D = \frac{1}{2} v^2 kA$, where F_D is the drag force, *v* is the velocity, *k* is the drag coefficient and *A* is the cross-section area. However, since the vessel is a body operating at a density boundary with sufficient ratio of the two fluid densities (air above water), the formula can be reduced to the simple relationship shown above (eq. [3]).

Replacing the variable *R* in [3] for its formula in [2] results in power being proportional to the ship's speed's cube:

$$P = k \cdot v^3 \quad [4]$$

where *k* represents a constant (kW/kn^3), the drag coefficient, which quantifies the drag or resistance of an object in a fluid environment; *v* represents the ship's speed (kn); and *P* represents the power of the vessel's main engines (kW).

In order to visualize the supposed effect of a determined speed reduction in power and, consequently, in the consumption of the main engine, the following scenario has been chosen: application of 15% speed reduction onboard the 47,430 kW-powered containership sailing with a design speed of 24 knots.

Firstly, we calculate the resistance coefficient (*k*) using the equation [4], with a result of 3.431 kW/kn^3:

$$k = 47{,}430\ kW \,/\, 24^3\ kn^3 = 3.431\ kW/kn^3$$

Once the value of *k* is got and knowing that the slow steaming speed is 20.4 knots, we can calculate the main engine power output after throttling down by employing the equation [4] again: 29,128.04 kW.

$$P = 3.431\ kW/kn^3 \cdot 20.4^3\ kn^3 = 29{,}128.04\ kW$$

Theoretically, with a speed reduction of less than 4 knots in this case (15% of the design speed), the power output is reduced by almost 40%.

This supports the statement put forward about the direct association between CO_2 emissions and ship speed due to the direct dependence of fuel consumption upon power. However, the following study cannot be based on this rough assumption since the relationship between these elements is more complex. Several formulae have been developed for this calculation (Cariou, Corbett et al., 2009; Kontovas, 2014; Lee et al., 2015; Smith et al., 2015; Comer et al., 2017); after the research, the equations to assess the environmental impact of the slow steaming per voyage suggested by Corbett et al. (2009) has been selected due to its greater complexity and greater number of variables to obtain more accurate results (eq. [5]and eq. [7]):

$$F_{ijk} = \left[MF_k \cdot \left(\frac{s_{1k}}{s_{0k}} \right)^3 + AF_k \right] \cdot \frac{d_{ij}}{24 s_{1k}} \quad [5]$$

where *i* represents the origin port; *j* represents the destination port; *k* represents an individual vessel serving the *ij* route; F_{ijk} represents the fuel consumption per trip (tonnes); MF_k represents main engine(s) daily fuel consumption -power source to propel the vessel through water- (tonnes); AF_k represents auxiliary engine(s) daily fuel consumption -power source to provide electrical demands- (tonnes); s_{1k} and s_{0k} represent the operational speed and the design speed of vessel k respectively (kn); and d_{ij} is the distance between two ports (nm).

Before digging into calculation, the specific fuel oil consumption (SFOC) must be addressed. The SFOC is the daily fuel consumption rate (in g/kWh) which it is in fact an energy efficiency indicator. Vessels are built to navigate close to the design speed (70-90% of the MCR[10]), a level at which the SFOC is optimal and at around 180-195 g/kWh; if the speed is reduced in a small quantity (15%), the SFOC tends to remain stable (Cariou, 2011).

Figure 3.1 shows the general tendency of the relative fuel consumption rate at different engine loads of three different marine engines. The trend is similar for all of them: higher consumption at very low and maximum engine load and the curve reaches its minimum at the design speed MCR (approximately 80%).

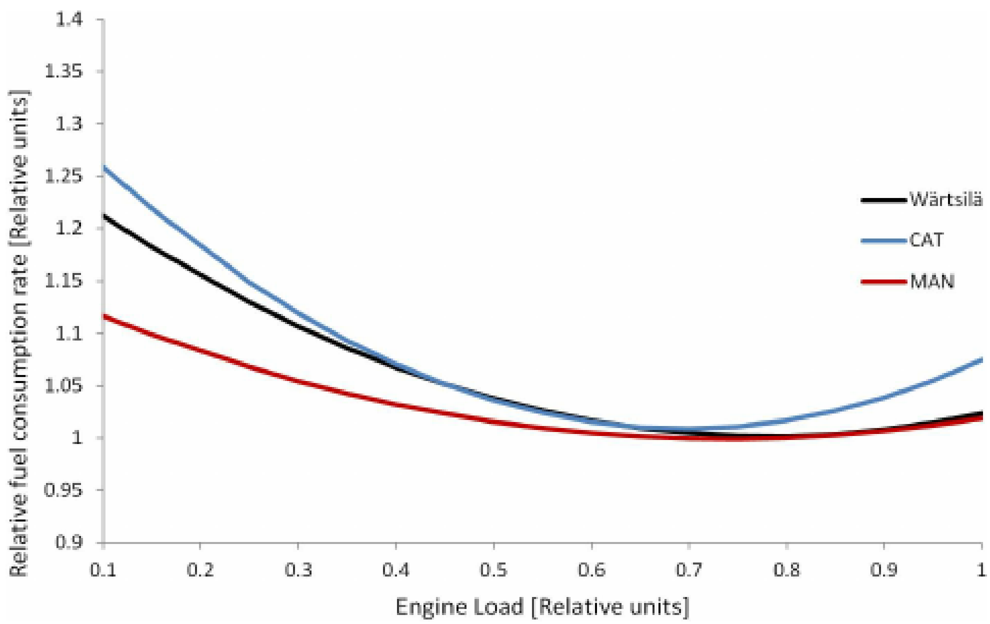

Figure 3.1. Relative SFOC as a function of the MCR, based on the data of Wärtsilä, Caterpillar and MAN (Jalkanen et al., 2011)

[10] Engine's maximum continuous rate; engine load factor.

In addition, it can be observed that for gent variations of engine load rate, the SFOC do not vary severely. Lastly, even if the tendency is similar in the three cases, depending on the engine manufacturer, the curve reaches different values: MAN has the most stable and constant engines regarding specific fuel consumption; Wärtsilä controls the SFOC when the load factor is raised, but as it throttles down, the fuel consumption is increased; finally, Caterpillar gets the biggest variation of SFOC when the engine output is both low and high.

In order to use the equation [5] the calculation of the main and auxiliary engines' fuel consumption per day is required and it can be easily got by the following formula:

$$F = SFOC \cdot MCR \cdot P \cdot 24 \quad [6]$$

where *F* is the fuel consumption per day, the *SFOC* is the specific fuel consumption of the engine (tonnes), *MCR* is the engine load rate or maximum continuous rate, *P* is the power output of the engine and 24 is the total number of hours within a day.

Applying this formula to each case we will obtain the values corresponding to F_{ME}: daily fuel consumption of the main engines and F_{AE}: daily fuel consumption of the auxiliary engines.

About technical data needed for the formulae shown above, the following values have been considered:

- Since the MCR for the design speed is regularly between 75 and 85 percent of the engine load, an average of 80% has been chosen.
- According to Cariou's study (2011), the MCR value falls to 60% when the speed is reduced to slow steaming levels (up to 15% reduction). Therefore, the following criteria has been followed: for a 10% reduction, the MCR will be 65%; for a 15% reduction, the MCR will be 60%; and for a 20% reduction, the MCR will be 55%.
- The SFOC is a fixed factor for each engine. Basing upon data from Jalkanen et al. (2012), the SFOC for a general two-stroke main engine at 80% MCR will be considered as 177 g/kWh; for an MCR value of 65%, the SFOC is 180 g/kWh; for an MCR value of 60%, the SFOC is 182 g/kWh; and for an MCR value of 55%, the SFOC rises up to 185 g/kWh.
- Auxiliary engines' load factor will be kept equal for both design and slow steaming speeds since the slow steaming consists basically in throttling down the main engine. According to Saputra et al. (2015), when cruising, the load

factor of the auxiliaries is 30%. About the SFOC for the previous MCR, the value of 211 g/kWh has been selected basing on Figure 3.2.

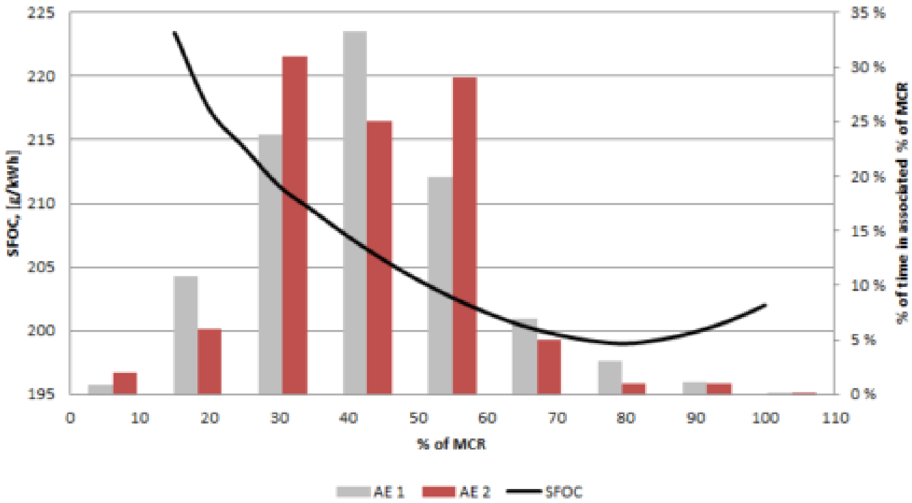

Figure 3.2. SFOC values at different auxiliary engine load rate (DNV GL, 2016)

To finish with the procedure explanation, the following equation will be employed in order to quantify CO_2 emissions (based on Corbett et al., 2009):

$$CO_2=3.17\cdot\sum_{i,j,k} F_{i,j,k} \quad [7]$$

where 3.17 is a factor to compute the amount of CO_2 in tonnes generated from the total amount of fuel burnt by the vessel's power plant.

3.1.1 Results

Tables 3.3, 3.4 and 3.5 summarize the results obtained from calculations for each speed reduction rate contained in Annex 1:

Table 3.3. Results of the environmental impact study for 10% speed reduction

	Fuel consumption		CO_2 emission		Reduction rate
	Design speed	Slow steaming	Design speed	Slow steaming	Fuel consumption & CO_2 emission
Containership	1,580.80	1,109.74	5,011.14	3,517.88	**29.80%**
Bulk carrier	149.24	123.38	473.09	391.11	**17.33%**
Oil tanker	992.06	680.05	3,144.83	2,155.76	**31.45%**
Car carrier	82.38	60.00	261.45	190.2	**27.25%**

With a speed reduction of 10%, CO_2 emissions can be lowered by 26.46% in average.

Table 3.4. Results of the environmental impact study for 15% speed reduction

	Fuel consumption		CO_2 emission		Reduction rate
	Design speed	Slow steaming	Design speed	Slow steaming	Fuel consumption & CO_2 emission
Containership	1,580.80	953.34	5,011.14	3,022.09	**39.69%**
Bulk carrier	149.24	116.10	473.09	368.04	**22.20%**
Oil tanker	992.06	575.67	3,144.83	1,824.87	**41.97%**
Car carrier	82.37	52.72	261.45	167.12	**36.08%**

With a speed reduction of 15%, CO_2 emissions can be lowered by 34.98% in average.

Table 3.5. Results of the environmental impact study for 20% speed reduction

	Fuel consumption (t)		CO_2 emission (t)		Reduction rate
	Design speed	Slow steaming	Design speed	Slow steaming	Fuel consumption & CO_2 emission
Containership	1,580.80	819.57	5,011.14	2,598.04	**48.15%**
Bulk carrier	149.24	110.68	473.09	350.86	**25.8%**
Oil tanker	992.06	485.86	3,144.83	1,540.18	**51.02%**
Car carrier	82.38	46.59	261.45	147.69	**43.51%**

Regarding the last scenario consisting on a speed reduction of 20%, CO_2 emissions are cut by 42.12% in average.

The results got from the previous study belong to a single voyage and, in cases of tramp services, the reduction rate will not remain constant and it is likely to decrease due to the uncertainty of shipping orders, wait time and sudden route changes, among other factors. In addition, it is important to highlight that manoeuvring, port approaches or channel transit have not been taken into account; therefore, these average CO_2 amount cuts are not entirely truthful.

Nevertheless, it has been verified that the simple action of slowing a vessel down brings along with significantly favourable environmental benefits up to 22% of CO_2 emission lowering when the speed is reduced by 10%, 29% when the speed is reduced by 15% and

35% when the speed is reduced by 20% (taking into account that the vessel is cruising 84% of the total voyage duration).

Besides, being the bulk carriers the most polluting vessels right after containerships, the result obtained is contradictory since fuel consumption and, therefore, the carbon release are relatively low. This is because, as a general rule and as it can be seen in the example provided, bulk carriers are not usually very powerful vessels; however, this type of ship accounts for 42.5% share of the world fleet in deadweight tonnage, multiplying the environmental impact to a great extent.

It is also established that for more powerful engines, the bigger the impact of changes in speed will be, as in the case of the carrier. Likewise, through the scenario of the oil tanker it can be deduced that the lower the power output of the auxiliary engine is, the greater the savings in fuel will turn out to be.

It is clear, therefore, that each vessel possesses her characteristics, and based on these, the effects of slow steaming will vary. However, even the least favourable results, bulk carrier's ones in this case study, are positive, with reductions rates from 17% to 25%, within the range established in this dissertation.

Finally, it should be noted that every 5% reduction, the differences are substantial: the results raise 10 points approximately from stage to stage, confirming the great impact and equal effectiveness of this simple practice consisting of reducing speed. For those who seek the least effect in transportation times but staying true to their commitment to the environment, a gentle 10% reduction could be their best option; for those who prioritize the limitation of carbon emissions before transport, they could bet on reductions greater than 20%, moving to the practice of extra slow steaming; and, lastly, it is verified that with an intermediate reduction of 15% (which in general in the merchant fleet would not exceed 5 knots for the fastest ships) emissions could be mitigated very considerably if the shipping companies and, consequently, their vessels would adopt this green measure.

Besides the present paper, there are certain researches assessing different sides of the slow steaming practice that concluded with similar outcomes both in numbers and conclusions, as shown in Table 3.6:

Table 3.6. Results from researches about the slow steaming

Author(s)	Subject	Results
Corbett et al. (2009)	Effectiveness of speed reduction on emissions from international shipping	Emission reduction of containership routes can be up to 70% when the speed is halved.
Kontovas (2009)	CO_2 emission statistics	Reducing a vessel's speed by 10% decreases emissions by at least 10-15%.
Wiesmann (2010)	Viability of the slow steaming as a long-term option	Overall savings could be in the range of 10–25%, depending on the proportion of vessels in a fleet that are slow steaming.
Cariou (2011)	Sustainability of the slow steaming	Slow steaming has reduced emissions by around 11% from 2009 to 2011.
Maloni et al. (2013)	Impact of the slow steaming on ocean carriers and shippers	Slow steaming lowers annual CO_2 emissions by 26.1%.
Lee et al. (2015)	Impact of the slow steaming on fuel consumption	If the speed can be continuously adjusted, lines can further reduce the fuel consumption.

Given the results above, it has been verified that slow steaming is an easy, feasible and efficient measure to tackle ships' carbon emissions to the atmosphere, cutting them by at least 20 percent when the speed is lowered by 15 percent.

3.2 ECONOMIC IMPACT STUDY

Even though this dissertation is focused from an environmental prism, the impact on the economy cannot be left aside since the green shipping development and implementation still tightly depends on stakeholders' economic interests, that is, money.

The main characteristic of speeding down is the fact that fuel consumption significantly descends and bunkering, that is, marine fuel expenditures, are vital in order to keep the ship fully operative. Indeed, these costs are the major disbursements a vessel entails (see figure 3.3). This translates into good news for the person responsible for the fuel, because the greater the reduction in consumption is, the greater the savings will become.

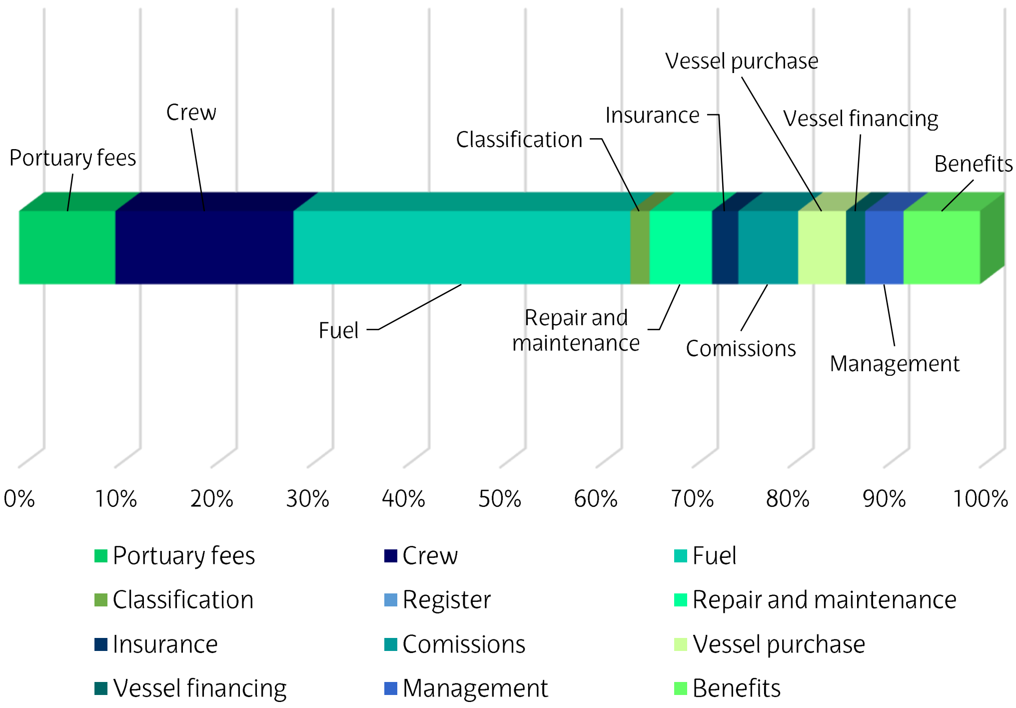

Figure 3.3. A 10,000 dwt tanker's costs distribution (Author based on data from UNCTAD, 2012)

As for the fuel, it is common knowledge that this market is volatile and unpredictable since petroleum's price is unstable. Marine fuels therefore depend on the fluctuations of this area of trade. At the time of this writing, a metric tonne of Heavy Fuel Oil (HFO) is worth $468.5[11]; this value will be used for the calculations bellow.

Once in the context, the slow steaming economic effects will be assayed below:

$$\text{Savings}=\left(F_{\text{Normal speed}}-F_{\text{Slow steaming speed}}\right)\text{tonnes}\cdot\text{fuel price}\,\frac{\$}{\text{tonne}}\quad[8]$$

3.2.1 Results

The obtained results from the calculations gathered in Annex 1 are exposed in Table 3.7 and correspond to a single voyage; as it can be observed, for heavy and fast ships such as containerships, the fuel saving rate is quite greater, albeit the benefits in other types of ship are not far behind: a slow steamed car carrier calling at the same port every 5 days, that is, carrying out the suggested Pasaia-Bristol-Pasaia route 73 times a year (146 voyages overall), can save up to $1,530,814.38 should fuel keeps the same price up until now in the gentlest of the cases (10% of reduction).

[11] In order to get the most reliable data about fuel prices for the calculations below, Ships & Bunker website have been accessed on 12 May 2019.

Table 3.7. Fuel savings in tonnes and costs

	Fuel savings					
	10% speed reduction		**15% speed reduction**		**20% speed reduction**	
	(t)	**($)**	**(t)**	**($)**	**(t)**	**($)**
Containership	471.06	220,691.61	627.46	293,965.01	761.23	356,636.25
Bulk carrier	25.86	12,115.41	33.14	15,526.09	38.56	18,065.36
Oil tanker	312.01	146,176.685	416.39	195,078.71	506.2	237,154.7
Car carrier	22.38	10,485.03	29.66	13,895.71	35.79	16,767.61

It may seem easily deducible the fact that as long as fuel prices remain high, the slow steaming will be boosted. Although it has been stated that this market is considerably changeable, everything suggests that on the grounds that IMO is promulgating more and more exigent requirements regarding cleaner and more efficient fuels, the prices will abide high, and the speed reduction will keep being fostered.

In addition to the favourable results above, there are other economic consequences that must be analysed. However, calculations are complex and vary from ship to ship. Furthermore, the slow steaming has a direct impact on certain aspects of the maritime industry such as the lay-up. The former concept, costs and further effects will be assessed in a more particular way and adapted to different stakeholders in Section 3.4.

In conclusion, even in the case of the least speed reduction, the generated savings are vast, which is a powerful incentive for those in charge of bunker payment to encourage them to support the slow steaming practice. Both the environmental and economic impacts are substantial and, unlike the prevailing trend until now, the current environmental circumstances oblige us to forget the concept of economic speed and its dependence on fluctuations in freight rates; it is time for the maritime industry to pave the way towards a more sustainable shipping method.

3.3 IMPACT ON FLEET AND TRADE

The first and most evident consequence is the loss of cargo capacity of the vessels: whilst main structural and navigation features and transported tonnage remain the same, i.e. *ceteris paribus*, if speed is reduced, the time required for the same journey rises, carrying less amount of goods per time unit. As a result, as part of a chain of side effects, a need to compensate that gap is generated, being the investment in additional service the only solution. With that in mind, due to the supplementary ships put afloat, all the signs are that the bigger the merchant fleet gets, the lower the contribution of the slow steaming to the reduction of CO_2 emissions will be. Therefore, based on that theory, it would be useless to implement this green solution in the world fleet. Nevertheless, according to Corbett et al. (2009), "when additional ships are added to maintain schedule frequency, lower speeds still provide CO_2 emissions", albeit, irremediably, the more ships active, the lesser environmental benefits.

In order to solve the problem set out above, the most environmentally-friendly way to fill up the void would consist of new construction vessels that have been fitted with energy efficiency measures. Thus, the increase in the number of emitting ships would be less damaging than if pollution was produced by older ones. Other green alternatives such as windship technologies could contribute as well, albeit most of them are immature options yet. On the contrary, energy efficiency measures are a reality and must be applied from now on.

However, if we stick to reality, the most likely and perhaps appropriate during at least the first years is to allocate the ships in lay-up to this end (see figure 3.4). In a nutshell, lay-up means to put vessels out of service for a certain period of time; depending on how long these ships remain idle, we can distinguish warm lay-up, for short periods, and cold lay-up, for longer stages. According to Alphaliner (2017), 342 containerships were laid up in 2017, accounting for 6.7% of the global cellular fleet at that time.

Figure 3.4. Lay-up in Bøvågen, Karmøy (Vormedal, 2016)

These ships are not usually new, but they have not been sufficiently exploited to scrap them. When the expenses involved in keeping the ship active exceed the benefits obtained through freight or there is little demand, shipowners decide to stop them for a determined time or even indefinitely. For example, the shipping sector experienced a great boom before the recession of 2008, point at which, despite the alarming indicators of an impending downfall, there were already $400 billion worth of additional ship orders (Mallidis et al., 2018). Given these troublesome circumstances and in view of the vast available capacity, shipowners face two barriers: first, reducing operational expenditure to sustain the profitability of their activity or second, putting out of service the surplus of their idle vessels.

Thanks to the throttle reduction, owners could give their fleet life: as the employment of slow steaming prolongs the ship's voyage duration, it enables stakeholders to absorb excess fleet capacity during periods of slack demand in their service routes (Maloni et al., 2013; Maillidis et al., 2018). Consequently, the employment of idle ship capacity is fostered. In other words, inactive vessels can be put into service for a few years until they are scrapped; this would open the way for more ecological vessels and would give place to those technologies that are currently under development, battling gradually the lay-up.

In terms of trade, both in the maritime sector and in any other type of transport, one of the most important factors is reliability. Reliability means that the merchandise arrives at its destination fulfilling the agreed times or, in default, those established by the carrier. If the products do not arrive or the reliability of delivery times cannot be guaranteed, the loss of customers is more likely to descend. In the maritime industry in particular, which covers 90% of global trade, reliability gains even more importance.

That said, slow steaming has a direct impact on this valuable and indispensable factor for shipping; in fact, schedule timeliness represents the fourth main benefit stemmed from speed reduction after fuel savings, lower CO_2 emission and absorption of excess fleet capacity (Maloni et al., 2013). This practice yields room for speed vessels up and ensures that they call at port on time.

However, it is inevitable that the duration of travel increases by 10-20% depending on the service route and port times along the journey (Lee et al., 2015). But, although delivery times are prolonged, they can be fulfilled with greater realiability than if the ships sailed full ahead without the option to vary the speed.

However, we have only assessed the consequences of slow steaming in general terms hitherto. Therefore, we consider that it is necessary to briefly detail and summarize the effect of speed reduction on short-sea shipping and ocean shipping, as they possess different characteristics.

- **Short sea shipping**. This modality is carried out by vessels operating in limited geographical areas and relatively short routes. On this matter, reliability is a must since the prevailing shipping is the liner service. Ships' journeys are thoroughly scheduled, and this timeliness is crucial for competitive issues. Nonetheless, most of these voyages are characterised by their rapidity and the possible delay or voyage lengthening caused by the slow steaming would be detrimental to this feature. Still, it is about a matter of adaptation and for these shorter routes, the extra shipping time would not be excessive (no longer than two days); however, reliability would be boosted and guaranteed.
- **Deep sea shipping**. This market, unlike short sea shipping, is mainly covered by tramp service, with undefined routes, destinations and non-fixed timetables. Delivery time and schedules would not get adversely affected that much, not because of voyage duration, which of course would be prolonged, but because of the fact that routes are not set. Therefore, slow steaming is even more applicable to this case than to the short sea shipping.

Anyway, as the former chief-executive of Maersk Line Eivind Kolding pointed out in the 2011 TOC Europe[12] Conference "reliability is the new rate war; we need an end-to-end view on reliability", setting aside the increase in delivery time.

Finally, although theoretically slow steaming is easily implemented and carried out, this issue must be spelled out. Not all types of ships are adequate to apply this measure due to the cargo they carry; reefer vessels, those carrying perishable aliments or even passenger ships may be affected on a larger scale. The condition and duration of food are invariable, so these goods condition the travel times; as for the cruises, even if they do not conduct long routes, the increase in duration can be tedious for the passengers. However, these three types of boats account for a tiny share of total world dwt (see Table 1.1 in Chapter 1) and could be declared exempt from the practice of speed reduction.

3.4 IMPACT ON STAKEHOLDERS

There are many personalities taking part of the process that the maritime transport involves: shipowners, charterers, carriers, shippers, freighters, brokers, consignees,

[12] TOC Europe is the leading business & networking event for executives in the Container Supply Chain and Dry Bulk sectors.

stevedores and so on. The slow steaming concerns three of them: carriers, shippers and shipowners.

In this section, the impact of the speed reduction on these stakeholders is analysed. For that aim, the following questions will be discussed for every of them:

Q1. What are the main activities affected by the slow steaming?

Q2. What are the expected variations in costs if slow steaming was implemented?

Q3. What are the benefits stemmed from the application of the slow steaming for the stakeholders?

3.4.1 Carriers

A carrier is a vessel or company that undertakes the professional conveyance of goods or people. The carrier can execute different tasks and perform more than one role in this complex shipping process. In many cases, carriers are responsible for disbursing bunker costs, and this factor will be taken into account when assaying the influence of the speed reduction in this stakeholder.

Answering to the previous questions, the main activity hit by the slow steaming is the navigation. As a result, the duration of the voyage increases and therefore, so do the running costs (supplies, lub oil, repair and maintenance, crew cost, spendable material, drydocking, insurance, spare parts, management, etc.). This could represent a big concern if the carrier is at the same time the shipowner since in all charter parties except for the bareboat one[13], the shipowner is in charge of these expenses (see Table 3.6 in Section 3.4.3).

However, the speed buffer that slowing down provides has two positive effects on carriers: the flexibility to increase sailing speeds after a delay of certain nature in order to meet the laydays and the reduction of voyage fuel costs (Mallidis et al., 2018). The former is a key point to ensure delivery times and better schedule adherence, a fundamental pillar in nowadays market. A ship can experience several setbacks such as storms, traffic congestion, sailing in fog or channel navigation, among others, that could be balanced out by speeding up. About the latter, fuel costs are the most volatile and

[13] A charter party is a maritime contract by which the operation of the vessel is agreed. It is signed by the owner and the charterer. In the case of the bareboat charter, the charterer is in charge of the whole operation of the vessel and therefore is responsible for the running costs whereas in the case of time and voyage charters the shipowner is still in charge of the operation of the ship.

expensive cost item that vessels involve (as previously seen in Section 3.2). Even if in liner service routes are precisely scheduled (and therefore necessary bunker is calculated), the fuel costs are broadly considered as variable expenses on behalf of the charterer[14], who in this study is considered carrier as well. As a result, the carrier would benefit from enormous savings in fuel and money.

Summing up, the main benefits that a carrier can obtain derive from fuel costs savings and reliability reinforcement, not forgetting the proof of the commitment to the environment by becoming a lower carbon-emitting carrier, a very valuable sign for customers looking for more sustainable maritime transport options.

3.4.2 Shippers

A shipper is the person or company who is usually the supplier or owner of goods shipped and transported by the carrier. As opposed to carriers, shippers have expressed significant concerns regarding slow steaming and longer transit times: 70% of these stakeholders expect lower rates (Maloni et al., 2013). These preoccupations are due to the increase pipeline inventory levels, that is, the amount of goods in-transit that have not reached yet the final consignee. Consequently, the stock and inventory forecasts would get pervaded by uncertainty and shippers may increase safety stock[15] level that could end up being in excess, causing extra useless costs and losses.

Besides, longer estimated shipping times could deter both habitual and potential customers who look for fast transport and are willing to receive their merchandise as quick as possible.

However, as mentioned in the previous part, speed reduction brings along with delivery time accuracy, which is becoming the leading factor in maritime-transport-related business. This means that the concern about promising fast delivery by shippers is no longer valid and, at the same time, as new schedules are more precise, the forecast horizon would not differ much, remaining the same or even more accurate.

Moreover, just as shippers, obtaining the *green label* makes a difference: the population is concerned about the CO_2 emissions to the atmosphere, and so do customers and many personalities belonging to the maritime sector. Thus, shippers should take

[14] Except in voyage charter party, for which the shipowner is responsible.
[15] In order to solve similar problems such as increased inventory issues and to optimize production systems, the just-in-time concept was created. This method developed by Toyota in Japan in the 1960s consists in a production organization system for companies, allowing them to reduce costs, especially raw material inventory.

advantage of this situation and promote their engagement with the environment to ensure and gain clients.

The main problem so that shippers oppose or show themselves skeptical to slow steaming may reside in the alleged differences between shippers and carriers, in other words, the unfairness and inequity in benefits and interests between these two parties. It is true that the research by Maloni et al. (2013) revealed that carriers do obtain significant cost savings after throttling down and that shipper's costs slightly increase (see figure 3.5); still, slow steaming has little positive impact on shippers.

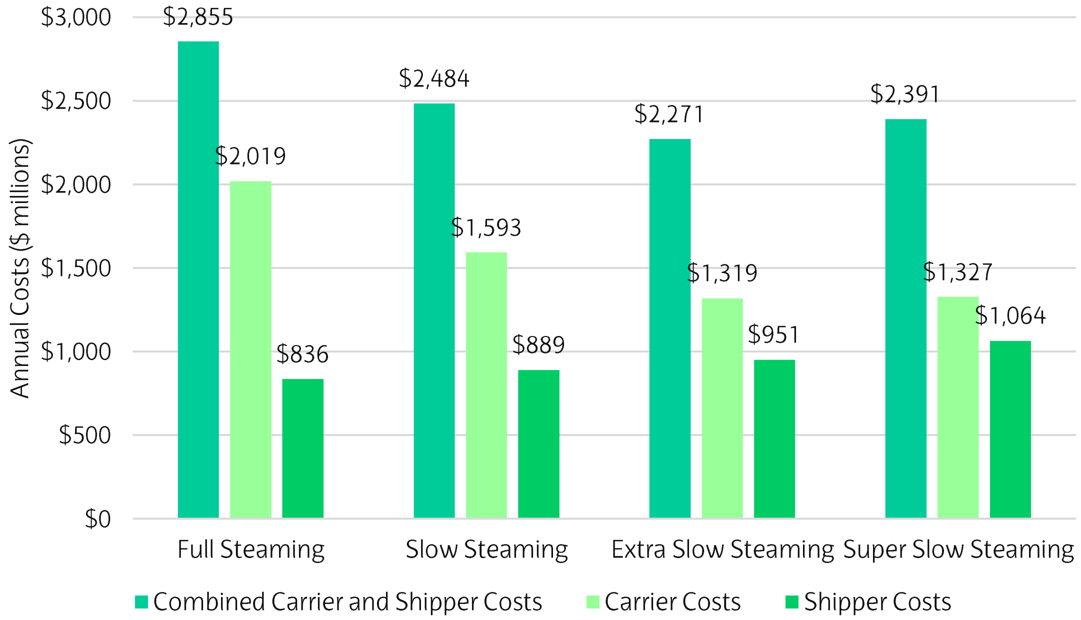

Figure 3.5. Annual ocean carrier and shipper costs at different slow steaming modes (Author based on data from Maloni et al., 2013)

As seen in the figure above, as the speed reduces, overall annual costs also decrease. However, there is a point of inflection from which this practice would cease to be profitable; speeds lower than extra slow steaming (e.g. super slow steaming) would no longer be beneficial as expenses start to rise again and, moreover, the maritime industry could not afford a deceleration of the world fleet of such magnitude.

The solution for the aforementioned issue about inequity of financial savings of both stakeholders that occasion the scarce acceptance of the speed reduction by shippers could consist of sharing out the overall benefits between them. This arrangement could be reached by means of a contractual agreement designed by both parties.

In short, shippers do not obtain huge benefits from the implementation of the slow steaming more than the delivery time reliability; nevertheless, speed reduction is not prejudicial to them since they do not make loss. Shippers stay the same, and as a matter of fact, they should commit to the slow steaming not for economic reasons but for the preservation of the environment.

3.4.3 Shipowners

Shipowners do not usually get involved in shipping and delivery matters since they do not tend to take charge of the operation of the vessel; they hire her instead to charterers that may be carriers as well. However, they are affected by some effects of the slow steaming.

First, if the shipowner runs the whole shipping business and acts as a carrier at the same time, he or she will be responsible for the bunker expenditure. Moreover, as it is shown in Table 3.8, in time charter parties it is generally agreed that the costs attached to the voyage, that is, variable expenses are generally paid by the shipowners.

Table 3.8. Costs share depending on the vessel operation mode (Author based on data from Dalgic et al., 2013)

COST NATURE	COSTS	COSTS SHARE DEPENDING ON CHARTER PARTY		
		BAREBOAT CHARTER	TIME CHARTER	VOYAGE CHARTER
Capital charges	- Investment - Interests - Repayment	SHIPOWNER	SHIPOWNER	SHIPOWNER
Daily running costs	- Crewing - Maintenance/repair - Spare pieces - Inspections - Insurance - Administration - Water - Lube oil	CHARTERER	SHIPOWNER	SHIPOWNER
Voyage-inherent costs	- Fuel costs - Port Charges - Canal Dues	CHARTERER	CHARTERER	SHIPOWNER
Cargo handling costs	- Cargo handling - Cargo claims	CHARTERER	CHARTERER	CHARTERER

Therefore, as speed reduction's main benefit is the fuel consumption reduction (and consequently, the big CO_2 emission amount decrease), shipowners may have interest in its application.

Keeping with costs, as explained in Section 3.4.1 about shippers, the prolongation of navigation time implies larger running costs, normally incurred by shipowners (except for bareboat charter mode). Unlike bunker costs reduction, this consequence can deter these stakeholders; still, voyages are increased by 10-20% maximum, which does not result in alarming expenditure increase and fuel savings can make up for these running costs variation.

Furthermore, slow steaming involves a direct impact on shipowners relative to their idle fleet. Speed reduction may foster the reactivation of laid up vessels, enabling owners to generate profits from the operation of the vessels again.

Summing up, all these factors confirm the need to include shipowners in the affected stakeholders list; it is not completely veracious to focus on just shippers and carriers since shipowners are one of the most powerful personalities in the maritime sector and, simply but definitely, because they are the owners of the vessels that will execute the slow steaming practice.

CHAPTER 4
DISCUSSION

4. DISCUSSION

Once both the economic and the environmental impact of the slow steaming have been studied in Chapter 3, in this fourth part the different green alternatives suggested in previous sections will be collated.

We have chosen four main domains in order to reach an objective result from the discussion: costs, implementation and operation, fuel consumption reduction effectiveness and impact on the trade and stakeholders.

Regarding the chosen alternatives, we have taken into account some of the options discussed in Chapter 2 that allow a more comprehensive analysis since they possess greater future forecast: all technologies based on wind propulsion (Kite Sail, DynaRig and Flettner Rotor), certain energy efficiency measures (hydrodynamics, waste heat recovery, scrubber, machinery improvements, and operational measures), the most developed alternative fuels (LNG, LPG and methanol) and the slow steaming.

4.1 CAPITAL COSTS

We refer as capital costs to the initial expenses incurred on the purchase of the technologies and the equipment to be used as well as those generated as a result of their installation on board, if applicable.

Table 4.1. Capital costs comparison[16] (Author based on data from GloMEEP, n.d.; Kirschbaum, 2007; Tom Perkins, 2007; The Glosten Associates, 2011; Ship Technology, 2015; Drewry, 2018; and MAN, 2018)

ALTERNATIVES		COST
Windship Technology	**Kite Sail**	$660,000
	DynaRig	$80,000,000
	Flettner Rotor	$400,000/per unit
Energy Efficiency Measures	**Hydrodynamics**	$150,000
	Waste Heat Recovery	$5,000,000
	Scrubber	$2,700,000
	Machinery improvements	$100,000
	Operational measures	Costless

[16] Most inexpensive costs have been taken into account.

Alternative Fuels	**LNG**	$8,520,000
	LPG	Under development
	Methanol conversion	$25,500,000
Slow Steaming		Costless

Table 4.1 provides an overview of the minimum average cost that each alternative entail; as it is shown, the expenditure is remarkably changeable depending on the measure implemented onboard. The slow steaming is presented as the most viable option at first, since it does not involve any disbursement. In addition, operational measures, such as weather rerouting[17], autopilot optimisation and trim and/or draft optimisation, are inexpensive or even costless as well. In contrast, the DynaRig system accounts for the greatest capital costs, followed by the acquirement and installation of the scrubber.

Besides the speed reduction and operational measures, the redesign of the hull and machinery improvements are relatively affordable; however, as it will be shown in the next sections, these options are not enough to reduce CO_2 emissions considerably or they are actions that are not suitable to be taken onboard existing ships.

About the windship technology, it is assumed that the initial disbursement is amortized over the next few years, turning into profits thanks to the reduction of fuel oil. By the same token, the outlay of the conversion of propulsion systems in order to burn greener alternative fuels is supposed to be paid off relatively rapidly; nevertheless, in the case of a worn-out vessel, the investment is more likely to turn into a loss.

4.2 IMPLEMENTATION AND OPERATION

Kite sail technology's installation does not imply any further complication. Actually, when hoisted, the sail does not hamper any deck job as it is flying up in the air by means of a single rope; when it is gathered up, it is stowed in a fixed and designated place for the kite, so manoeuvring, loading and unloading operations do not get affected. In addition, since it is rigged on the forecastle, on the bow, the kite sail system can be implemented in mostly every existing and new construction ships. About stability questions, there is no need to rearrange weight distribution due to it consists of a

[17] Weather forecasts and sea conditions are used in order to design optimised routes in ocean voyages.

lightweight materials and mechanisms. Finally, with regards to operation, its almost automatic performance eases its application on board, albeit crew members would need to go through a training stage to get familiar with the kite sail system.

Contrary to kite sails, DynaRig specially affects ship's stability, since this alternative consists of the installation of several high masts (and sails) in the vessel. As a result, the centre of gravity would change and the operations of loading, unloading, ballast management and stowage would have to be recalculated and adapted to the new disposition. Furthermore, the arrangement of the masts could entail loss of cargo capacity and difficulties to ships while carrying out habitual harbour activities (mostly on containerships because of the port cranes or bulk carriers with running hatchways). Bearing these disadvantages in mind, it is preferable to consider DynaRig for new vessels (see *WASP* Ecoliner in section 2.2); if a shipowner decides to refit a vessel with this technology, he or she will be more likely to pay out a large amount of money that will probably not turn out profitable compared to more affordable sustainable alternatives. About the operation, the DynaRig is an automated system, so, like kite sails, the crew is required to be trained in the proper use of this technology.

About the Flettner rotors, they involve similar requirements that the previous solution does; however, this green option entails more complexity compared to the DynaRig and it is even more convoluted in comparison with the kite sail. Firstly, these spinning cylinders are even heavier than Dynaring masts (see its features in section 2.2) and considerably high to change the location of the centre of gravity of the vessel as a whole. Consequently, many aspects involving operation and ship stability would change. Secondly, it is possible to install just one rotor (on the bow, as kite sails), so the effects would be less striking; however, in order to get the maximum thrust possible, more cylinders would be needed. Thirdly, merchant vessels with numerous cargo lines (oil, gas and chemical tankers) are not suitable to be refitted with them because of the lacking available free deck space and the disposition of the tubes. In addition to them, the rotors could be damaged during port operations because of shore cranes in the case of a containership, for example. Last but not least, it is important to highlight that the rotors are likely to hamper the vision from the bridge, hindering the task of navigation. In addition, depending on the placement of the signal mast and the height of the rotors, the radar image could display shadow sectors caused by the cylinders. Finally, regarding the operation, in general terms, the system works automatically, but it does not exempt the crew from learning how to employ it, so a previous training is needed not only for getting familiar with the technical operation but with the ship's behaviour after the placement of heavy and high rotors on board.

As this is one of the most complex technologies, we found interesting to show the development of the "EcoFlettner" project[18], part of a bigger undertaking called "MariGREEN", consisting on the development of different technologies and tools for sustainable propulsion in shipping, funded via the Ems Dollart Region of the European Union's INTERREG program.

The installation of a single rotor on the motor vessel *Fhen Pollux,* a 90-metre long multi-purpose freighter of Fehn Ship Management shipping company from Leer (Germany), lasted 18 days overall. The process consisted of the foundation, welding works and openings in deck, in addition to a fuel meter that measures fuel consumption. The correct positioning of the basement is crucial in order to ensure the correct performance of the spinning cylinders.

Once the foundation is rigged, the rotor needs power connection, as well as the control console needs to be connected to the cylinder. For that purpose, more welding is required, as well as several metres of cable. While the project is being developed, the crew was being trained by the Prof. Michael Vahs from the Faculty of Maritime Sciences at the University of Applied Sciences Emden/Leer (see figure 4.1), since they need to know how the vessel behaves when a Flettner Rotor has been installed on the forecastle, changing her stability and performance at sea, in addition to watch conditions. According to Vahs (2018), "among other things, it's about getting used to the changed field of vision [...] the rotor can cover small objects – the navigators must be prepared for this". About steering characteristics, he also stated that they "also change a little".

About the simulator, in the same way the rotor was especially designed for the *Fhen Pollux,* the virtual cylinder was identically reproduced and the programmed so that the crew had the same view as in reality from the bridge and could experience the change of behaviour of the vessel once the rotor is fitted onboard. According to Vahs "this is the only simulator in the world that allows you to sail with a Flettner rotor on board".

[18] All data regarding the "EcoFlettner" project has been retrieved on 24 April 2019 from http://en.marigreen.eu/ecoflettner-installation/

Figure 4.1. The crew of the *Fhen Polux* at training sessions conducted at the ship handling simulator of Nautitec GmbH (Berentzen, 2018)

After two weeks, the rotors were placed, and the testing period began in order to calculate the mass of the ship and its centre of gravity. Once the ship met all the navigational requirements, the vessel set sail for sea trials. The data gathered by the end of the year 2018 revealed, according to Prof. Vahs (2018) that "the EcoFlettner saves a noticeable amount of fuel. We are also able to prove, that for ship owners the investment into this sailing system is worth considering, because it pays off in a few years".

With regard to energy efficiency measures, most of the machinery and hydrodynamic alterations need to be executed when the vessel is in dry dock, process that may take from weeks to months and the stay in the shipyard makes the vessel remain inactive for a determined period of time, consequently generating loss of earnings; others, cannot be carried out on existing ships. Therefore, we cannot establish properly the type of implementation that energy efficiency measures involve. In addition to the previous issue, the restricted space on board to rig new or bigger equipment hampers their implementation. Regarding operation, the advantage of these options is that, in general terms, there is no need of handling them.

On the contrary, operational measures are relatively inexpensive (weather rerouting in essence is costless) and most of them can be implemented at the very moment aboard without further due. These improvements are most profitable when they are applied from the beginning of a ship's life on the basis of two main reasons:

- as a vessel gets older, reparations are more likely to be fancier and to take more time to be refitted with new systems; and
- if new construction ships are designed aiming to consume and emit less from the beginning, the energy efficiency measures can be combined with other green alternatives (synergy), boosting their contribution to the low carbon shipping.

In conclusion, shipyards, shipowners and naval architects must implement energy efficiency measures from now on so that the merchant fleet evolves into a more environmentally friendly community.

Regarding alternative fuels, the installation process is similar to the previous case of energy efficiency measures: both the total conversion to a new fuel and the installation of a dual engine mean substantial changes in the ship that result in numerous days for her reconditioning. For instance, the conversion of the *Stena Germanica* lasted 45 days at Poland's Remontowa shipyard (Lloyd's Register, 2015).

In this case, not only the duration of the rearrangement but the fuel tank distribution and capacity and the requirements of the fuel type must be borne in mind. The LNG, for example, is transported in liquefied state and in order to keep the gas liquid, it must be pressurized or cooled, unlike conventional fuel oil. Moreover, these substances are hazardous, due to their flammable characteristics. As a result, the transportation of methanol, LPG or LNG requires special training of the crew on safety hazards and response to incidents.

Finally, regarding the slow steaming, it is evident that there is no need to wait for its implementation since no installation nor rearrangement is required. This technique consists just on slowing down the ship's speed: no adjustment but the velocity must be made. Nonetheless, it is not applicable to the whole existing merchant fleet, since some type of vessels cannot be slowed down, namely perishable good carriers and passenger ships; still, these vessels together account for less than 2% of the global fleet dwt.

4.3 FUEL CONSUMPTION SAVINGS

Fuel consumption reduction is the main factor to be taken into account when assessing which of the green alternatives at hand is the best solution to tackle atmospheric carbon pollution. All the results are presented in Table 4.2.

Table 4.2. Fuel consumption reduction (Based on SkySails, n.d.; Argitech, 2015; Carrington, 2017 and Chryssakis, 2017)

ALTERNATIVES		FUEL CONSUMPTION REDUCTION
Windship Technology	Kite Sail	10-15%
	DynaRig	35%
	Flettner Rotor	7-10%
Energy Efficiency Measures	Hydrodinamics	13-20%
	Waste Heat Recovery	0-8%
	Scrubber	+5%
	Machinery improvements	4-8%
	Operational measures	Undetermined
Alternative Fuels[19]	LNG	Dependent on arrangement
	LPG	Dependent on arrangement
	Methanol	Dependent on arrangement
Slow Steaming		22-35%

Windship technologies in general are a good option for a more sustainable shipping; however, the main issue is that they directly depend on wind conditions and their fuel consumption reduction percentage can be easily varied and most probably, lowered. the DynaRig, thanks to its great environmental benefits can keep being effective even if the prevailing meteorological conditions are not optimal. Yet, it is one of the least applicable options onboard existing ships and its initial cost is the highest of all the alternatives proposed in this dissertation.

Regarding energy efficiency measures, the fuel reduction rate is too low if just a single action was implemented. Therefore, in order to get significant results, several measures should be installed onboard, taking into account the consequent disbursement. In

[19] Current propulsion systems burning alternative fuels such as LNG are dual, that is the engines consume both fuel oil or diesel oil and gas, and it is difficult to stablish a fuel consumption reduction rate.

addition, although hydrodynamic improvements can lower fuel consumption by 20%, this option is hardly applicable to existing ships and therefore, it should be borne in mind for new constructions.

About the slow steaming, the fuel reduction is quite variable: as it has been explained in Section 3, the fuel consumption varies depending on the rate of speed reduction. Hence, slow steaming can cut emissions from 20% to even 50%.

Finally, it is hard to determine the carbon emission reduction efficiency of the alternative fuels. There are two possible scenarios:

- **Total conversion to a unique fuel**. By using methanol, which is the example of the *Stena Germanica,* CO_2 emissions can be cut up to 25%. If LNG or LPG were used as main energy source, the carbon footprint could be lowered by 17-20%.
- **Installation of dual engines**. This is the most common practice nowadays among shipping companies pursuing a more environmentally friendly maritime transportation. However, it is difficult to establish the consumption ratio of each fuel. Everything points to the fact that although CO_2 emissions are reduced, its effectiveness is not comparable to the previous case in which only one substance was burned. Likewise, it can be deduced that the environmental benefits are not superior to slow steaming, albeit dual engines are a very competitive alternative.

4.4 IMPACT ON TRADE AND STAKEHOLDERS

Starting with slow steaming, it may be the major side-effect causing option. First and most important consequence for any stakeholders and their business is the undeniable lengthening of transportation period. Both for carriers and sometimes shipowners would get benefits from this practice: while the ship is emitting less CO_2 by slowing her down, they are saving money since fuel consumption decreases considerably. In contrast, there is no benefit apparently for shippers, who oppose to this alternative claiming that longer voyages imply more inventory costs and therefore, losses. However, in the previous chapter (see 3.4.2) it is said that the expenditure would remain quite constant and instead, they would gain reliability.

In terms of trade, alternative fuels and energy efficiency measures would apparently perform in the same way ships have done hitherto, keeping the same delivery schedule. Windship technologies, however, are wind dependent and it obvious that meteorological phenomena are not constant, and so would be the thrust provided by the kite sail, rotors, or DynaRig system. But, taking into account that vessels would still be fitted with their original propulsion systems, it can be deduced that if there is no wind thrust, the vessels will operate in the same way as they did before, yet, contributing to the increase of the carbon footprint.

Finally, regarding stakeholders, the only change that could affect mostly to carriers and shipowners is the price of the alternative fuels but their acquisition at this moment is not a mayor problem since the demand is low. For instance, according to DNV GL[20], in September 2018 the LNG price per tonne was $450; nonetheless, as natural gas becomes one of the main sources of energy for ships, the price will rise, as is the case with the HFO.

4.5 IN SUMMARY

As seen through this chapter, the green alternatives have been assess based upon the following features: applicability at the very moment with no further delay, inexpensiveness, simplicity and effectiveness.

From the first comparison, it can be easily deduced that slow steaming and operational improvements are the most economical sustainable option. All of them are a safe practice that do not imply any investment nor technical change.

With respect to implementation and operation, the simple action of throttling the engine down is the only action to be taken regarding slow steaming. All wind technologies involve a more laborious installation, and the crew must be trained to use them correctly, as well as to know the effect they have on the behaviour of the ship. The same happens with energy efficiency measures; they are still technical solutions, so they involve some time of reconditioning expect for operational measures; in this case, the crew must also know, if necessary, the operation of the system of the new improvements and facilities, but in any case, it would not be in the same degree as with the windship solutions. As for the alternative fuels, fitting new dual engines or converting the whole propulsion system into a new one requires several weeks of overhauling, and likewise, the crew must be trained in order to handle these new and hazardous fuels.

[20] Data retrieved on 31 May 2019 from https://www.dnvgl.com/maritime/lng/current-price-development-oil-and-gas.html

Regarding fuel consumption reduction and its translation into CO_2 emission cut, some alternatives obtain a similar result (around 15-20 percent). In this case, the best solution has been chosen based on the cost-performance relationship. There is no doubt that almost the same benefits are obtained by investing more than $600,000 in kite sails than by investing absolutely nothing if we bet on the speed reduction. Changing hydrodynamics, which consists in the improvement of the hull shape and performance through water, is also quite cost-effective; however, back to its applicability, this option can be hardly carried out on existing vessels.

Finally, as for the effects on trade and stakeholders, the last IMO Strategy to reduce the carbon footprint by the maritime industry requests that the impacts on States and stakeholders should be assessed and borne in mind as appropriate before the adoption of the measure. In this respect, the slow steaming starts out at disadvantage because, although it does not involve any initial capital cost, the fact of extending the duration of journeys has a direct effect on trade, and therefore, on shippers and carriers, as explained in section 3.4. The other alternatives do not imply, at first sight, major prejudice to the stakeholders nor trade.

CHAPTER 5
CONCLUSIONS

5. CONCLUSIONS

As shown in this dissertation, maritime transport generates stratospheric amounts of CO_2 into the atmosphere, among other harmful substances. Therefore, there is an undeniable need to reduce them in order to protect our cities, islands and quality of life; in short, to preserve our planet and, consequently, ourselves.

It is true that we have a broad horizon at hand filled with green alternatives that could mark a milestone in navigation; however, no matter how promising and efficient the options may be, most of them are not applicable at the very moment due to the lack of maturity of the technologies and their technical complexity, the low access to finance and investment and the unavailability of competent crew.

However, among those sustainable alternatives, the slow steaming must be addressed. It is the only option that can be applicated onboard at the moment and the GHGs' footprint can be amazingly reduced with the simple action of reducing the ships' velocity a couple of knots. And, for the record, the IMO itself has suggested it as a short-term emission control measure, which is one of the main reasons to be in favour of it as it can be use during a few years while other technologies are being developed.

The main disadvantage of the speed reduction is the increase of the voyages' duration and, consequently, the loss of capacity. Moreover, the application of the slow steaming on liners could, initially, harm the trade and the timetables already established. Likewise, there are certain exceptions in which a speed reduction could not be implemented, e.g. vessels that transport perishable food or passenger ships.

On the one hand, the loss of capacity brings per se favourable consequences to the maritime industry: job creation, deadline reliability guaranteed and lay-up reduction. With regard to the latter, in particular, it is obvious that the increase of active ships may apparently affect the good results obtained from the slow steaming. Nevertheless, in a short-term period, the environmental benefits will keep being sufficiently significant for betting on the speed reduction during a relatively short period of time.

Related to the aforementioned, in addition to giving life to moored or beached ships, the construction of new vessels would get affected in a positive way. In this case, all new ships must meet the requirements of stricter rules, and energy efficiency measures can be implemented from the beginning, giving a new path to other green alternatives.

Thus, the oldest and least environmentally friendly vessels can be scrapped, being replaced by new ones that take more care of the planet.

On the other hand, the current trade is quite settled, where deadlines and time management are already established, especially in the liner market. Therefore, slow steaming is difficult to accept, and this problem constitutes a barrier for its implementation. In addition, there are certain types of vessels in which a greater delay is not advisable, as is the case of those ships transporting perishable goods; cruise ships could be adversely affected as well, because passengers may not accept longer trips as voyages would be more tedious and uncomfortable.

However, with a 10% of speed lowering, the results are significantly beneficial, and it would not extremely harm the balance of the schedules. For shipping trades other than short sea, a 15% of reduction rate could be applied, and as the practice becomes widely accepted and implemented as part of an adaptation period, vessels could step into the extra slow steaming, throttling down even more and obtaining greater environmental and economic results.

As far as regulations are concerned, in my opinion, they are scarce. On the one hand, the sea has been free to control air pollution until the last amendments to the MARPOL Annex VI (last decade), whilst on land, the issue of GHG emission control has been addressed and regulated with more impetus. On the other hand, it is important to point out that exhaust gases from ships are being regulated in the port area mainly, leaving cruising and international navigation in the shade, which is the activity in which the merchant vessels invest more time. Moreover, within the limitation in the scope of application, regulatory actions are lacking.

Continuing with the subject, I consider that, nowadays and even more in the shipping industry, money comes out on top and wins the game to environmental matters. Nonetheless, we have reached the critical point in which, in any case, actions must be taken in order to stop the tendency of our planet to heat up due to the high CO_2 content in the atmosphere. There are still many areas of blind spots in international agreements to deal with. As it is about activities that are generally carried out in international seas, countries do not enter into matter of emission control. As a result, this issue is not part of national plans and is left aside. Hence the importance of the IMO treaties.

At this point, interests can no longer prevail over this global need. I strongly believe that much more restrictive measures should be adopted, such as the prohibition of certain fuels and the promotion of the use of others (LNG and LPG), and high-value sanctions to those companies that exceed the emission quota, among others. Despite the economic damage that they might cause in the beginning, as time goes by, every action will be adaptable. So far, the IMO has only promulgated some sort of control plans, strategies, recommendations and even incentives so that the objectives regarding the lowering of GHGs are achieved. In this regard, I firmly believe that the Organization should be tougher, more imposing, and more rigorous, adopting a less lenient role, for example, establishing mandatory maximum speeds.

In view of these circumstances, the results obtained from different speed reduction scenarios have more than enough proven that, in spite of the issues and the consequences to which it gives rise, the benefits of the slow steaming can cover and counteract the collateral. Because of this, I consider it is the most sustainable option of the very moment during this progressive transition towards a maritime industry more conscious and respectful with the environment; the adaptation to this practice is just a matter of time. When the new green technologies are ready for use in the merchant fleet, the slow steaming will have fulfilled its function and its replacement will be possible.

CHAPTER 6

SOURCES AND BIBLIOGRAPHY

6. SOURCES AND BIBLIOGRAPHY

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ANNEX 1

ENVIRONMENTAL AND ECONOMICAL IMPACT OF THE SLOW STEAMING: CALCULATIONS

1. ENVIRONMENTAL IMPACT CALCULATION

All final results are compared with the fuel consumption and emissions corresponding to the primary speed, that is, the design speed. Thus, the calculations of fuel consumption and carbon emissions before slow steaming are calculated in first place following the steps (1), (2) and (3) shown below.

(1) Main and auxiliary engines' fuel consumption per day (t): $F = SFOC \cdot MCR \cdot P \cdot 24$ [6]

- **Containership**

$$F_{ME}=SFOC \cdot MCR \cdot P \cdot 24=177\,\frac{g}{kWh} \cdot 0.8 \cdot 47{,}430\text{ kW} \cdot 24\text{h}=161.19\text{ t}$$

$$F_{AE}=SFOC \cdot MCR \cdot P \cdot 24=211\,\frac{g}{kWh} \cdot 0.3 \cdot 8{,}500\text{ kW} \cdot 24\text{h}=12.91\text{ t}$$

- **Bulk carrier**

$$F_{ME}=SFOC \cdot MCR \cdot P \cdot 24=177\,\frac{g}{kWh} \cdot 0.8 \cdot 7{,}800\text{ kW} \cdot 24\text{h}=26.51\text{ t}$$

$$F_{AE}=SFOC \cdot MCR \cdot P \cdot 24=211\,\frac{g}{kWh} \cdot 0.3 \cdot 2{,}040\text{ kW} \cdot 24\text{h}=14.69\text{ t}$$

- **Oil tanker**

$$F_{ME}=SFOC \cdot MCR \cdot P \cdot 24=177\,\frac{g}{kWh} \cdot 0.8 \cdot 15{,}310\text{ kW} \cdot 24\text{h}=52.09\text{ t}$$

$$F_{AE}=SFOC \cdot MCR \cdot P \cdot 24=211\,\frac{g}{kWh} \cdot 0.3 \cdot 1{,}370\text{ kW} \cdot 24\text{h}=2.08\text{ t}$$

- **Car carrier**

$$F_{ME}=SFOC \cdot MCR \cdot P \cdot 24=177\,\frac{g}{kWh} \cdot 0.8 \cdot 16{,}800\text{ kW} \cdot 24\text{h}=57.09\text{ t}$$

$$F_{AE}=SFOC \cdot MCR \cdot P \cdot 24=211\,\frac{g}{kWh} \cdot 0.3 \cdot 5{,}800\text{ kW} \cdot 24\text{h}=8.81\text{ t}$$

(2) Fuel consumption per voyage at design speed (t): $F_{ijk}=\left[MF_k \cdot \left(\frac{s_{1k}}{s_{0k}}\right)^3+AF_k\right] \cdot \frac{d_{ij}}{24 s_{1k}}$ [5]

- **Containership**

$$F=\left[161.19 \cdot \left(\frac{24}{24}\right)^3+12.91\right] \cdot \frac{5{,}230}{24 \cdot 24}=1580.80\text{ t}$$

- **Oil tanker**

$$F=\left[52.09 \cdot \left(\frac{15}{15}\right)^3+2.08\right] \cdot \frac{6{,}593}{24 \cdot 15}=992.06\text{ t}$$

- **Bulk carrier**

$$F=\left[26.51 \cdot \left(\frac{16}{16}\right)^3+14.69\right] \cdot \frac{1{,}391}{24 \cdot 16}=149.24\text{ t}$$

- **Car carrier**

$$F=\left[57.09 \cdot \left(\frac{20}{20}\right)^3+8.81\right] \cdot \frac{600}{24 \cdot 20}=82.38\text{ t}$$

(3) CO_2 emissions at design speed (t): $CO_2=3.17\sum_{i,j,k} F_{i,j,k}$ [7]

- **Containership**

$$CO_2=3.17\sum_{i,j,k} F_{i,j,k}=3.17 \cdot 1580.80=5{,}011.14\text{ t}$$

- **Oil tanker**

$$CO_2=3.17\sum_{i,j,k} F_{i,j,k}=3.17 \cdot 992.06=3{,}144.83\text{ t}$$

- **Bulk carrier**

$$CO_2=3.17\sum_{i,j,k}F_{i,j,k}=3.17\cdot 149.24=473.09\ t$$

- **Car carrier**

$$CO_2=3.17\sum_{i,j,k}F_{i,j,k}=3.17\cdot 82.38=261.45\ t$$

Once the carbon emissions at design speed are got, the fuel consumption at different slow steaming speeds must be computed.

(4) Main and auxiliary engines' fuel consumption per day at slow steaming (t):

$$F = SFOC \cdot MCR \cdot P \cdot 24 \quad [6]$$

Slow steaming (10%)

- **Containership**

$$F_{ME}=SFOC\cdot MCR\cdot P\cdot 24=180\frac{g}{kWh}\cdot 0.65\cdot 47{,}430\ kW\cdot 24h=133.18\ t$$

$$F_{AE}=SFOC\cdot MCR\cdot P\cdot 24=211\frac{g}{kWh}\cdot 0.3\cdot 8{,}500\ kW\cdot 24h=12.91\ t$$

- **Bulk carrier**

$$F_{ME}=SFOC\cdot MCR\cdot P\cdot 24=180\frac{g}{kWh}\cdot 0.65\cdot 7{,}800\ kW\cdot 24h=21.90\ t$$

$$F_{AE}=SFOC\cdot MCR\cdot P\cdot 24=211\frac{g}{kWh}\cdot 0.3\cdot 2{,}040\ kW\cdot 24h=14.69\ t$$

- **Oil tanker**

$$F_{ME}=SFOC\cdot MCR\cdot P\cdot 24=180\frac{g}{kWh}\cdot 0.65\cdot 15{,}310\ kW\cdot 24h=42.99\ t$$

$$F_{AE}=SFOC\cdot MCR\cdot P\cdot 24=211\frac{g}{kWh}\cdot 0.3\cdot 1{,}370\ kW\cdot 24h=2.08\ t$$

- **Car carrier**

$$F_{ME}=SFOC\cdot MCR\cdot P\cdot 24=180\frac{g}{kWh}\cdot 0.65\cdot 16{,}800\ kW\cdot 24h=47.17\ t$$

$$F_{AE}=SFOC\cdot MCR\cdot P\cdot 24=211\frac{g}{kWh}\cdot 0.3\cdot 5{,}800\ kW\cdot 24h=8.81\ t$$

Slow steaming (15%)

- **Containership**

$$F_{ME}=SFOC\cdot MCR\cdot P\cdot 24=182\frac{g}{kWh}\cdot 0.6\cdot 47{,}430\ kW\cdot 24h=124.30\ t$$

$$F_{AE}=SFOC\cdot MCR\cdot P\cdot 24=211\frac{g}{kWh}\cdot 0.3\cdot 8{,}500\ kW\cdot 24h=12.91\ t$$

- **Bulk carrier**

$$F_{ME}=SFOC\cdot MCR\cdot P\cdot 24=182\frac{g}{kWh}\cdot 0.6\cdot 7{,}800\ kW\cdot 24h=20.44\ t$$

$$F_{AE}=SFOC\cdot MCR\cdot P\cdot 24=211\frac{g}{kWh}\cdot 0.3\cdot 2{,}040\ kW\cdot 24h=14.69\ t$$

- **Oil tanker**

$F_{ME}=SFOC\cdot MCR\cdot P\cdot 24=182\,\frac{g}{kWh}\cdot 0.6\cdot 15{,}310\ kW\cdot 24h=40.12\ t$

$F_{AE}=SFOC\cdot MCR\cdot P\cdot 24=211\,\frac{g}{kWh}\cdot 0.3\cdot 1{,}370\ kW\cdot 24h=2.08\ t$

- **Car carrier**

$F_{ME}=SFOC\cdot MCR\cdot P\cdot 24=182\,\frac{g}{kWh}\cdot 0.6\cdot 16{,}800\ kW\cdot 24h=44.03\ t$

$F_{AE}=SFOC\cdot MCR\cdot P\cdot 24=211\,\frac{g}{kWh}\cdot 0.3\cdot 5{,}800\ kW\cdot 24h=8.81\ t$

Slow steaming (20%)

- **Containership**

$F_{ME}=SFOC\cdot MCR\cdot P\cdot 24=185\,\frac{g}{kWh}\cdot 0.55\cdot 47{,}430\ kW\cdot 24h=115.82\ t$

$F_{AE}=SFOC\cdot MCR\cdot P\cdot 24=211\,\frac{g}{kWh}\cdot 0.3\cdot 8{,}500\ kW\cdot 24h=12.91\ t$

- **Bulk carrier**

$F_{ME}=SFOC\cdot MCR\cdot P\cdot 24=185\,\frac{g}{kWh}\cdot 0.55\cdot 7{,}800\ kW\cdot 24h=19.05\ t$

$F_{AE}=SFOC\cdot MCR\cdot P\cdot 24=211\,\frac{g}{kWh}\cdot 0.3\cdot 2{,}040\ kW\cdot 24h=14.69\ t$

- **Oil tanker**

$F_{ME}=SFOC\cdot MCR\cdot P\cdot 24=185\,\frac{g}{kWh}\cdot 0.55\cdot 15{,}310\ kW\cdot 24h=37.39\ t$

$F_{AE}=SFOC\cdot MCR\cdot P\cdot 24=211\,\frac{g}{kWh}\cdot 0.3\cdot 1{,}370\ kW\cdot 24h=2.08\ t$

- **Car carrier**

$F_{ME}=SFOC\cdot MCR\cdot P\cdot 24=185\,\frac{g}{kWh}\cdot 0.55\cdot 16{,}800\ kW\cdot 24h=41.03\ t$

$F_{AE}=SFOC\cdot MCR\cdot P\cdot 24=211\,\frac{g}{kWh}\cdot 0.3\cdot 5{,}800\ kW\cdot 24h=8.81\ t$

(5) Fuel consumption per voyage at slow steaming speed (t):

$$F_{ijk}=\left[MF_k\cdot\left(\frac{s_{1k}}{s_{0k}}\right)^3+AF_k\right]\cdot\frac{d_{ij}}{24s_{1k}}\quad [5]$$

Slow steaming (10%)

- **Containership**

$F=\left[133.18\cdot\left(\frac{21.6}{24}\right)^3+12.91\right]\cdot\frac{5{,}230}{24\cdot 21.6}=1109.74\ t$

- **Oil tanker**

$F=\left[42.99\cdot\left(\frac{13.5}{15}\right)^3+2.08\right]\cdot\frac{6{,}593}{24\cdot 13.5}=680.05\ t$

- **Bulk carrier**

$$F=\left[21.90\cdot\left(\frac{14.4}{16}\right)^3+14.69\right]\cdot\frac{1,391}{24\cdot 14.4}=123.38\ t$$

- **Car carrier**

$$F=\left[47.17\cdot\left(\frac{18}{20}\right)^3+8.81\right]\cdot\frac{600}{24\cdot 18}=60.00\ t$$

Slow steaming (15%)

- **Containership**

$$F=\left[124.30\cdot\left(\frac{20.4}{24}\right)^3+12.91\right]\cdot\frac{5,230}{24\cdot 20.4}=953.34\ t$$

- **Oil tanker**

$$F=\left[40.12\cdot\left(\frac{12.75}{15}\right)^3+2.08\right]\cdot\frac{6,593}{24\cdot 12.75}=575.67\ t$$

- **Bulk carrier**

$$F=\left[20.44\cdot\left(\frac{13.6}{16}\right)^3+14.69\right]\cdot\frac{1,391}{24\cdot 13.6}=116.10\ t$$

- **Car carrier**

$$F=\left[44.03\cdot\left(\frac{17}{20}\right)^3+8.81\right]\cdot\frac{600}{24\cdot 17}=52.72\ t$$

Slow steaming (20%)

- **Containership**

$$F=\left[115.82\cdot\left(\frac{19.2}{24}\right)^3+12.91\right]\cdot\frac{5,230}{24\cdot 19.2}=819.57\ t$$

- **Oil tanker**

$$F=\left[37.39\cdot\left(\frac{12}{15}\right)^3+2.08\right]\cdot\frac{6,593}{24\cdot 12}=485.86\ t$$

- **Bulk carrier**

$$F=\left[19.05\cdot\left(\frac{12.8}{16}\right)^3+14.69\right]\cdot\frac{1,391}{24\cdot 12.8}=110.68\ t$$

- **Car carrier**

$$F=\left[41.03\cdot\left(\frac{16}{20}\right)^3+8.81\right]\cdot\frac{600}{24\cdot 16}=46.59\ t$$

Next, the corresponding CO_2 emissions to each speed reduction rate must be calculated in order to figure out the environmental impact of the slow steaming, comparing the preliminary CO_2 release at design speed and the CO_2 quantities computed in point (6).

(6) CO_2 emissions at slow steaming speed (t): $CO_2=3.17\sum_{i,j,k}F_{i,j,k}$ [7]

Slow steaming (10%)

- **Containership**

$$CO_2=3.17\sum_{i,j,k}F_{i,j,k}=3.17\cdot 1,109.74=3517,88\ t$$

- **Oil tanker**

$$CO_2=3.17\sum_{i,j,k}F_{i,j,k}=3.17\cdot 680.05=2,155.76\ t$$

- **Bulk carrier**

$$CO_2=3.17\sum_{i,j,k}F_{i,j,k}=3.17\cdot 123.38=391.11\ t$$

- **Car carrier**

$$CO_2=3.17\sum_{i,j,k}F_{i,j,k}=3.17\cdot 60,00=190.2\ t$$

Slow steaming (15%)

- **Containership**

$$CO_2=3.17\sum_{i,j,k}F_{i,j,k}=3.17\cdot 953.34=3,022.09\ t$$

Oil tanker

$$CO_2=3.17\sum_{i,j,k}F_{i,j,k}=3.17\cdot 575.67=1,824.87\ t$$

- **Bulk carrier**

$$CO_2=3.17\sum_{i,j,k} F_{i,j,k}=3.17\cdot 116.10=368.04\ t$$

- **Car carrier**

$$CO_2=3.17\sum_{i,j,k} F_{i,j,k}=3.17\cdot 52.72=167.12\ t$$

Slow steaming (20%)

- **Containership**

$$CO_2=3.17\sum_{i,j,k} F_{i,j,k}=3.17\cdot 819.57=2{,}598.04\ t$$

- **Oil tanker**

$$CO_2=3.17\sum_{i,j,k} F_{i,j,k}=3.17\cdot 485.86=1{,}540.18\ t$$

- **Bulk carrier**

$$CO_2=3.17\sum_{i,j,k} F_{i,j,k}=3.17\cdot 110.68=350.86\ t$$

- **Car carrier**

$$CO_2=3.17\sum_{i,j,k} F_{i,j,k}=3.17\cdot 46.59=147.69\ t$$

Finally, we calculate the CO_2 emission reduction after applying different slow steaming rates.

(7) Fuel and CO_2 emissions reduction per slow steaming rate and per voyage (t):

$$CO_2 \text{ emission reduction} = CO_2 \text{ at design speed} - CO_2 \text{ at slow steaming} \quad [9]$$

Slow steaming (10%)

- **Containership**

CO_2 emission reduction =5,011.14 – 3,517.88 = 1,493.26 t

- **Bulk carrier**

CO_2 emission reduction =473.09 – 391.11 = 81,98 t

- **Oil tanker**

CO_2 emission reduction =3,114.83 – 2,155.76 = 959,07 t

- **Car carrier**

CO_2 emission reduction =261.45 – 190.2 = 71,25 t

Slow steaming (15%)

- **Containership**

CO_2 emission reduction =5,011.14 – 3,022.09 = 1,989.05 t

- **Bulk carrier**

CO_2 emission reduction =473.09 – 368.04 = 105,05 t

- **Oil tanker**

CO_2 emission reduction =3,114.83 – 1,824.87 = 1,289.96 t

- **Car carrier**

CO_2 emission reduction =261.45 – 167.12 = 94,33 t

<u>Slow steaming (20%)</u>

- **Containership**

CO_2 emission reduction =5,011.14 – 2,598.04 = 2,413.10 t

- **Bulk carrier**

CO_2 emission reduction =473.09 – 350.86 = 122,23 t

- **Oil tanker**

CO_2 emission reduction =3,114.83 – 1,540.18 = 1,574.65 t

- **Car carrier**

CO_2 emission reduction =261.45 – 147.69 = 113.76 t

2. ECONOMIC IMPACT CALCULATION

The economic impact calculation consists just on multiplying the fuel savings in tonnes by the current price of HFO, which at the time of this dissertation has a value of $ 468.5 per tonne. The following formula will be applied for such purpose:

$$Savings=(F_{Normal\ speed}-F_{Slow\ steaming\ speed})tonnes \cdot fuel\ price \frac{\$}{tonne} \quad [8]$$

<u>Slow steaming (10%)</u>

- **Containership**

Savings = (1,580.80 – 1,109.74) · 468.5 = $ 220,691.61

- **Bulk carrier**

Savings = (149.24 – 123.38) · 468.5 = $ 12,115.41

- **Oil tanker**

Savings = (992.06 – 680.05) · 468.5 = $146,176.685

- **Car carrier**

Savings = (82.38 – 60.00) · 468.5 = $10,485.03

<u>Slow steaming (15%)</u>

- **Containership**

Savings = (1,580.80 – 953.34) · 468.5 = $ 293,965.01

- **Bulk carrier**

Savings = (149.24 – 116.10) · 468.5 = $ 15,526.09

- **Oil tanker**

Savings = (992.06 – 575.67) · 468.5 = $ 195,078.71

- **Car carrier**

Savings = (82.38 – 52.72) · 468.5 = $ 13,895.71

<u>Slow steaming (20%)</u>

- **Containership**

Savings = (1,580.80 – 819.57) · 468.5 = $ 356,636.25

- **Bulk carrier**

Savings = (149.24 – 110.68) · 468.5 = $ 18,065.36

- **Oil tanker**

Savings = (992.06 – 485.86) · 468.5 = $ 237,154.7

- **Car carrier**

Savings = (82.38 – 46.59) · 468.5 = $ 16,767.61

ANNEX 2

THE INITIAL IMO STRATEGY ON REDUCTION OF GHG EMISSIONS FROM SHIPS MEPC.304(72)

Note by the International Maritime Organization to the UNFCCC Talanoa Dialogue

ADOPTION OF THE INITIAL IMO STRATEGY ON REDUCTION OF GHG EMISSIONS FROM SHIPS AND EXISTING IMO ACTIVITY RELATED TO REDUCING GHG EMISSIONS IN THE SHIPPING SECTOR

SUMMARY

The International Maritime Organization's (IMO) Marine Environment Protection Committee (MEPC) has for some time now been considering actions to address greenhouse gas (GHG) emissions from ships engaged in international trade. It met for its seventy-second session (MEPC 72) from 9 to 13 April 2018, at IMO Headquarters in London, with the participation of more than 100 Member States, three associate members, two United Nations bodies including UNFCCC, eight intergovernmental organizations and 47 non-governmental organizations.

During this meeting, the Committee adopted resolution MEPC.304(72) on *Initial IMO Strategy on reduction of GHG emissions from ships.* The vision set out in the text of this important Initial Strategy confirms IMO's commitment to reducing GHG emissions from international shipping and, as a matter of urgency, to phasing them out as soon as possible in this century.

The Initial Strategy, and its adopting resolution, is set out in annex 1 to this submission. This Initial Strategy is the latest action taken by the IMO to address GHG emissions from ships and existing activity related to reducing GHG emissions from international shipping is set out in annex 2 to this submission.

Context

1 International shipping plays an essential role in the facilitation of world trade as the most cost-effective and energy-efficient mode of mass cargo transport, making a vital contribution to international trade and being a key pillar of the development of a sustainable global economy.

2 The International Maritime Organization (IMO) was established by Governments as a specialized agency under the United Nations to provide the machinery for intergovernmental cooperation in the field of regulation of ships engaged in international trade. IMO is responsible for the global regulation of all aspects of international shipping and has a key role in ensuring that lives at sea are not put at risk, including security of shipping, and that the environment is not polluted by ships' operations – as summed up in IMO's mission statement: **Safe, secure and efficient shipping on clean oceans**.

3 Following the suggestion during MEPC 72, supported by many delegations, for IMO to participate in the Talanoa Dialogue, the Secretariat was invited to consider submission of relevant information, including the Initial Strategy, to the Talanoa Dialogue portal.

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ANNEX 1

RESOLUTION MEPC.304(72)

Adopted on 13 April 2018

INITIAL IMO STRATEGY ON REDUCTION OF GHG EMISSIONS FROM SHIPS

THE MARINE ENVIRONMENT PROTECTION COMMITTEE

RECALLING Article 38(e) of the Convention on the International Maritime Organization (the Organization) concerning the functions of the Marine Environment Protection Committee (the Committee) conferred upon it by international conventions for the prevention and control of marine pollution from ships,

ACKNOWLEDGING that work to address greenhouse gas (GHG) emissions from ships has been undertaken by the Organization continuously since 1997, in particular, through adopting global mandatory technical and operational energy efficiency measures for ships under MARPOL Annex VI,

ACKNOWLEDGING ALSO the decision of the thirtieth session of the Assembly in December 2017 that adopted for the Organization a strategic direction entitled "Respond to Climate Change",

RECALLING the United Nations 2030 Agenda for Sustainable Development,

1 ADOPTS the *Initial IMO Strategy on reduction of GHG emissions from ships* (hereinafter the Initial Strategy) as set out in the annex to the present resolution;

2 INVITES the Secretary-General of the Organization to make adequate provisions in the Integrated Technical Cooperation Programme (ITCP) to support relevant follow up actions of the Initial Strategy that may be further decided by the Committee and undertaken by developing countries, particularly Least Developed Countries (LDCs) and Small Island Developing States (SIDS);

3 AGREES to keep the Initial Strategy under review, with a view to adoption of a Revised IMO Strategy on reduction of GHG emissions from ships in 2023.

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Annex

INITIAL IMO STRATEGY ON REDUCTION OF GHG EMISSIONS FROM SHIPS

Contents

1 INTRODUCTION

1.1 The International Maritime Organization (IMO) is the United Nations specialized agency responsible for safe, secure and efficient shipping and the prevention of pollution from ships.

1.2 The Strategy represents the continuation of work of IMO as the appropriate international body to address greenhouse gas (GHG) emissions from international shipping. This work includes Assembly resolution A.963(23) on *IMO policies and practices related to the reduction of greenhouse gas emissions from ships*, adopted on 5 December 2003, urging the Marine Environment Protection Committee (MEPC) to identify and develop the mechanisms needed to achieve the limitation or reduction of GHG emissions from international shipping.

1.3 In response to the Assembly's request, work to address GHG emissions from ships has been undertaken, including inter alia:

.1 MEPC 62 (July 2011) adopted resolution MEPC.203(62) on *Inclusion of regulations on energy efficiency for ships in MARPOL Annex VI* introducing mandatory technical (EEDI) and operational (SEEMP) measures for the energy efficiency of ships. To date more than 2,700 new ships have been certified to the energy efficiency design requirement;

.2 MEPC 65 (May 2013) adopted resolution MEPC.229(65) on *Promotion of technical co-operation and transfer of technology relating to the improvement of energy efficiency of ships*, which, among other things, requests the IMO, through its various programmes (ITCP [1], GloMEEP project [2], MTCC network [3], etc.), to provide technical assistance to Member States to enable cooperation in the transfer of energy efficient technologies, in particular to developing countries; and

.3 MEPC 70 (October 2016) adopted, by resolution MEPC.278(70), amendments to MARPOL Annex VI to introduce the d*ata collection system for fuel oil consumption of ships*, containing mandatory requirements for ships to record and report their fuel oil consumption. Ships of 5,000 gross tonnage and above (representing approximately 85% of the total CO_2 emissions from international shipping) are required to collect consumption data for each type of fuel oil they use, as well as other, additional, specified data including proxies for "transport work".

1.4 This Initial Strategy is the first milestone set out in the *Roadmap for developing a comprehensive IMO Strategy on reduction of GHG emissions from ships* (the Roadmap) approved at MEPC 70. The Roadmap identifies that a revised Strategy is to be adopted in 2023.

Context

1.5 The Initial Strategy falls within a broader context including:

.1 other existing instruments related to the law of the sea, including UNCLOS, and to climate change, including the UNFCCC and its related legal instruments, including the Paris Agreement;

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1 Integrated Technical Cooperation Programme http://www.imo.org
2 Global Maritime Energy Efficiency Partnerships http://glomeep.imo.org/
3 Global Maritime Technology Cooperation Centres Network http://gmn.imo.org/

.2 the leading role of the Organization for the development, adoption and assistance in implementation of environmental regulations applicable to international shipping;

.3 the decision of the thirtieth session of the Assembly in December 2017 that adopted for the Organization a Strategic Direction entitled "Respond to climate change"; and

.4 the United Nations 2030 Agenda for Sustainable Development.

Emissions and emission scenarios

1.6 The *Third IMO GHG Study 2014* has estimated that GHG emissions from international shipping in 2012 accounted for some 2.2% of anthropogenic CO_2 emissions and that such emissions could grow by between 50% and 250% by 2050. Future IMO GHG studies would help reduce the uncertainties associated with these emission estimates and scenarios.

Objectives of the Initial Strategy

1.7 The Initial Strategy is aimed at:

.1 enhancing IMO's contribution to global efforts by addressing GHG emissions from international shipping. International efforts in addressing GHG emissions include the Paris Agreement and its goals and the United Nations 2030 Agenda for Sustainable Development and its SDG 13: *"Take urgent action to combat climate change and its impacts"*;

.2 identifying actions to be implemented by the international shipping sector, as appropriate, while addressing impacts on States and recognizing the critical role of international shipping in supporting the continued development of global trade and maritime transport services; and

.3 identifying actions and measures, as appropriate, to help achieve the above objectives, including incentives for research and development and monitoring of GHG emissions from international shipping.

2 VISION

IMO remains committed to reducing GHG emissions from international shipping and, as a matter of urgency, aims to phase them out as soon as possible in this century.

3 LEVELS OF AMBITION AND GUIDING PRINCIPLES

Levels of ambition

3.1 Subject to amendment depending on reviews to be conducted by the Organization, the Initial Strategy identifies levels of ambition for the international shipping sector noting that technological innovation and the global introduction of alternative fuels and/or energy sources for international shipping will be integral to achieve the overall ambition. The reviews should take into account updated emission estimates, emissions reduction options for international shipping, and the reports of the Intergovernmental Panel on Climate Change (IPCC), as relevant. Levels of ambition directing the Initial Strategy are as follows:

.1 carbon intensity of the ship to decline through implementation of further phases of the energy efficiency design index (EEDI) for new ships

to review with the aim to strengthen the energy efficiency design requirements for ships with the percentage improvement for each phase to be determined for each ship type, as appropriate;

.2 carbon intensity of international shipping to decline

to reduce CO_2 emissions per transport work, as an average across international shipping, by at least 40% by 2030, pursuing efforts towards 70% by 2050, compared to 2008; and

.3 GHG emissions from international shipping to peak and decline

to peak GHG emissions from international shipping as soon as possible and to reduce the total annual GHG emissions by at least 50% by 2050 compared to 2008 whilst pursuing efforts towards phasing them out as called for in the Vision as a point on a pathway of CO_2 emissions reduction consistent with the Paris Agreement temperature goals.

Guiding principles

3.2 The principles guiding the Initial Strategy include:

.1 the need to be cognizant of the principles enshrined in instruments already developed, such as:

.1 the principle of non-discrimination and the principle of no more favourable treatment, enshrined in MARPOL and other IMO conventions; and

.2 the principle of common but differentiated responsibilities and respective capabilities, in the light of different national circumstances, enshrined in the UNFCCC, its Kyoto Protocol and the Paris Agreement;

.2 the requirement for all ships to give full and complete effect, regardless of flag, to implementing mandatory measures to ensure the effective implementation of this strategy;

.3 the need to consider the impacts of measures on States, including developing countries, in particular, on LDCs and SIDS as noted by MEPC 68 (MEPC 68/21, paragraphs 4.18 to 4.19) and their specific emerging needs, as recognized in the Organization's Strategic Plan (resolution A.1110(30)); and

.4 the need for evidence-based decision-making balanced with the precautionary approach as set out in resolution MEPC.67(37).

4 LIST OF CANDIDATE SHORT-, MID- AND LONG-TERM FURTHER MEASURES WITH POSSIBLE TIMELINES AND THEIR IMPACTS ON STATES

Timelines

4.1 Candidate measures set out in this Initial Strategy should be consistent with the following timelines:

.1 possible short-term measures could be measures finalized and agreed by the Committee between 2018 and 2023. Dates of entry into force and when the measure can effectively start to reduce GHG emissions would be defined for each measure individually;

.2 possible mid-term measures could be measures finalized and agreed by the Committee between 2023 and 2030. Dates of entry into force and when the measure can effectively start to reduce GHG emissions would be defined for each measure individually; and

.3 possible long-term measures could be measures finalized and agreed by the Committee beyond 2030. Dates of entry into force and when the measure can effectively start to reduce GHG emissions would be defined for each measure individually.

4.2 In aiming for early action, the timeline for short-term measures should prioritize potential early measures that the Organization could develop, while recognizing those already adopted, including MARPOL Annex VI requirements relevant for climate change, with a view to achieve further reduction of GHG emissions from international shipping before 2023.

4.3 Certain mid- and long-term measures will require work to commence prior to 2023.

4.4 These timelines should be revised as appropriate as additional information becomes available.

4.5 Short-, mid- and long-term further measures to be included in the Revised IMO GHG Strategy should be accompanied by implementation schedules.

4.6 The list of candidate measures is non-exhaustive and is without prejudice to measures the Organization may further consider and adopt.

Candidate short-term measures

4.7 Measures can be categorized as those the effect of which is to directly reduce GHG emissions from ships and those which support action to reduce GHG emissions from ships. All the following candidate measures[4] represent possible short-term further action of the Organization on matters related to the reduction of GHG emissions from ships:

.1 further improvement of the existing energy efficiency framework with a focus on EEDI and SEEMP, taking into account the outcome of the review of EEDI regulations;

[4] The Initial Strategy is subject to revision based on fuel oil consumption data collected during 2019-2021 and does not prejudge any specific further measures that may be implemented in Phase 3 of the three-step approach.

.2 develop technical and operational energy efficiency measures for both new and existing ships, including consideration of indicators in line with the three-step approach that can be utilized to indicate and enhance the energy efficiency performance of shipping, e.g. Annual Efficiency Ratio (AER), Energy Efficiency per Service Hour (EESH), Individual Ship Performance Indicator (ISPI), Fuel Oil Reduction Strategy (FORS);

.3 establishment of an Existing Fleet Improvement Programme;

.4 consider and analyse the use of speed optimization and speed reduction as a measure, taking into account safety issues, distance travelled, distortion of the market or to trade and that such measure does not impact on shipping's capability to serve remote geographic areas;

.5 consider and analyse measures to address emissions of methane and further enhance measures to address emissions of Volatile Organic Compounds;

.6 encourage the development and update of national action plans to develop policies and strategies to address GHG emissions from international shipping in accordance with guidelines to be developed by the Organization, taking into account the need to avoid regional or unilateral measures;

.7 continue and enhance technical cooperation and capacity-building activities under the ITCP;

.8 consider and analyse measures to encourage port developments and activities globally to facilitate reduction of GHG emissions from shipping, including provision of ship and shore-side/on-shore power supply from renewable sources, infrastructure to support supply of alternative low- carbon and zero-carbon fuels, and to further optimize the logistic chain and its planning, including ports;

.9 initiate research and development activities addressing marine propulsion, alternative low-carbon and zero-carbon fuels, and innovative technologies to further enhance the energy efficiency of ships and establish an International Maritime Research Board to coordinate and oversee these R&D efforts;

.10 incentives for first movers to develop and take up new technologies;

.11 develop robust lifecycle GHG/carbon intensity guidelines for all types of fuels, in order to prepare for an implementation programme for effective uptake of alternative low-carbon and zero-carbon fuels;

.12 actively promote the work of the Organization to the international community, in particular, to highlight that the Organization, since the 1990's, has developed and adopted technical and operational measures that have consistently provided a reduction of air emissions from ships, and that measures could support the Sustainable Development Goals, including SDG 13 on Climate Change; and

.13 undertake additional GHG emission studies and consider other studies to inform policy decisions, including the updating of Marginal Abatement Cost Curves and alternative low-carbon and zero-carbon fuels.

Candidate mid-term measures

4.8 Measures can be categorized as those the effect of which is to directly reduce GHG emissions from ships and those which support action to reduce GHG emissions from ships. All the following candidate measures represent possible mid-term further action of the Organization on matters related to the reduction of GHG emissions from ships:

.1 implementation programme for the effective uptake of alternative low- carbon and zero-carbon fuels, including update of national actions plans to specifically consider such fuels;

.2 operational energy efficiency measures for both new and existing ships including indicators in line with three-step approach that can be utilized to indicate and enhance the energy efficiency performance of ships;

.3 new/innovative emission reduction mechanism(s), possibly including Market-based Measures (MBMs), to incentivize GHG emission reduction;

.4 further continue and enhance technical cooperation and capacity-building activities such as under the ITCP; and

.5 development of a feedback mechanism to enable lessons learned on implementation of measures to be collated and shared through a possible information exchange on best practice.

Candidate long-term measures

4.9 All the following candidate measures represent possible long-term further action of the Organization on matters related to the reduction of GHG emissions from ships:

.1 pursue the development and provision of zero-carbon or fossil-free fuels to enable the shipping sector to assess and consider decarbonization in the second half of the century; and

.2 encourage and facilitate the general adoption of other possible new/innovative emission reduction mechanism(s).

Impacts on States

4.10 The impacts on States of a measure should be assessed and taken into account as appropriate before adoption of the measure. Particular attention should be paid to the needs of developing countries, especially small island developing States (SIDS) and least developed countries (LDCs).

4.11 When assessing impacts on States the impact of a measure should be considered, as appropriate, inter alia, in the following terms:

.1 geographic remoteness of and connectivity to main markets;

.2 cargo value and type;

.3 transport dependency;

.4 transport costs;

.5 food security;

.6 disaster response;

.7 cost-effectiveness; and

.8 socio-economic progress and development.

4.12 The specification for and agreement on the procedure for assessing and taking into account the impacts of measures related to international shipping on States should be undertaken as a matter of urgency as part of the follow-up actions.

4.13 Disproportionately negative impacts should be assessed and addressed, as appropriate.

5 BARRIERS AND SUPPORTIVE MEASURES; CAPACITY-BUILDING AND TECHNICAL COOPERATION; R&D

5.1 The Committee recognizes that developing countries, in particular the LDCs and SIDS, have special needs with regard to capacity building and technical cooperation.

5.2 The Committee acknowledges that development and making globally available new energy sources that are safe for ships could be a specific barrier to the implementation of possible measures.

5.3 The Committee could assist the efforts to promote low-carbon technologies by facilitating public-private partnerships and information exchange.

5.4 The Committee should continue to provide mechanisms for facilitating information sharing, technology transfer, capacity-building and technical cooperation, taking into account resolution MEPC.229(65) on *Promotion of technical co-operation and transfer of technology relating to the improvement of energy efficiency of ships*.

5.5 The Organization is requested to assess periodically the provision of financial and technological resources and capacity-building to implement the Strategy through the ITCP and other initiatives including the GloMEEP project and the MTCC network.

6 FOLLOW-UP ACTIONS TOWARDS THE DEVELOPMENT OF THE REVISED STRATEGY

6.1 A programme of follow-up actions of the Initial Strategy should be developed.

6.2 The key stages for the adoption of a Revised IMO GHG Strategy in 2023 as set out in the Roadmap, are as follows:

Spring 2018 (MEPC 72)	Adoption of the Initial Strategy[5], including, inter alia, a list of candidate short-, mid- and long-term further measures with possible timelines, to be revised as appropriate as additional information becomes available
January 2019	Start of Phase 1: Data collection (Ships to collect data)
Spring 2019 (MEPC 74)	Initiation of Fourth IMO GHG Study using data from 2012-2018
Summer 2020	Data from 2019 to be reported to IMO
Autumn 2020 (MEPC 76)	Start of Phase 2: data analysis (no later than autumn 2020) Publication of Fourth IMO GHG Study for consideration by MEPC 76
Spring 2021 (MEPC 77)	Secretariat report summarizing the 2019 data pursuant to regulation 22A.10 Initiation of work on adjustments on Initial IMO Strategy, based on Data Collection System (DCS) data
Summer 2021	Data for 2020 to be reported to IMO
Spring 2022 (MEPC 78)	Phase 3: Decision step Secretariat report summarizing the 2020 data pursuant to regulation 22A.10
Summer 2022	Data for 2021 to be reported to IMO
Spring 2023 (MEPC 80)	Secretariat report summarizing the 2021 data pursuant to regulation 22A.10 Adoption of Revised IMO Strategy, including short-, mid- and long-term further measure(s), as required, with implementation schedules

6.3 The Marginal Abatement Cost Curve (MACC) for each measure, as appropriate, should be ascertained and updated, and then evaluated on a regular basis.

7 PERIODIC REVIEW OF THE STRATEGY

7.1 The Revised Strategy is to be adopted in Spring 2023.

7.2 The Revised Strategy should be subject to a review five years after its final adoption.

7.3 The Committee should undertake the review including defining the scope of the review and its terms of reference.

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5 Initial IMO Strategy is subject to revision based on DCS data during 2019-2021 and does not prejudge any specific further measures that may be implemented in Phase 3 of the three-step approach.

ANNEX 2

EXISTING IMO ACTIVITY RELATED TO REDUCING GHG EMISSIONS IN THE SHIPPING SECTOR

INTRODUCTION

1 The International Maritime Organization (IMO) was established by Governments as a specialized agency under the United Nations to provide the machinery for intergovernmental cooperation in the field of regulation of ships engaged in international trade. IMO is responsible for the global regulation of all aspects of international shipping and has a key role in ensuring that lives at sea are not put at risk, including security of shipping, and that the environment is not polluted by ships' operations – as summed up in the IMO's mission statement: to promote safe, secure, environmentally sound, efficient and sustainable shipping through cooperation.

2 IMO is the global standard-setting authority for the safety, security and environmental performance of international shipping. Its regulatory framework covers all aspects of technical matters pertaining to the safety of ships and of life at sea, efficiency of navigation, and the prevention and control of marine and air pollution from ships. Following several high profile oil spills, the original focus of IMO's environmental work was on the prevention of marine pollution by oil, resulting in the adoption of the first-ever comprehensive anti-pollution convention, the International Convention for the Prevention of Pollution from Ships (MARPOL) in 1973. This has changed over the last few decades to include a much wider range of measures to prevent marine pollution, and the original MARPOL Convention has been amended to include requirements addressing pollution from chemicals, other harmful substances, garbage, sewage and, under an Annex VI adopted in 1997 by a Protocol to MARPOL, air pollution and control of emissions from ships.

CONTROL OF EMISSIONS FROM SHIPS – MARPOL ANNEX VI: REGULATIONS FOR THE PREVENTION OF AIR POLLUTION FROM SHIPS

3 In November 1991, the IMO Assembly adopted resolution A.719(17) on *Prevention of Air Pollution from Ships,* stating the desire to reduce air pollution from ships by cooperative efforts of Member Governments which may be best achieved by establishing a new annex to MARPOL which would provide rules for restriction and control of emission of harmful substances from ships into the atmosphere.

4 In September 1997, a Conference of Parties to MARPOL adopted the Protocol of 1997 to amend the Convention. The Protocol, which entered into force on 19 May 2005, incorporated in MARPOL a new Annex VI, entitled "Regulations for the prevention of air pollution from ships", with the aim of controlling airborne emissions from ships of sulphur oxides (SO_X), nitrogen oxides (NO_X), ozone-depleting substances (ODS), volatile organic compounds (VOCs) and their contribution to global air pollution and environmental impacts.

5 Eight years after its adoption, but only two months after its entry into force, the Marine Environment Protection Committee (MEPC), at its fifty-third session (MEPC 53 in July 2005), decided that Annex VI should undergo a general revision. The decision was based on new knowledge of the harmful impact that ships' exhaust gases may have on ecosystems and human health and recognized that technological developments would enable significant improvements of the current standards.

6 After three years of intensive work, MEPC 58 (October 2008) unanimously adopted a revised MARPOL Annex VI and the associated Technical Code on control of emissions of nitrogen oxides from marine diesel engines (NO_X Technical Code 2008) for surveying and certifying marine diesel engines, both of which entered into force on 1 July 2010. The revised Annex VI introduced even more stringent limits for the emission of air pollutants from ships, together with phased-in reductions, to be achieved through fuel oil quality and marine diesel engine design or equivalent technologies, in particular for SO_X and particulate matter (PM) and NO_X emissions.

IMO AND THE UNFCCC POLICY FRAMEWORK

7 Prior to the signing in December 1997 of the Kyoto Protocol to the United Nations Framework Convention on Climate Change (UNFCCC), the aforementioned IMO International Air Pollution Conference in September 1997 adopted conference resolution 8 which recognized that CO_2 emissions, being greenhouse gases (GHGs), have an adverse impact on the environment, and noted that UNFCCC had recognized that GHGs also originate from international shipping and contribute to the global inventory of emissions. The resolution invited the MEPC to consider what CO_2 reduction strategies may be feasible in light of the relationship between CO_2 and atmospheric pollutants, especially NO_X, since NO_X emissions may exhibit an inverse relationship to CO_2 reductions.

8 In December 2003, the IMO Assembly adopted resolution A.963(23) on *IMO policies and practices related to the reduction of greenhouse gas emissions from ships* that urged the MEPC to identify and evaluate mechanisms to achieve the limitation or reduction of greenhouse gas emissions from international shipping and keep the matter under review and that, in doing so, it should cooperate with the Conference of the Parties (COP) to the UNFCCC.

9 Article 2.2 of the Kyoto Protocol states that the Parties included in Annex I shall pursue limitation or reduction of emissions of GHGs not controlled by the Montreal Protocol from aviation and marine bunker fuels, working through the International Civil Aviation Organization (ICAO) and IMO, respectively.

10 No reference to IMO (nor ICAO) is made in either the articles of the 2015 Paris Agreement on Climate Change (the Paris Agreement) or the decisions to implement the agreement, including on the pre-2020 ambition (the period between the Kyoto Protocol commitment period ending on 31 December 2020 and the Paris Agreement entering into effect on 1 January 2020).

11 The forty-third session of the Subsidiary Body for Scientific and Technological Advice (SBSTA), held during COP 21 in Paris in December 2015, took note of the information received from and progress reported by the Secretariats of ICAO and IMO on their ongoing work on addressing emissions from fuel used for international aviation and maritime transport respectively, and invited the Secretariats to continue to report at future sessions of SBSTA on relevant work on this issue.

12 IMO reported to SBSTA 45 at COP 22 in Morocco in November 2016 on progress made subsequent to the Paris Agreement, including the adoption of the data collection system for fuel oil consumption of ships and the approval of the *Roadmap for developing a comprehensive IMO strategy on reduction of GHG emissions from ships*.

13 As requested by Assembly resolution A.963(23), and reaffirmed by MEPC 69 (April 2016), the Secretariat shall continue reporting to UNFCCC SBSTA under the agenda item on "Emissions from fuel used for international aviation and maritime transport" and participate in related United Nations system activities.

IMO GREENHOUSE GAS STUDIES

14 The 1997 Air Pollution Conference resolution 8 on *CO_2 emissions from ships* that initiated IMO's work to address GHG emissions from ships invited IMO to undertake a study of CO_2 emissions from ships for the purpose of establishing the amount and relative percentage of such emissions as part of the global inventory of CO_2 emissions. MEPC 63 (March 2012) noted that uncertainty existed in the estimates and projections of emissions from international shipping and agreed that further work should take place to provide the MEPC with reliable and up-to-date information to base its decisions on. MEPC 64 (October 2012) endorsed, in principle, an outline for an update of the GHG emissions estimate, and an expert workshop in Spring 2013 further considered the methodology and assumptions to be used to update the study. To date, three IMO Greenhouse Gas Studies have been published:

.1 the First IMO GHG Study, published in 2000, estimated that international shipping in 1996 contributed about 1.8% of the global total anthropogenic CO_2 emissions;

.2 the Second IMO GHG Study, published in 2009, estimated international shipping emissions in 2007 to be 880 million tonnes, or about 2.7% of the global total anthropogenic CO_2 emissions; and

.3 the Third IMO GHG Study, published in 2014 [6], estimated international shipping emissions in 2012 to be 796 million tonnes, or about 2.2% of the global total anthropogenic CO_2 emissions. The Study also updated the CO_2 estimates for 2007 to 885 million tonnes, or 2.8%.

15 The Third IMO GHG Study 2014 (MEPC 67/INF.3 and Corr.1) employed both top-down and bottom-up (individual ship activity) methods to provide two different and independent analysis tools for estimating emissions from ships. The top-down estimate mainly used data on marine fuel oil (bunker) sales (divided into international, domestic and fishing) from the International Energy Agency (IEA), and is the approach used by the Intergovernmental Panel on Climate Change (IPCC) to calculate CO_2 emissions from international bunkers. However, the top-down method is considered less accurate than the bottom-up method as IEA and the Organization for Economic Co-operation and Development (OECD) identified specific types of error in energy data that involve marine bunkers. The first is allocation or classification error involving imports, exports and marine bunker statistics. The second is country-to-country differences in data quality, specifically related to poor accuracy for international bunkers or stock changes.

16 The bottom-up estimate combined the global fleet technical data from the maritime information provider, IHS Fairplay, with fleet activity data derived from Automatic Identification System (AIS) observations to provide statistics on activity, energy use and emissions for all ships from 2007 to 2012. This approach removed uncertainties attributed to the use of average values and represented a substantial improvement in the resolution of shipping activity, energy demand and emissions data, showing that high-quality inventories of shipping emissions can be produced through the use of quality analysis, such as rigorous testing of bottom-up results against noon reports and Long-range Identification and Tracking (LRIT) and AIS data from a variety of providers, both shore-based and satellite-received data.

17 Although international shipping is already the most energy-efficient mode of mass cargo transportation and carries over 80% of all goods by volume (over 55% in terms of

[6] The Study can be downloaded online: http://www.imo.org/OurWork/Environment/PollutionPrevention/AirPollution/Pages/Greenhouse-Gas-Studies-2014.aspx

freight activity by tonne-mile[7]), a global approach to further enhance its energy efficiency and effective emission control is needed as, depending on future economic and energy developments, the Third IMO GHG Study forecasted a growth in CO_2 emissions for international maritime transport of 50 to 250% in the period up to 2050.

18 Up-to-date emission estimates are considered necessary, in general, to provide a better foundation for future work by IMO to address GHG emissions from international shipping. Ocean transport is fuel-efficient and without these updated figures it would be difficult to provide a meaningful baseline to illustrate the steadily ongoing improvement in fuel efficiency due to improved hull design, more effective diesel engines and propulsion systems and more effective utilization of individual ships resulting from the introduction of mandatory technical and operational measures. Importantly, the 2012 estimate provides a baseline estimate for international shipping emissions prior to the entry into force of regulations on energy efficiency for ships in 2013.

ENERGY EFFICIENCY OF INTERNATIONAL SHIPPING

19 In July 2011, IMO adopted mandatory measures to improve the energy efficiency of international shipping through resolution MEPC.203(62), representing the first-ever mandatory global energy efficiency standard for an international industry sector, the first legally binding instrument to be adopted since the Kyoto Protocol that addresses GHG emissions and the first global mandatory GHG-reduction regime for an international industry sector.

20 The amendments adopted by resolution MEPC.203(62) added a new chapter 4 entitled "Regulations on energy efficiency for ships" to MARPOL Annex VI. This package of technical and operational requirements which apply to ships of 400 GT and above, are known as the Energy Efficiency Design Index (EEDI), applicable to new ships, which sets a minimum energy efficiency level for the work undertaken (e.g. CO_2 emissions per tonne-mile) for different ship types and sizes, and the Ship Energy Efficiency Management Plan (SEEMP), applicable to all ships. These mandatory requirements entered into force on 1 January 2013. The Energy Efficiency Operational Indicator (EEOI) for monitoring operational energy efficiency of ships also remains available for voluntary application.

21 The EEDI requirement aims to increase the energy efficiency of new ships over time. It is a non-prescriptive, performance-based mechanism that leaves the choice of technologies to use in a specific ship design to the industry. As long as the required energy efficiency level is attained, ship designers and builders are free to use the most cost-efficient solutions in complying with the regulations. It is therefore intended to stimulate innovation in, and continued development of, the technical elements influencing the energy efficiency of a ship. By February 2017 more than 2200 new ships have been certified to the energy efficiency design requirements.

22 The EEDI has been developed for the largest and most energy-intensive segments of the world merchant fleet and, following the inclusion of additional ship types, will embrace approximately 85% of emissions from international shipping. EEDI reduction factors are set until 2025 to the extent that ships constructed in 2025 will be required to be at least 30% more energy efficient than those constructed in 2014. The SEEMP establishes a mechanism for operators to improve the energy efficiency of existing ships against business-as-usual operations, in a cost-effective manner and also provides an approach for monitoring ship and fleet efficiency performance over time.

23 All ships of 400 GT and above engaged in international trade are required to implement and maintain a SEEMP that establishes a mechanism for operators to improve the energy efficiency of ships. This should be achieved by monitoring the energy efficiency

7 International Council on Clean Transportation (ICCT), Long-term potential for increased shipping efficiency through the adoption of industry-leading practices, Wang & Lutsey, 2013.

performance of a ship's transportation work, using, for example, the EEOI as a monitoring and/or benchmarking tool and at regular intervals considering new technologies and practices to improve energy efficiency.

24 A study [8] undertaken following the adoption of the mandatory energy efficiency measures indicates that the uptake of SEEMP measures will have a significant effect in the short to medium term, while EEDI measures should have a greater impact in the longer term, as fleet renewal takes place and new technologies are adopted. Estimates suggest that a successful implementation of this energy efficiency framework by 2050 could reduce shipping CO_2 emissions by up to 1.3 gigatonnes per year against the business-as-usual scenario. To put this in context, the Third IMO GHG Study 2014 estimated global CO_2 emissions to be 35.64 gigatonnes in 2012.

25 Four important guidelines have been adopted [9], intended to assist in the implementation of the mandatory regulations on energy efficiency for ships, as follows:

.1 *2014 Guidelines on the method of calculation of the attained Energy Efficiency Design Index (EEDI) for new ships*, *as amended* (resolution MEPC.245(66));

.2 *2016 Guidelines for the development of a Ship Energy Efficiency Management Plan (SEEMP)* (resolution MEPC.282(70));

.3 *2014 Guidelines on survey and certification of the Energy Efficiency Design Index (EEDI), as amended* (resolution MEPC.254(67)); and

.4 *2013 Guidelines for calculation of reference lines for use with the Energy Efficiency Design Index (EEDI)* (resolution MEPC.231(65)).

26 MEPC 65 (May 2013) agreed to include several additional ship types in the EEDI framework and further guidance was agreed, or existing guidance amended, to support the uniform implementation of the energy efficiency regulations. Furthermore, a work plan was endorsed to continue work on the development of the EEDI framework for ship types and sizes and propulsion systems not covered by the current EEDI requirements and to consider guidelines on propulsion power needed to maintain the manoeuvrability of a ship under adverse conditions.

27 MEPC 69 (April 2016) considered an interim report of its correspondence group conducting a review of the status of technological developments relevant to implementing Phase 2 of the EEDI regulations. This review is required by regulation 21.6 of MARPOL Annex VI, with a further review to take place before Phase 3. Following consideration, MEPC 69 instructed the group to continue considering the status of technological developments for ro-ro cargo and ro-ro passenger ships and to make recommendations to MEPC 70 on whether the time periods, the EEDI reference line parameters for relevant ship types and the reduction rates in regulation 21 of MARPOL Annex VI should be retained or, if proven necessary, amended.

28 MEPC 70 (October 2016) agreed to retain the EEDI requirements for Phase 2 (except for ro-ro cargo ships and passenger ships which will be considered further at MEPC 71) and on the need for a thorough review of EEDI Phase 3 (1 January 2025 and onwards) requirements, including discussion on its earlier implementation and the possibility of

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8 Estimated CO_2 emissions reduction from introduction of mandatory technical and operational energy efficiency measures for ships, Lloyd's Register and DNV, October 2011 (MEPC 63/INF.2).

9 Originally adopted by MEPC 63 (March 2012) and subsequently revised and/or amended.

establishing a Phase 4. Phase 3 requirements provide that new ships be built to be 30% more energy efficient compared to the baseline.

29 MEPC 71 (July 2017) approved draft amendments to regulation 21 of MARPOL Annex VI regarding EEDI requirements for ro-ro cargo and ro-ro passenger ships, which were subsequently adopted at MEPC 72 (April 2018).

30 In addition, MEPC 71 also established a Correspondence Group on EEDI review beyond phase 2, under the coordination of Japan, and instructed it to recommend to MEPC 73 the time period and the reduction rates for EEDI phase 3 requirements, and consider a possible introduction of EEDI phase 4 requirements with associated time period and reduction rates.

Development of further measures to enhance the energy efficiency of ships

31 At MEPC 65 (May 2013) several delegations recognized the importance of enhancing energy efficiency and reducing fuel consumption with subsequent reductions of CO_2 emissions and other pollutants emitted to air. The Committee noted considerable support for the development of further measures to enhance the energy efficiency of shipping and to use a three-step approach, i.e. data collection and data analysis, followed by decision- making on what further measures, if any, are required (the three-step approach).

32 MEPC 68 (May 2015) noted that one purpose of a data collection system was to analyse energy efficiency and that for this analysis to be effective, some transport work data needed to be included. In this regard, the Committee agreed that data collected by IMO, particularly that related to transport work, should be confidential and not publicly available, and that resulting administrative burdens, the impact on industry and variables that influence energy efficiency needed to be addressed.

33 IMO therefore focussed on the development of a data collection system for ships and MEPC 69 (April 2016) reaffirmed that it would follow the three-step approach and agreed that confidentiality of data is crucial and that no third-party access to the data should be permitted.

34 MEPC 70 (October 2016) adopted mandatory MARPOL Annex VI requirements for ships to record and report their fuel oil consumption. Under the amendments, ships of 5,000 GT and above (representing approximately 85% of the total CO_2 emissions from international shipping) will be required to collect consumption data for each type of fuel oil they use, as well as, additionally, other specified data, including proxies for "transport work". The aggregated data will be reported to the flag State after the end of each calendar year and the flag State, having determined that the data have been reported in accordance with the requirements, will issue a Statement of Compliance to the ship. Flag States will be required to subsequently transfer this data to an IMO Ship Fuel Oil Consumption Database. The Secretariat is required to produce an annual report to the MEPC, summarizing the data collected.

REDUCTION OF GREENHOUSE GAS EMISSIONS FROM SHIPS

35 The MEPC has a standing item on "Reduction of GHG emissions from ships" on its agenda. MEPC 69 (April 2016) considered several submissions addressing the issue and, following an extensive debate:

.1 welcomed the Paris Agreement and acknowledged the major achievement of the international community in concluding the agreement;

.2 recognized and commended the current efforts and those already implemented by IMO to enhance the energy efficiency of ships;

.3 widely recognized and agreed that further appropriate improvements related to shipping emissions can and should be pursued;

.4 recognized the role of IMO in mitigating the impact of GHG emissions from international shipping;

.5 agreed to the common understanding that the approval at MEPC 69 and subsequent adoption of the data collection system was the priority;

.6 reiterated its endorsement of the three-step approach; and

.7 agreed to establish a working group at MEPC 70, with a view to an in-depth discussion on how to progress the matter.

Comprehensive IMO strategy on reduction of GHG emissions from ships

36 MEPC 70 (October 2016) approved a *Roadmap for developing a comprehensive IMO strategy on reduction of GHG emissions from ships*, which identified that an initial GHG reduction strategy should be adopted in 2018. The Roadmap contains a list of activities, including further IMO GHG studies and significant intersessional work with relevant timelines and provides for alignment of those new activities with the ongoing work on the aforementioned three-step approach to ship energy efficiency improvements. This provides a way forward to the adoption of a revised strategy in 2023 to include short-, mid-, and long-term further measures, as required, with implementation schedules.

37 To progress the work intersessionally, MEPC 70 agreed to the establishment of an intersessional Working Group on Reduction of GHG emissions from ships.

Initial strategy on reduction of GHG emissions from ships

38 Following two sessional and three intersessional meetings of the Working Group on Reduction of GHG emissions from ships, the *Initial IMO Strategy on Reduction of GHG emissions from ships* was adopted by MEPC 72 (April 2018) in line with the timeline stipulated in the Roadmap (see annex 1 of this submission).

Identification of a list of candidate further measures

39 As identified by resolution A.963(23), the list of further measures could include technical, operational and market-based measures. As the preceding paragraphs indicate, IMO has made significant progress to date on the development and delivery of technical and operational energy efficiency measures for ships, including the adoption of the data collection system for fuel oil consumption.

Technical and operational energy efficiency measures

40 For existing ships, MEPC 67 considered the development of mandatory fleet-wide operational energy efficiency standards but since no clear way forward on the need for such standards for ships could be concluded at that session, the Committee agreed that document MEPC 67/5/4, addressing energy efficiency metric options, should be held in abeyance until a future session, and invited Member Governments and international organizations to submit comments and proposals addressing the questions set out in paragraph 15 of document MEPC 67/5 and in document MEPC 67/5/6 to MEPC 68 (MEPC 67/20, paragraph 5.9). Following further consideration, MEPC 68 agreed that the development of a data collection

system for ships should progress and follow the three-step approach (MEPC 68/21, paragraph 4.8). MEPC 70 identified further possible development of the EEDI framework for new ships (see paragraph 28).

Market-based measures to address GHG emissions from international shipping

41 Resolution A.963(23) urged MEPC to identify and develop the mechanism or mechanisms needed to achieve the limitation or reduction of GHG emissions from international shipping and, in doing so, to give priority to, inter alia, an evaluation of the use of technical, operational and market-based solutions. MEPC 55 adopted a work plan to identify and develop the mechanisms needed to achieve the limitation or reduction of CO_2 emissions from international shipping (MEPC 55/23, annex 9).

42 MEPC recognized that, in view of projected increases in the world's population and trade, market-based measures (MBMs) may be necessary to supplement the adopted technical and operational measures to ensure even further reductions in GHG emissions from international shipping (MEPC 59/24, paragraph 4.92). Several MBM proposals from governments and organizations were received and MEPC 60 established an expert group to undertake a feasibility study and impact assessment of the proposals (MEPC 60/22, paragraph 4.89). The outcome of the study and assessment was subsequently examined by an intersessional working group (GHG-WG 3) in March 2011, which was tasked with providing advice on, among other subjects, the compelling need and purpose of MBMs as possible mechanisms to reduce GHG emissions from international shipping; and with evaluating the outcome of work conducted by the expert group, which had also endeavoured to assess the impact of the proposed MBMs on, among others, international trade, the maritime sector of developing countries, least developed countries (LDCs) and Small Island Developing States (SIDS), as well as the corresponding environmental benefits.

43 Following completion of the expert group's study, some of the proposed MBMs were combined or further developed by their respective proponents and, in examining the proposals, the intersessional working group had an extensive exchange of views on issues related to, inter alia, the desirability of MBMs providing: certainty in emission reductions or carbon price; revenues for mitigation, adaptation and capacity-building activities in developing countries; incentives for technological and operational improvements in shipping; and offsetting opportunities. Based on such policy considerations, the group reported to the MEPC, in accordance with its terms of reference, related to: the grouping of the MBMs; the strengths and weaknesses of the MBM groups; their relation to relevant international conventions; and the aforementioned possible impacts. The report of GHG-WG 3 (MEPC 62/5/1) was held in abeyance by MEPC 62 and considered at MEPC 63 (MEPC 63/21, paragraph 5.7).

44 If an MBM for international shipping was considered further, then part of any consideration could be the possibility of raising funds from the implementation of such a measure. MEPC 63 noted (MEPC 63/23, paragraph 5.34.7) that there were several possible uses for revenues generated by an MBM for international shipping, as identified in the MBM proposals, including:

.1 incentivizing shipping to achieve improved energy efficiency;

.2 offsetting – purchase of approved emission reduction credits;

.3 providing a rebate to developing countries;

.4 financing adaptation and mitigation activities in developing countries;

.5 financing improvement of maritime transport infrastructure in developing countries (e.g. Africa);

.6 supporting R&D to improve energy efficiency of international shipping; and

.7 supporting IMO's Integrated Technical Co-operation Programme (ITCP).

45 Should an MBM be introduced for international shipping, MEPC 63 recognized the need for a continued impact assessment and that its focus should be on possible impacts on consumers and industries in developing countries (MEPC 63/23, paragraph 5.14).

46 Following further consideration at MEPC 64 (October 2012), the Committee agreed to keep the documents presented in abeyance and postpone further debate on MBMs to MEPC 65 (MEPC 64/23, paragraph 5.15). MEPC 65 (May 2013) agreed to suspend discussions on market-based measures and related issues to a future session (MEPC 65/21, paragraph 5.1).

Reduction target for international shipping

47 MEPC 60 noted that there would be a need to consider whether the international maritime sector should be subject to an explicit emission ceiling (cap) or a reduction target comprising the entire world fleet of merchant vessels (MEPC 60/22, paragraph 4.89). The paramount questions would be how and by which international organization such a cap or reduction target should be established. Other questions related to whether a cap or a target line would include the methodology by which the cap/target is set and maintained as well as the possible connection with other transport modes and how they are regulated internationally.

48 MEPC 60 agreed that the debate on reduction targets was a vital part of IMO's GHG work (MEPC 60/22, paragraph 4.93) and the issue of a reduction target for international shipping was included in its agenda item on "Reduction of GHG emissions from ships". However, due to time constraints, the Committee held the matter in abeyance until consideration of MBMs was suspended at MEPC 65.

49 The Paris Agreement identifies a target of global temperature increase above pre-industrial level of "well below 2°C" with an aim of limiting the increase to 1.5°C. Reference is made to the temperature goals of the Paris Agreement in the “Levels of ambition” included in the *Initial IMO Strategy on Reduction of GHG emissions from ships* (see annex 1 of this submission).

CONTROL OF OTHER EMISSIONS FROM SHIPS

50 The adoption of MARPOL Annex VI in 1997, its entry into force in 2005 and its subsequent revision in 2008 represent significant steps towards establishing a robust global regime responsive to the air quality issues experienced in coastal areas. By reducing harmful emissions to air from ships, the measures are expected to have a significant beneficial impact on the atmospheric environment and on human health, particularly for those people living in port cities and coastal communities. As of 18 April 2018, 89 IMO Member States, the combined merchant fleets of which constitute approximately 96.18% of the gross tonnage of the world's merchant fleet, have ratified MARPOL Annex VI.

Sulphur Oxides (SO_X) and Particulate Matter (PM)

51 SO_X and PM emission controls apply to all fuel oils, as defined in regulation 2.9 of MARPOL Annex VI, combustion equipment and devices onboard and therefore include both main and all auxiliary engines together with items such as boilers and inert gas generators. These controls are divided into those applicable inside Emission Control Areas (ECAs) established to limit the emission of SO_X and PM and those applicable outside such areas, and are primarily achieved by limiting the maximum sulphur content of the fuel oils as loaded, bunkered and subsequently used onboard. These fuel oil sulphur limits (expressed in terms of % m/m, that is, by mass) have been subject to a series of step changes over the

years (regulations 14.1 and 14.4 of MARPOL Annex VI). Currently, the sulphur limit outside an ECA established to limit SO_X and PM emissions is 3.50% m/m and will fall to 0.50% m/m on 1 January 2020, following a review of the availability of the required compliant fuel oil completed at MEPC 70 (October 2016) – further information is provided below.

52 Most ships operating both outside and inside ECAs will therefore use different fuel oils in order to comply with the respective limits. In such cases, prior to entry into an ECA, the ship is required to have fully changed over to using ECA-compliant fuel oil and to have onboard written procedures showing how the changeover is to be undertaken (regulation 14.6 of MARPOL Annex VI). Similarly, a changeover from using ECA-compliant fuel oil is not to commence until after exiting the ECA. At each changeover it is required that the quantities of ECA-compliant fuel oils onboard are recorded, together with the date, time and position of the ship when either completing the changeover prior to entry or commencing changeover after exit from such areas. This is to be recorded in a logbook as prescribed by the ship's flag State, and in the absence of any specific requirement in this regard the record could be made, for example, in the ship's Annex I Oil Record Book.

53 The first level of control in this respect is therefore the actual sulphur content of the fuel oils as bunkered. This value is to be stated by the fuel oil supplier on the bunker delivery note and hence is, together with other related aspects, directly linked to the fuel oil quality requirements as covered under regulation 18 of MARPOL Annex VI. Thereafter it is for the ship's crew to ensure, in respect of ECA-compliant fuel oils, that through avoiding loading into otherwise part-filled storage, settling or service tanks, or in the course of transfer operations, such fuel oils do not become mixed with other, higher sulphur content fuel oils, so that the fuel oil as actually used within an ECA exceeds the applicable limit.

54 Consequently, regulation 14 of MARPOL Annex VI provides both the limit values and the means to comply. However, there are other means by which equivalent levels of SO_X and PM emission control, both outside and inside ECAs, could be achieved. These may be divided into methods termed primary (in which the formation of the pollutant is avoided) or secondary (in which the pollutant is formed but subsequently removed to some degree prior to discharge of the exhaust gas stream to the atmosphere). Regulation 4.1 of MARPOL Annex VI allows for the application of such methods, subject to approval by the administration. In approving such "equivalents" an Administration should take into account any relevant guidelines. There are no guidelines in respect of any primary methods. In terms of secondary control methods, guidelines have been adopted and subsequently amended for exhaust gas cleaning systems that operate by water washing the exhaust gas stream prior to discharge to the atmosphere (resolution MEPC.259(68)). In using such arrangements there would be no constraint on the sulphur content of the fuel oils as bunkered other than that given by the system's certification.

55 There are no provisions for PM in regulation 14, but it is recognized that the sulphur content of fuel oil relates to the PM of the exhaust. PM consists of particles of soot or smoke resulting from the burning of, primarily, heavier oils. It is considered to be a major health hazard as particulates may penetrate deep into the lungs and blood and cause cancer (see also Black Carbon discussion below).

56 As indicated, MEPC 70 agreed to “1 January 2020” as the effective date of implementation for ships to comply with global 0.50% m/m sulphur content of fuel oil requirement and, in this connection, adopted resolution MEPC.280(70) on the effective date of implementation of the fuel oil standard in regulation 14.1.3 of MARPOL Annex VI.

57 MEPC 70, in recognizing the concerns expressed regarding implementation, instructed the 4th session of the Sub-Committee on Pollution Prevention and Response (PPR 4) to develop a draft justification and scope for new output on consistent implementation of the

0.50% m/m sulphur limit. PPR 4 in January 2017 agreed a draft justification and scope for new output on consistent implementation of the 0.50% m/m sulphur limit.

Consistent implementation of regulation 14.1.3 of MARPOL Annex VI

58 MEPC 71 in July 2017 approved the new output on "Consistent implementation of regulation 14.1.3 of MARPOL Annex VI", for inclusion in the PPR Sub-Committee's biennial agenda for 2018-2019 and the provisional agenda for PPR 5, with a target completion year of 2019.

59 MEPC 71 also approved the following scope of work:

.1 **preparatory and transitional issues** that may arise with a shift from the 3.50% m/m sulphur limit to the new 0.50% m/m limit;

.2 **impact on fuel and machinery systems** that may result from the use of fuel oils with a 0.50% m/m sulphur limit;

.3 **verification issues and control mechanisms and actions** that are necessary to ensure compliance and consistent implementation;

.4 **development of a draft standard format (a standardized system) for reporting fuel oil non-availability** as provided in regulation 18.2.4 of MARPOL Annex VI that may be used to provide evidence if a ship is unable to obtain fuel oil compliant with the provisions stipulated in regulations 14.1.3 and 14.4.3;

.5 **development of guidance, as appropriate, that may assist Member States and stakeholders** in assessing the sulphur content of fuel oil delivered for use on board ship, based on the consideration of mechanisms to encourage verification that fuel oils supplied to ships meet the specified sulphur limit as stated on the bunker delivery note;

.6[10] **request to ISO to consider the framework of ISO 8217** with a view to keeping consistency between the relevant ISO standards on marine fuel oils and the implementation of regulation 14.1.3 of MARPOL Annex VI;

.7 **any consequential regulatory amendments and/or guidelines necessary** to address issues raised in items .1 to .6 above or otherwise considered necessary to ensure consistent of regulation 14.1.3 of MARPOL Annex VI; and

.8[11] **consideration of the safety implications relating to the option of blending fuels in order to meet the 0.50% m/m sulphur limit**.

60 Having been forwarded by PPR 5 as an urgent matter, MEPC 72 (April 2018) approved draft amendments to MARPOL Annex VI for a prohibition on the carriage of non-compliant fuel oil for combustion purposes for propulsion or operation on board a ship, with a view to adoption at MEPC 73 (October 2018).

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10 Completed at MEPC 71 (MEPC 71/17, paragraph 14.27.5). A letter has also been sent to ISO by the Secretariat on 4 September 2017.

11 Agreed by MEPC 71 (MEPC 71/17, paragraph 14.27.2)

Nitrogen Oxides (NO_X)

61 NO_X can act as indirect greenhouse gases by producing the tropospheric GHG ozone via photochemical reactions in the atmosphere. The control of diesel engine NO_X emissions is achieved through the survey and certification requirements leading to the issue of an Engine International Air Pollution Prevention (EIAPP) Certificate and the subsequent demonstration of in service compliance in accordance with the requirements of regulations 13.8 of MARPOL Annex VI and 5.3.2 of the NO_X Technical Code 2008.

62 The NO_X control requirements of MARPOL Annex VI apply to installed marine diesel engines of over 130 kW output power other than those used solely for emergency purposes, irrespective of the tonnage of the ship on which such engines are installed. Definitions of "installed" and "marine diesel engine" are given in regulations 2.12 and 2.14 of MARPOL Annex VI, respectively. Different levels (Tiers) of control apply based on the ship construction date, a term defined in regulations 2.19 and hence 2.2, and within any particular Tier the actual limit value is determined from the engine's rated speed. The most stringent limit, Tier III, applies only to specified ships while operating in ECAs established to limit NO_X emissions. Outside such areas Tier II controls apply. A marine diesel engine installed on a ship constructed on or after 1 January 2016 and operating in the North American ECA and the United States Caribbean Sea ECA shall comply with the Tier III NO_X standards.

63 The emission value for a marine diesel engine is to be determined in accordance with the NO_X Technical Code 2008 in the case of Tier II and Tier III limits. Most Tier I engines have been certified to the earlier 1997 version of the NO_X Technical Code which, in accordance with the *Guidelines for the application of the NO_X Technical Code relative to certification and amendments of Tier I engines* (MEPC.1/Circ.679), may continue to be used in certain cases until 1 January 2011. Certification issued in accordance with the 1997 NO_X Technical Code remains valid over the service life of such engines.

Emission control areas designated under MARPOL Annex VI

64 MARPOL Annex VI includes provisions to establish ECAs for the control of emissions of NO_X, SO_X and PM. The North American ECA (August 2011) and the United States Caribbean Sea ECA (January 2013) have been designated as ECAs for the control of emissions of SO_X, NO_X and PM. The North American ECA comprises the sea areas 200 nautical miles off the Pacific coasts of the United States and Canada; off the Gulf of Mexico and Atlantic coasts of the United States, Canada and the French territories; and off the coasts of the populated Hawaiian Islands. The United States Caribbean Sea ECA comprises waters adjacent to the coasts of Puerto Rico and the United States Virgin Islands.

65 The Baltic Sea (May 2005) and the North Sea including the English Channel (November 2006) had been designated for the control of SO_X emissions only. MEPC 71 (July 2017) adopted amendments to MARPOL Annex VI to designate the North Sea and the Baltic Sea as emission control areas (ECAs) for nitrogen oxides (NO_X) under regulation 13 of MARPOL Annex VI. Both ECAs will take effect on 1 January 2021, thereby considerably lowering emissions of NO_X from international shipping in those areas.

66 Provisions were approved at MEPC 70 to allow ships fitted with non-Tier III compliant marine diesel engines to be built, converted, repaired and/or maintained at shipyards located in the designated NO_X Tier III ECAs.

Use of gas as fuel for international shipping

67 There is significant interest in the use of gas as fuel for international shipping as its combustion results in less harmful pollutants being emitted than by fuel oil. Depending on the

gas used, the emissions can be virtually sulphur-free and there can be reduced emissions of NO_X (some engines solely fuelled by gas can meet Tier III limits), CO_2 and PM. This development lead to requests for the risks of using gas, and other low flashpoint fuels, to be appropriately regulated. Following several years of work, the International Code of Safety for Ships using Gases or other Low-flashpoint Fuels (IGF Code) was adopted in 2015, along with new SOLAS regulations making the Code mandatory which require ships constructed after 1 January 2017 to comply with the requirements of the IGF Code.

68 Furthermore, to allow the use of gas as a fuel under MARPOL Annex VI, the definitions of "fuel oil" and "marine diesel engine" have been amended and further amendments were made to permit the testing of gas-fuelled and dual fuelled engines to enable them to be appropriately certified under the NO_X Technical Code 2008. One of the current limitations for the use of gas as a fuel is the lack of a global gas bunkering network supporting an international trading fleet of gas-fuelled ships. Other alternative fuels for ships under consideration include methanol (see paragraph 68.5) and hydrogen in fuel cells.

Black Carbon

69 MEPC 62 (July 2011) agreed to the following work plan for the BLG Sub-Committee to consider the impact on the Arctic of emissions of Black Carbon from international shipping (MEPC 62/24, paragraph 4.20):

.1 develop a definition for Black Carbon emissions from international shipping;

.2 consider measurement methods for Black Carbon and identify the most appropriate method for measuring Black Carbon emissions from international shipping; and

.3 investigate appropriate control measures to reduce the impact of Black Carbon emissions from international shipping.

70 The matter is now being considered by the Sub-Committee on Pollution Prevention and Response (PPR) under its agenda item on "Consideration of the impact on the Arctic of emissions of Black Carbon from international shipping". MEPC 68 (May 2015) approved a definition of Black Carbon for international shipping agreed by PPR 2 (January 2015). MEPC 68 also noted that at that stage it was not possible to consider possible control measures to reduce the impact on the Arctic of emissions of Black Carbon from international shipping.

71 PPR 3 (January 2016) developed a measurement reporting protocol for voluntary data collection of Black Carbon and invited interested Member Governments and international organizations to use the protocol and submit data to PPR 4. Voluntary measurement studies using the agreed definition of Black Carbon were reported to PPR 4 (January 2017) and are continuing, in order to identify the most appropriate measurement method(s).

72 PPR 4 noted that some delegations encouraged information on potential control measures to be submitted to PPR 5. PPR 5 (January 2018) agreed the *Reporting protocol for voluntary measurement studies to collect Black Carbon data* as well as most appropriate Black Carbon measurement methods for data collection. PPR 5 encouraged Member States and international organizations to continue to collect Black Carbon data, using the agreed reporting protocol and the agreed measurement methods, and submit relevant data to the next session of the Sub-Committee.

IMO-published technical studies

73 In support of the work of the MEPC and to provide timely information to Member Governments, specifically to support developing countries with the implementation of the provisions of MARPOL Annex VI, and using funds donated by Canada and Norway, the Secretariat has undertaken and published[12] a series of technical studies as follows:

.1 investigation of appropriate control measures (abatement technologies) to reduce Black Carbon emissions from international shipping;

.2 emission control and energy efficiency measures for ships in the port area;

.3 studies on the feasibility and use of liquid natural gas (LNG) as a fuel for shipping;

.4 optimization of energy consumption as part of implementation of a Ship Energy Efficiency Management Plan (SEEMP); and

.5 methanol as marine fuel: environmental benefits, technology readiness and economic feasibility.

PROMOTION OF TECHNICAL COOPERATION AND TRANSFER OF TECHNOLOGY RELATING TO THE IMPROVEMENT OF ENERGY EFFICIENCY OF SHIPS

74 In order to support countries that lack the requisite resources, experience or skills to implement IMO treaties, IMO has developed an Integrated Technical Co-operation Programme (ITCP) which is designed to assist Governments by helping them build the necessary capacity. Through technical cooperation and capacity-building activities, IMO helps to transfer know-how to those countries that need it, thereby promoting wider and more effective implementation of IMO measures.

75 Linked to the implementation of energy efficiency measures, and specifically to regulation 23 of MARPOL Annex VI, MEPC 65 (May 2013) adopted resolution MEPC.229(65) on *Promotion of technical co-operation and transfer of technology relating to the improvement of energy efficiency of ships*, requiring Administrations, in cooperation with IMO and other international bodies, to promote and provide, as appropriate, support directly or through the IMO to Member States, especially developing countries that request technical assistance. It also requires the Administration of a Party to MARPOL Annex VI to cooperate actively with other Parties, subject to its national laws, regulations and policies, to promote the development and transfer of technology and exchange of information to States that request technical assistance, particularly developing States.

76 Pursuant to resolution MEPC.229(65), MEPC 66 (April 2014) established an Ad Hoc Expert Working Group on Facilitation of Transfer of Technology for Ships. MEPC 69 considered the final report of the group and noted the outcome of its work, as follows:

.1 A scoping document on the establishment of an inventory of energy efficiency technologies for ships was forwarded to the GEF-UNDP-IMO project "Transforming the global maritime transport industry towards a low carbon future through improved energy efficiency" (GloMEEP). Using this scoping document, GloMEEP has developed an information portal for energy efficiency technologies for ships[13].

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12 http://www.imo.org/en/OurWork/Environment/PollutionPrevention/AirPollution/Pages/IMO-Publications.aspx

13 http://glomeep.imo.org/resources/energy-efficiency-techologies-information-portal/

.2 Development of a *Model agreement between Governments on technological cooperation for the implementation of the regulations in chapter 4 of MARPOL Annex VI* (MEPC.1/Circ.861).

.3 Recommendations provided to guide and assist Member States, industry and other entities within States in implementing the regulations of chapter 4 of MARPOL Annex VI.

.4 Assessments made to identify barriers to transfer of technology and potential implications and impacts on the implementation of the regulations in chapter 4 of MARPOL Annex VI, in particular on developing States, as a means to identify their technology transfer and financial needs.

77 MEPC 69 also noted that a comprehensive update of the "Train the Trainer" package on "Energy Efficient Ship Operation" had been undertaken to include a new module on the regulatory framework related to the energy efficiency of ships, an EEDI calculator for training purposes, and other related updated information, such as the findings from the Third IMO GHG Study 2014. Member Governments and other interested delegations were encouraged to make use of it. MEPC 69 further noted that IMO's technical cooperation activities would seek to address the specific needs of LDCs and SIDS with regard to the implementation of ship energy efficiency requirements.

78 Building on the success of the cooperation agreement between the Korean International Co-operation Agency (KOICA) and IMO on "Building Capacities in East Asia countries to address Greenhouse Gas Emissions from Ships" undertaken between 2011 and 2013, IMO has engaged in two partnership projects to further technical cooperation and technology transfer: the aforementioned GloMEEP project and the establishment of a global network of regional Maritime Technology Cooperation Centres (MTCCs) (Global MTCC Network (GMN) project).

79 The two-year GloMEEP project, an initiative of the Global Environment Facility (GEF), the United Nations Development Programme (UNDP) and IMO, focusses in particular on building capacity to implement technical and operational measures in developing countries, where shipping is increasingly concentrated and controlled. Ten IMO Member States have signed up as lead pilot countries: Argentina, China, Georgia, India, Jamaica, Malaysia, Morocco, Panama, Philippines and South Africa. They are being supported through a series of national and regional workshops and the development of guides in taking a fast-track approach to pursuing relevant legal, policy and institutional reforms, and driving national and regional Government action and industry innovation to support the effective implementation of IMO's energy efficiency requirements.

80 The GMN project aims to form a global network of regional centres of excellence (MTCCs) to promote the uptake of low-carbon technologies and operations in maritime transport. The five target regions, Africa, Asia, the Caribbean, Latin America and the Pacific, have been selected for their significant number of LDCs and SIDS. Three of the five centres, i.e. MTCC-Africa (Kenya), MTCC-Asia (China) and MTCC-Caribbean (Trinidad&Tobago), have now been selected as part of the GMN project, with the remaining (Latin-America and Pacific) expected to be selected during 2017. The four-year project, administered by IMO with €10 million in funding from the European Union, is designed to enable beneficiary countries to limit and reduce GHG emissions from their shipping sectors through technical assistance and capacity building, while encouraging the uptake of innovative energy-efficient technologies among a large number of users through the widespread dissemination of technical information and know-how. This is expected to heighten the impact of technology transfer.

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ANNEX 3

EXCERPTS FROM MARPOL ANNEX VI – RESOLUTION MEPC.176(58) AND AMENDMENTS

RESOLUTION MEPC.176(58)

Adopted on 10 October 2008

AMENDMENTS TO THE ANNEX OF THE PROTOCOL OF 1997 TO AMEND THE INTERNATIONAL CONVENTION FOR THE PREVENTION OF POLLUTION FROM SHIPS, 1973, AS MODIFIED BY THE PROTOCOL OF 1978 RELATING THERETO

(Revised MARPOL Annex VI)

THE MARINE ENVIRONMENT PROTECTION COMMITTEE,

RECALLING Article 38(a) of the Convention on the International Maritime Organization concerning the functions of the Marine Environment Protection Committee (the Committee) conferred upon it by international conventions for the prevention and control of marine pollution,

NOTING article 16 of the International Convention for the Prevention of Pollution from Ships, 1973 (hereinafter referred to as the" 1973 Convention"), article VI of the Protocol of 1978 relating to the International Convention for the Prevention of Pollution from Ships, 1973 (hereinafter referred to as the "1978 Protocol") and article 4 of the Protocol of 1997 to amend the International Convention for the Prevention of Pollution from Ships, 1973, as modified by the Protocol of 1978 relating thereto (herein after referred to as the "1997 Protocol"), which together specify the amendment procedure of the 1997 Protocol and confer upon the appropriate body of the Organization the function of considering and adopting amendments to the 1973 Convention, as modified by the 1978 and 1997 Protocols,

NOTING ALSO that, by the 1997 Protocol, Annex VI, entitled Regulations for the Prevention of Air Pollution from Ships (hereinafter referred to as "Annex VI"), is added to the 1973 Convention, HAVING CONSIDERED the draft amendments to MARPOL Annex VI,

1. ADOPTS, in accordance with article 16(2)(d) of the 1973 Convention, the amendments to Annex VI, the text of which is set out at Annex to the present resolution;

2. DETERMINES, in accordance with article 16(2)(f)(iii) of the 1973 Convention, that the amendments shall be deemed to have been accepted on 1 January 2010, unless prior to that date, not less than one-third of the Parties or Parties the combined merchant fleets of which constitute not less than 50 per cent of the gross tonnage of

the world's merchant fleet, have communicated to the Organization their objection to the amendments;

3. INVITES the Parties to note that, in accordance with article 16(2)(g)(ii) of the 1973 Convention, the said amendments shall enter into force on l July 20 l 0 upon their acceptance in accordance with paragraph 2 above;

4. REQUESTS the Secretary-General, in conformity with article 16(2)(e) of the 1973 Convention, to transmit to all Parties to the 1973 Convention, as modified by the 1978 and 1997 Protocols, certified copies of the present resolution and the text of the amendments contained in the Annex;

5. REQUESTS FURTHER the Secretary-General to transmit to the Members of the Organization which are not Parties to the 1973 Convention, as modified by the 1978 and 1997 Protocols, copies of the present resolution and its Annex; and

6. INVITES the Parties to MARPOL Annex VI and other Member Governments to bring the amendments to MARPOL Annex VI to the attention of shipowners, ship operators, shipbuilders, marine diesel engine manufacturers, marine fuel suppliers and any other interested groups.

ANNEX

REVISED MARPOL ANNEX VI

Regulations for the Prevention of Air Pollution from Ships

Chapter 3

Requirements for control of emissions from ships

Regulation 13

Nitrogen oxides (NO_x)

Application

1.1 This regulation shall apply to:

.1 each marine diesel engine with a power output of more than 130 kW installed on a ship; and

.2 each marine diesel engine with a power output of more than 130 kW that undergoes a major conversion on or after I January 2000 except when demonstrated to the satisfaction of the Administration that such engine is an identical replacement to the engine that it is replacing and is otherwise not covered under paragraph 1.1.1 of this regulation.

1.2 This regulation does not apply to:

.1 a marine diesel engine intended to be used solely for emergencies, or solely to power any device or equipment intended to be used solely for emergencies on the ship on which it is installed, or a marine diesel engine installed in lifeboats intended to be used solely for emergencies; and

.2 a marine diesel engine installed on a ship solely engaged in voyages within waters subject to the sovereignty or jurisdiction of the State the flag of which the ship is entitled to fly, provided that such engine is subject to an alternative NO_X control measure established by the Administration.

1.3 Notwithstanding the provisions of paragraph 1.1 of this regulation, the Administration may provide an exclusion from the application of this regulation for any marine diesel engine that is installed on a ship constructed, or for any marine diesel engine that undergoes a major conversion, before 19 May 2005, provided that the ship on which the engine is installed is solely engaged in voyages to ports or offshore terminals within the State the flag of which the ship is entitled to fly.

Major conversion

2.1 For the purpose of this regulation, major conversion means a modification on or after 1 January 2000 of a marine diesel engine that has not already been certified to the standards set forth in paragraph 3, 4, or 5.1.1 of this regulation where:

.1 the engine is replaced by a marine diesel engine or an additional marine diesel engine is installed, or

.2 any substantial modification, as defined in the revised NO_X Technical Code 2008, is made to the engine, or

.3 the maximum continuous rating of the engine is increased by more than 10% compared to the maximum continuous rating of the original certification of the engine.

2.2 For a major conversion involving the replacement of a marine diesel engine with a non-identical marine diesel engine or the installation of an additional marine diesel engine, the standards in this regulation in force at the time of the replacement or addition of the engine shall apply. On or after 1 January 2016, in the case of replacement engines only, if it is not possible for such a replacement engine to meet the standards set forth in paragraph 5.1.1 of this regulation (Tier III), then that replacement engine shall meet the standards set forth in paragraph 4 of this regulation (Tier II). Guidelines are to be developed by the Organization to set forth the criteria of when it is not possible for a replacement engine to meet the standards in paragraph 5.1.1 of this regulation.

2.3 A marine diesel engine referred to in paragraph 2.1.2 or 2.1.3 of this regulation shall meet the following standards:

.1 for ships constructed prior to 1 January 2000, the standards set forth III paragraph 3 of this regulation shall apply; and

.2 for ships constructed on or after 1 January 2000, the standards in force at the time the ship was constructed shall apply.

Tier I

3 Subject to regulation 3 of this Annex, the operation of a marine diesel engine that is installed on a ship constructed on or after 1 January 2000 and prior to 1 January

2011 is prohibited, except when the emission of nitrogen oxides (calculated as the total weighted emission of NO_2) from the engine is within the following limits, where n = rated engine speed (crankshaft revolutions per minute):

.1 17.0 g/kWh when n is less than 130 rpm;

.2 $45 \cdot n^{(-0,2)}$ g/kWh when n is 130 or more but less than 2,000 rpm;

.3 9.8 g/kWh when n is 2,000 rpm or more.

Tier II

4 Subject to regulation 3 of this Annex, the operation of a marine diesel engine that is installed on a ship constructed on or after I January 2011 is prohibited, except when the emission of nitrogen oxides (calculated as the total weighted emission of N02) from the engine is within the following limits, where n = rated engine speed (crankshaft revolutions per minute):

.1 14.4 g/kWh when n is less than 130 rpm;

.2 $44 \cdot n^{(-0.23)}$ g/kWh when n is 130 or more but less than 2,000 rpm;

.3 7.7 g/kWh when n is 2,000 rpm or more.

Tier III

5.1 Subject to regulation 3 of this Annex, the operation of a marine diesel engine that is installed on a ship constructed on or after I January 2016:

.1 is prohibited except when the emission of nitrogen oxides (calculated as the total weighted emission of NO_2) from the engine is within the following limits, where n = rated engine speed (crankshaft revolutions per minute):

.1.1 3.4 g/kWh when n is less than 130 rpm;

.1.2 $9 \cdot n^{(-0.2)}$ g/kWh when n is 130 or more but less than 2,000 rpm; and

.1.3 2.0 g/kWh when n is 2,000 rpm or more;

.2 is subject to the standards set forth in paragraph 5.1.1 of this regulation when the ship is operating in an emission control area designated under paragraph 6 of this regulation; and

.3 is subject to the standards set forth in paragraph 4 of this regulation when the ship is operating outside of an emission control area designated under paragraph 6 of this regulation.

5.2 Subject to the review set forth in paragraph 10 of this regulation, the standards set forth in paragraph 5. 1.1 of this regulation shall not apply to:

.1 a marine diesel engine installed on a ship with a length (L), as defined in regulation 1.19 of Annex I to the present Convention, less than 24 metres when it has been specifically designed, and is used solely, for recreational purposes; or

.2 a marine diesel engine installed on a ship with a combined nameplate diesel engine propulsion power of less than 750 kW if it is demonstrated, to the satisfaction of the Administration, that the ship cannot comply with the standards set forth in paragraph 5.1.1 of this regulation because of design or construction limitations of the ship.

Emission control area

6 For the purposes of this regulation, a NOX Tier III emission control area shall be any sea area, including any port area, designated by the Organization in accordance with the criteria and procedures set forth in appendix III to this Annex. The NOX Tier III emission control areas are:

.1 the North American Emission Control Area, which means the area described by the coordinates provided in appendix VII to this Annex;

.2 the United States Caribbean Sea Emission Control Area, which means the area described by the coordinates provided in appendix VII to this Annex;

.3 the Baltic Sea Emission Control Area as defined in regulation 1.11.2 of Annex I of the present Convention; and

.4 the North Sea Emission Control Area as defined in regulation 1.14.6 of Annex V of the present Convention.

Marine diesel engines installed on a ship constructed prior to 1 January 2000

7.1 Notwithstanding paragraph 1.1.1 of this regulation, a marine diesel engine with a power output of more than 5,000 kW and a per cylinder displacement at or above 90 litres installed on a ship constructed on or after l January 1990 but prior to l January 2000 shall comply with the emission limits set forth in paragraph 7.4 of this regulation, provided that an approved method for that engine has been certified by an Administration of a Party and notification of such certification has been submitted to the Organization by the certifying Administration.

Compliance with this paragraph shall be demonstrated through one of the following:

.1 installation of the certified approved method, as confirmed by a survey using the verification procedure specified in the approved method file, including appropriate notation on the ship's International Air Pollution Prevention Certificate of the presence of the approved method; or

.2 certification of the engine confirming that it operates within the limits set forth in paragraph 3, 4, or 5.1.1 of this regulation and an appropriate notation of the engine certification on the ship's International Air Pollution Prevention Certificate.

7.2 Paragraph 7.1 of this regulation shall apply no later than the first renewal survey that occurs 12 months or more after deposit of the notification in paragraph 7.1. If a shipowner of a ship on which an approved method is to be installed can demonstrate to the satisfaction of the Administration that the approved method was not commercially available despite best efforts to obtain it, then that approved method shall be installed on the ship no later than the next annual survey of that ship which falls after the approved method is commercially available.

7.3 With regard to a ship with a marine diesel engine with a power output of more than 5,000 kW and a per cylinder displacement at or above 90 litres installed on a ship constructed on or after I January 1990 but prior to I January 2000, the International Air Pollution Prevention Certificate shall, for a marine diesel engine to which paragraph 7.1 of this regulation applies, indicate that either an approved method has been applied pursuant to paragraph 7.1.1 of this regulation or the engine has been certified pursuant to paragraph 7.1.2 of this regulation or that an approved method does not yet exist or is not yet commercially available as described in paragraph 7.2 of this regulation.

7.4 Subject to regulation 3 of this Annex, the operation of a marine diesel engine described in paragraph 7.1 of this regulation is prohibited, except when the emission of nitrogen oxides (calculated as the total weighted emission ofN02) from the engine is within the following limits, where n = rated engine speed (crankshaft revolutions per minute):

.1 17.0 g/kWh when n is less than 130 rpm;

.2 $45 \cdot n^{(-0.2)}$ g/kWh when n is 130 or more but less than 2,000 rpm; and

.3 9.8 g/kWh when n is 2,000 rpm or more.

7.5 Certification of an approved method shall be in accordance with chapter 7 of the revised NO_X Technical Code 2008 and shall include verification:

.1 by the designer of the base marine diesel engine to which the approved method applies that the calculated effect of the approved method will not decrease engine rating by more than 1.0%, increase fuel consumption by more than 2.0% as measured according to the appropriate test cycle set forth in the revised NO_X Technical Code 2008, or adversely affect engine durability or reliability; and

.2 that the cost of the approved method is not excessive, which is determined by a comparison of the amount of NO, reduced by the approved method to achieve the standard set forth in paragraph 7.4 of this paragraph and the cost of purchasing and installing such approved method.

Certification

8 The revised NO, Technical Code 2008 shall be applied in the certification, testing, and measurement procedures for the standards set forth in this regulation.

9 The procedures for determining NO, emissions set out in the revised NO, Technical Code 2008 are intended to be representative of the normal operation of the engine. Defeat devices and irrational emission control strategies undermine this intention and shall not be allowed. This regulation shall not prevent the use of auxiliary control devices that are used to protect the engine and/or its ancillary equipment against operating conditions that could result in damage or failure or that are used to facilitate the starting of the engine.

Review

10 Beginning in 2012 and completed no later than 2013, the Organization shall review the status of the technological developments to implement the standards set

forth in paragraph 5.1.1 of this regulation and shall, if proven necessary, adjust the time periods (effective date) set forth in that paragraph.

Regulation 14

Sulphur oxides (SO_X) and particulate matter

General requirements

1 The sulphur content of any fuel oil used on board ships shall not exceed the following limits:

.1 4.50% m/m prior to I January 2012;

.2 3.50% m/m on and after I January 2012; and

.3 0.50% m/m on and after 1 January 2020.

2 The worldwide average sulphur content of residual fuel oil supplied for use on board ships shall be monitored taking into account guidelines developed by the Organization.

Requirements within emission control areas

3 For the purpose of this regulation, emission control areas shall include:

.1 the Baltic Sea area as defined in regulation 1.11.2 of Annex I, the North Sea as defined in regulation 5(1)(f) of Annex V; and

.2 any other sea area, including port areas, designated by the Organization in accordance with criteria and procedures set forth in appendix III to this Annex.

4 While ships are operating within an emission control area, the sulphur content of fuel oil used on board ships shall not exceed the following limits:

.1 1.50% m/m prior to I July 20I0;

.2 1.00% m/m on and after 1 July 2010; and

.3 0.10% m/m on and after I January 2015.

5 The sulphur content of fuel oil referred to in paragraph 1 and paragraph 4 of this regulation shall be documented by its supplier as required by regulation 18 of this Annex.

6 Those ships using separate fuel oils to comply with paragraph 4 of this regulation and entering or leaving an emission control area set forth in paragraph 3 of this regulation shall carry a written procedure showing how the fuel oil changeover is to be done, all owing sufficient time for the fuel oil service system to be fully flushed of all fuel oils exceeding the applicable sulphur content specified in paragraph 4 of this regulation prior to entry into an emission control area. The volume of low sulphur fuel oils in each tank as well as the date, time, and position of the ship when any fuel-oil-change-over operation is completed prior to the entry into an emission control area or commenced after exit from such an area, shall be recorded in such log-book as prescribed by the Administration.

7 During the first twelve months immediately following an amendment designating a specific emission control area under paragraph 3.2 of this regulation, ships operating in that emission control area are exempt from the requirements in paragraphs 4 and 6 of this regulation and from the requirements of paragraph 5 of this regulation insofar as they relate to paragraph 4 of this regulation.

Review provision

8 A review of the standard set forth in paragraph 1.3 of this regulation shall be completed by 2018 to determine the availability of fuel oil to comply with the fuel oil standard set forth in that paragraph and shall take into account the following elements:

.I the global market supply and demand for fuel oil to comply with paragraph 1.3 of this regulation that exist at the time that the review is conducted;

.2 an analysis of the trends in fuel oil markets; and

.3 any other relevant issue.

9 The Organization shall establish a group of experts, comprising of representatives with the appropriate expertise in the fuel oil market and appropriate maritime, environmental, scientific and legal expertise, to conduct the review referred to in paragraph 8 of this regulation. The group of experts shall develop the appropriate information to inform the decision to be taken by the Parties.

10 The Parties, based on the information developed by the group of experts, may decide whether it is possible for ships to comply with the date in paragraph 1.3 of this

regulation. If a decision is taken that it is not possible for ships to comply, then the standard in that paragraph shall become effective on I January 2025.

Regulation 15

Volatile organic compounds (VOCs)

1 If the emissions of VOCs from a tanker are to be regulated in a port or ports or a terminal or terminals under the jurisdiction of a Party, they shall be regulated in accordance with the provisions of this regulation.

2 A Party regulating tankers for VOC emissions shall submit a notification to the Organization. This notification shall include information on the size of tankers to be controlled, the cargoes requiring vapour emission control systems, and the effective date of such control. The notification shall be submitted at least six months before the effective date.

3 A Party that designates ports or terminals at which VOC emissions from tankers are to be regulated shall ensure that vapour emission control systems, approved by that Party taking into account the safety standards for such systems developed by the Organization, are provided in any designated port and terminal and are operated safely and in a manner so as to avoid undue delay to a ship.

4 The Organization shall circulate a list of the ports and terminals designated by Parties to other Parties and Member States of the Organization for their information.

5 A tanker to which paragraph 1 of this regulation applies shall be provided with a vapour emission collection system approved by the Administration taking into account the safety standards for such systems developed by the Organization and shall use this system during the loading of relevant cargoes. A port or terminal that has installed vapour emission control systems in accordance with this regulation may accept tankers that are not fitted with vapour collection systems for a period of three years after the effective date identified in paragraph 2 of this regulation.

6 A tanker carrying crude oil shall have on board and implement a VOC management plan approved by the Administration. Such a plan shall be prepared taking into account the guidelines developed by the Organization. The plan shall be specific to each ship and shall at least:

.1 provide written procedures for minimizing VOC emissions during the loading, sea passage and discharge of cargo;

.2 give consideration to the additional VOC generated by crude oil washing;

.3 identify a person responsible for implementing the plan; and

.4 for ships on international voyages, be written in the working language of the master and officers and, if the working language of the master and officers is not English, French, or Spanish, include a translation into one of these languages.

7 This regulation shall also apply to gas carriers only if the types of loading and containment systems allow safe retention of non-methane VOCs on board or their safe return ashore.

[...]

Regulation 18

Fuel oil availability and quality

Fuel oil availability

1 Each Party shall take all reasonable steps to promote the availability of fuel oils that comply with this Annex and inform the Organization of the availability of compliant fuel oils in its ports and terminals.

2.1 If a ship is found by a Party not to be in compliance with the standards for compliant fuel oils set forth in this Annex, the competent authority of the Party is entitled to require the ship to:

.1 present a record of the actions taken to attempt to achieve compliance; and

.2 provide evidence that it attempted to purchase compliant fuel oil in accordance with its voyage plan and, if it was not made available where planned, that attempts were made to locate alternative sources for such fuel oil and that despite best efforts to obtain compliant fuel oil, no such fuel oil was made available for purchase.

2.2 The ship should not be required to deviate from its intended voyage or to delay unduly the voyage in order to achieve compliance.

2.3 If a ship provides the information set forth in paragraph 2.1 of this regulation, a Party shall take into account all relevant circumstances and the evidence presented to determine the appropriate action to take, including not taking control measures.

2.4 A ship shall notify its Administration and the competent authority of the relevant port of destination when it cannot purchase compliant fuel oil.

2.5 A Party shall notify the Organization when a ship has presented evidence of the non-availability of compliant fuel oil.

Fuel oil quality

3 Fuel oil for combustion purposes delivered to and used on board ships to which this Annex applies shall meet the following requirements:

.1 except as provided in paragraph 3.2 of this regulation:

.1.1 the fuel oil shall be blends of hydrocarbons derived from petroleum refining. This shall not preclude the incorporation of small amounts of additives intended to improve some aspects of performance;

.1.2 the fuel oil shall be free from inorganic acid; and

.1.3 the fuel oil shall not include any added substance or chemical waste that:

.1.3.1 jeopardizes the safety of ships or adversely affects the performance of the machinery, or

.1.3.2 is harmful to personnel, or

.1.3.3 contributes overall to additional air pollution;

.2 fuel oil for combustion purposes derived by methods other than petroleum refining shall not:

.2.1 exceed the applicable sulphur content set forth in regulation 14 of this Annex;

.2.2 cause an engine to exceed the applicable NO, emission limit set forth in paragraphs 3, 4, 5.l.! and 7.4 of regulation 13;

.2.3 contain inorganic acid; or

.2.3.1 jeopardize the safety of ships or adversely affect the performance of the machinery, or

.2.3.2 be harmful to personnel, or

.2.3.3 contribute overall to additional air pollution.

4 This regulation does not apply to coal in its solid form or nuclear fuels. Paragraphs 5, 6, 7.1, 7.2, 8.1, 8.2,9.2,9.3, and 9.4 of this regulation do not apply to gas fuels such as liquefied natural gas, compressed natural gas or liquefied petroleum gas. The sulphur content of gas fuels delivered to a ship specifically for combustion purposes on board that ship shall be documented by the supplier.

5 For each ship subject to regulations 5 and 6 of this Annex, details of fuel oil for combustion purposes delivered to and used on board shall be recorded by means of a bunker delivery note that shall contain at least the information specified in appendix V to this Annex.

6 The bunker delivery note shall be kept on board the ship in such a place as to be readily available for inspection at all reasonable times. It shall be retained for a period of three years after the fuel oil has been delivered on board.

7.1 The competent authority of a Party may inspect the bunker delivery notes on board any ship to which this Annex applies while the ship is in its port or offshore terminal, may make a copy of each delivery note, and may require the master or person in charge of the ship to certify that each copy is a true copy of such bunker delivery note. The competent authority may also verify the contents of each note through consultations with the port where the note was issued.

7.2 The inspection of the bunker delivery notes and the taking of certified copies by the competent authority under this paragraph shall be performed as expeditiously as possible without causing the ship to be unduly delayed.

8.1 The bunker delivery note shall be accompanied by a representative sample of the fuel oil delivered taking into account guidelines developed by the Organization. The sample is to be sealed and signed by the supplier's representative and the master or officer in charge of the bunker operation on completion of bunkering operations and retained under the ship's control until the fuel oil is substantially consumed, but in any case, for a period of not less than 12 months from the time of delivery.

8.2 If an Administration requires the representative sample to be analysed, it shall be done in accordance with the verification procedure set forth in appendix VI to determine whether the fuel oil meets the requirements of this Annex.

9 Parties undertake to ensure that appropriate authorities designated by them:

.1 maintain a register of local suppliers of fuel oil;

.2 require local suppliers to provide the bunker delivery note and sample as required by this regulation, certified by the fuel oil supplier that the fuel oil meets the requirements of regulations 14 and 18 of this Annex;

.3 require local suppliers to retain a copy of the bunker delivery note for at least three years for inspection and verification by the port State as necessary;

.4 take action as appropriate against fuel oil suppliers that have been found to deliver fuel oil that does not comply with that stated on the bunker delivery note;

.5 inform the Administration of any ship receiving fuel oil found to be non-compliant with the requirements of regulation 14 or 18 of this Annex; and

.6 inform the Organization for transmission to Parties and Member States of the Organization of all cases where fuel oil suppliers have failed to meet the requirements specified in regulations 14 or 18 of this Annex.

10 In connection with port State inspections carried out by Parties, the Parties further undertake to:

.1 inform the Party or non-Party under whose jurisdiction a bunker delivery note was issued of cases of delivery of non-compliant fuel oil, giving all relevant information; and

.2 ensure that remedial action as appropriate is taken to bring non-compliant fuel oil discovered into compliance.

11 For every ship of 400 gross tonnage and above on scheduled services with frequent and regular port calls, an Administration may decide after application and consultation with affected States that compliance with paragraph 6 of this regulation may be documented in an alternative manner that gives similar certainty of compliance with regulations 14 and 18 of this Annex.