UNIVERSITY OF PIRAEUS

Department of International and European Studies

Postgraduate Program

Energy: Strategy, Law and Economics

Dissertation Title:

Towards greener shipping:

Regulatory measures on ship energy efficiency and emissions reduction

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Piraeus, 2021

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To my father

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Abstract

The seaborne trade accounts for approximately 90 per cent of the global trade and economy, proving the power of this industry. The maritime transport of goods and raw materials remains the most cost-effective and energy-efficient means of transporting of large volume of cargo in comparison to road and rail. Nevertheless, the need for the immediate international actions on the climate crisis and global warming entails the reduction of emissions resulting from all sectors. The Kyoto Protocol indicated in its Article 2.2 the International Maritime Organization (IMO) as the global regulator for the reduction of emissions from international shipping. In line with that the International Maritime Organization (IMO) has developed a regulatory framework addressing to the control of the emissions of the air pollutants and to the improvement of ship energy efficiency, by limiting the emissions of the greenhouse gases. This thesis includes the main regulatory measures adopted for the reduction of the emissions of the Sulphur Oxides (SO_x), Particulate Matter (PM), Nitrogen Oxides (NO_x), and of the greenhouse gases (GHG), including Carbon Dioxide (CO_2), Methane (CH_4) and Nitrous Oxide (N_2O), expressed in CO_2e and concludes to the significance of the efforts of the International Maritime Organization (IMO) into minimizing the impact of the international shipping to the climate change.

Introduction

Undoubtedly our planet faces a climate crisis that is caused due to numerous human activities, which alter the natural equilibrium of the atmosphere, leading to global warming and other environmental issues. According to a report of World Meteorological Organization (WMO), released in 2019, the planet is at least one degree Celsius above preindustrial levels and close to what scientists warn would be "an unacceptable risk"(United Nations). Apart from this aspect though, climate change affects directly or indirectly the human health, provoking a large number of serious health issues and even augmenting the death rates worldwide. In order to tackle this global threat, the international community has made different kinds of efforts, by signing agreements, creating plans and legislations and implementing specific environmental policies. The global attempts' peak is the ratification of Paris agreement in 2015, setting the goal to limit global warming to well below 2, preferably to 1.5 degrees Celsius, compared to pre-industrial levels.

Although the share of international shipping to climate change cannot be compared to this of other industries and means of transports, the same cannot be neglected, especially due to the fact of the observed rising trends of emissions from ships. In response to this urgent need for prompt action with the aim of mitigating the climate change, the International Maritime Organization (IMO), through the Marine Environment Protection Committee (MEPC), has in depth studied the contribution of merchant shipping to this global issue and established a regulatory framework for the control and limitation of the ships' emissions and the improvement of the ships' energy efficiency. This regulatory regime comprises a large list of measures adopted and amended over the years, based on the technological advancements and implementation experience.

The aim of this thesis is to summarize and present the regulatory measures adopted by the International Maritime Organization (IMO) included under the MARPOL ANNEX VI and conclude to the necessity of their implementation, despite any potential cost arising. In particular:

In Chapter One, the analysis of the climate change and the greenhouse effect is provided in order to be comprehended the alarming situation of our planet and the need for international act.

In Chapter Two, the contribution of the shipping sector and the regulatory framework resulting through MARPOL ANNEX VI is presented.

In Chapter Three, the regulatory measures concerning the Sulphur Oxides (SOx) and Particulate Matter (PM) and Nitrogen Oxides (NOx), applying inside and outside the Emission Control Areas (ECA), are mentioned.

In Chapter Four, the regulatory measures for the ship energy efficiency, including the Energy Efficiency Design Index (EEDI), the Ship Energy Efficiency Management Plan (SEEMP), the Energy Efficiency Operational Indicator (EEOI) and the latest measures of the Energy Efficiency Existing Ship Index (EEXI) and the Carbon Intensity Indicator (CII) are further analyzed.

Finally, in Chapter Five the conclusions, regarding the necessity of the regulatory measures on ships' energy efficiency and emission reduction, are cited.

CHAPTER ONE: CLIMATE CHANGE AND THE GREENHOUSE EFFECT

1.1 Climate System and Climate Change

The climate of an area is defined as the average of weather conditions for a long-term period of time. The term of weather is referred to the fluctuating state of the atmosphere around us, more specifically to rapidly developing changes occurring in limited time-range, from week to week or even for a shorter period, within a day or a few minutes. Moreover, a wide range of meteorological variables is commonly used in order to measure the weather conditions, such as the atmospheric pressure, the wind, the temperature, the humidity and the precipitation. A severe phenomenon, such as a snowstorm could be described as weather, if it is not continuous in a long time scale. On the other hand, any kind of a repeated atmospheric phenomenon could shape the climate of a certain region. Thus, climate constitutes the synthesis of weather conditions of a certain region and it is consisted of the statistical information describing the changes of the weather conditions of this specific region for over a certain time-span, in terms of their mean and variability (Melas a.o.2000, IPCC 2001). A typical period of analysis of weather conditions, in order to characterize the climate of a region, is this of thirty years. Climate regimes found on Earth may vary depending on numerous geographical factors, such as the latitude, distance to the sea and presence or absence of mountains. Climate also varies in time, from year to year, decades to decades or longer time-scales and is affected in great measure by external causes, such as the human activities, which are limited predictable, but have a remarkable impact on the climate state.

According to the report of IPCC “Climate Change 2001: The Scientific Basis”, the climate system is determined as a complicated and interactive system consisting of five major components: the atmosphere, the hydrosphere, including all liquid surface and subterranean water, both fresh and saline water, the cryosphere, comprising the ice sheets of Greenland and Antarctica, continental glaciers and snow fields, sea ice and permafrost, the land surface and the biosphere

. The aforementioned subsystems are interrelated, interdependent and interacting, through intricate physical, chemical and biological processes on a wide time range and space. Apart from internal interactions, they are also significantly influenced by various external factors. The most important external forcing mechanism is the Sun. The ultimate source of energy that drives the climate system is the radiation from the Sun. The solar radiation delivers the energy that drives weather phenomena and shapes the climate. Roughly one third of the solar radiation is reflected back into space while the rest is absorbed by the different components of the climate system: the atmosphere, oceans, land and various life forms. Besides the reflected shortwave solar radiation, the earth emits infrared radiation to space. The balance between incoming solar radiation and outgoing radiation determines the global climate (Melas a.o. 2000). Also, the balance of incoming and outgoing energy and its distribution to the climate system determines the Earth’s energy budget. In case of the incoming energy is greater that the outgoing, the Earth's energy budget is positive and the climate system is getting warmer. In case of more outgoing emitted energy, then the Earth's energy budget is negative and results to a colder climate system. Balancing the global energy budget is a fundamental aspect of the climate system.

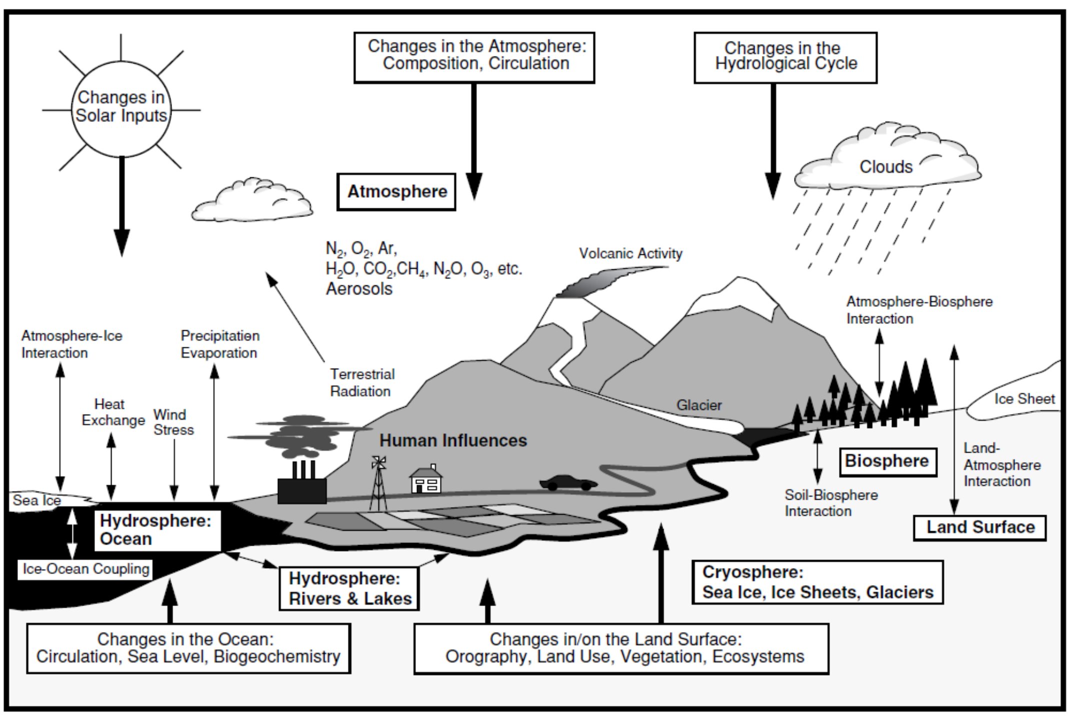

Figure 1: Schematic view of the components of the global climate system, their processes and interactions and some aspects that may change (IPCC, 2001: Climate Change 2001: The Scientific Basis)

Any internal or external factor that has a direct influence on the equilibrium of the incoming solar radiation and the outgoing emitted radiation and the mechanism of redistribution of the energy through the climate system, induce climate variability and climate change. As per International Panel on Climate Change (IPCC), climate change refers to a change in the state of the climate that can be identified by changes in the mean and/or the variability of its properties and that persists for an extended period, typically decades or longer. The climate change may be due to natural internal processes or external forcings such as modulations of the solar cycles, volcanic eruptions and persistent anthropogenic changes in the composition of the atmosphere or in land use. The Framework Convention on Climate Change (UNFCCC), in its Article 1, defines climate change as: ‘a change of climate which is attributed directly or indirectly to human activity that alters the composition of the global atmosphere and which is in addition to natural climate variability observed over comparable time periods.’ The UNFCCC thus makes a distinction between climate change attributable to human activities altering the atmospheric composition and climate variability attributable to natural causes (IPCC).

1.2 The Greenhouse Effect

The greenhouse effect is a natural phenomenon that is beneficial for the global climate system and the existence of human kind on Earth, since it plays a critical role into preserving the average adequate temperature in order to provide the necessary conditions to harbor life on our planet. The greenhouse effect was first discovered by Joseph Fourier in 1827, experimentally verified by John Tyndall in 1861, and quantified by Svante Arrhenius in 1896. The greenhouse effect is a physical process, whereby part of the infrared radiation, emitted by the Earth’s surface (after being heated by the solar radiation), is absorbed by certain trace gases of the atmosphere, which are known as greenhouse gases. These gases reradiate the infrared radiation towards the Earth in all directions, including downward to the Earth’s surface, resulting to the increase of the temperature of the surface of the planet. The greenhouse gases allow the sunlight to pass through the atmosphere to the surface of Earth and capture heat within the atmosphere, as does the glass of the greenhouse. This natural mechanism is an essential part of the energy balance of the Earth, because without the natural greenhouse effect, the global average surface temperature of 15 ˚C would drop to - 19 ˚C, inducing a tremendous alteration of 34 ˚C, rendering Earth an inhabitable planet for the human race.

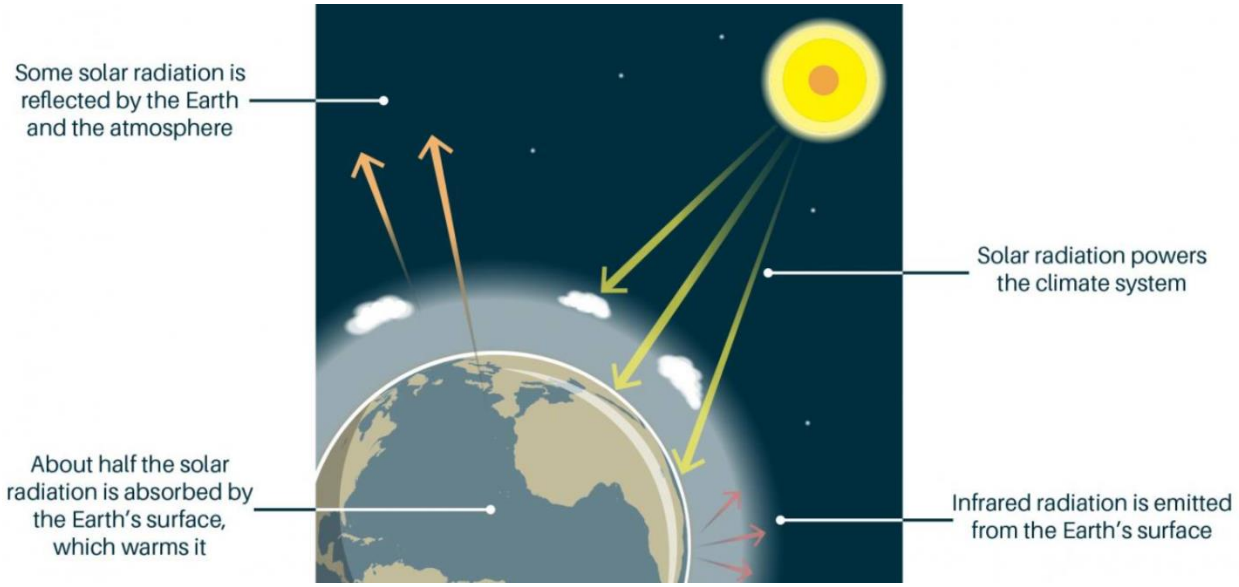

Figure 2: The Greenhouse Effect (British Geological Survey)

The whole of the greenhouse gases does not present the same level of contribution to the greenhouse effect. On the contrary, each one of below mentioned gases contribute in a different scale, depending on the percentage of each found at the atmosphere, the grade of heat that it traps and its re-radiation to the Earth's surface. In descending order of concentration, the gases that contribute most to the Earth's greenhouse effect are:

- water vapor (H_2O)
- carbon dioxide (CO_2)
- methane (CH_4)
- nitrous oxide(N_2O)
- ozone (O_3)
- fluorinated gases: hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), sulphur hexafluoride (SF_6), nitrogen trifluoride (NF_3)

The atmosphere of the Earth is consisted of 78 per cent nitrogen, 21 per cent oxygen, 0.9 per cent argon, and only 0.1 per cent of the above mentioned natural greenhouse gases. Human beings, like other living organisms, have always influenced their environment. It is only since the beginning of the Industrial Revolution, in the mid-18th century, that the impact of human activities has begun to extend to a much larger scale, continental or even global. Human activities, in particular those involving the combustion of fossil fuels for industrial or domestic usage, and biomass burning, produce greenhouse gases and aerosols which affect the composition of the atmosphere (IPCC 2001). The burning of fossil fuels has elevated carbon dioxide (CO_2) levels from an atmospheric concentration of approximately 280 parts per million (ppm) in pre-industrial times to over 400 ppm in 2018 (BGS). Furthermore the agriculture, the deforestation, the change of the use of land, the economic and population growth are listed under the anthropogenic factors that lead to the increase of the emissions of several greenhouse gases. This continuous increase of emissions have upset the equilibrium between emissions of greenhouse gases from natural sources on the one hand and removal of these gases by so-called "sink" on the other, which had kept atmospheric concentrations relatively constant in pre-industrial times (Bodansky, 1993). The term "sinks" includes the vegetation, the plans and trees, which sequester carbon through the natural procedure of photosynthesis, soil and the oceans, which absorb carbon at the surface and store it at great depths. The notable modification of the amount of the greenhouse gases by the enlargement of human activities has resulted to the enhancement of the greenhouse effect. More specifically, the enhanced greenhouse effect is determined as the increase of concentration of these greenhouse gases in the atmosphere that act as heat trappers, by absorbing and emitting more infrared radiation towards Earth, contributing this way to the global warming, melting ice-caps and as a consequence the rising sea levels and flooding. In the post-industrial era the global average temperature has increased in total by approximately more than 1 degree Celsius, as a result of the enhanced greenhouse effect.

1.3 The Greenhouse Gases

The greenhouse gases have been briefly presented at previous sub-chapter. Some greenhouse gases occur naturally and other enter the atmosphere as a result of both natural processes, such as decomposition of organic matter, and human activities, such as burning fossil fuels and agriculture. The greenhouse gases that occur both naturally and from human activities include water vapors (H_2O), carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O) and ozone (O_3). There are also greenhouse gases that have not natural sources, but are side products of industrial processes or manufactured for human purposes such as cleaning agents, refrigerants, and electrical insulators. These include the fluorinated gases: hydrofluorocarbons (HCFCs), perfluorcarbons, PFCs, and sulfur hexafluoride, (SF6) (ACS, Chemistry for Life). Furthermore, each greenhouse gas affects the climate system and by extension climate change in various ways. The aforementioned varied influence of each greenhouse gas depends on three essential factors:

- The concentration or abundance of a particular gas to the atmosphere: The concentration of each greenhouse gas in the atmosphere is typically measured in parts per million (ppm), parts per billion (ppb), and even parts per trillion (ppt) by volume. The larger the emissions of a particular greenhouse gas are, the higher its concentrations would be in the atmosphere. (EPA,IPCC)

- The lifetime of each greenhouse gas to the atmosphere: Atmospheric lifetime of greenhouse gases varies, since their atmospheric residence time is answered in different time-scales. Greenhouse gases could remain in the atmosphere from a few years to thousands of years, before being removed by natural processes. Consequently it is easily understood that the greenhouse gases stay in the atmosphere for a long-term period and they are uniformly mixed, leading to the conclusion that the amount that it is measured in the atmosphere is approximately similar worldwide, despite the emissions' sources. (EPA,IPCC)

- The level of impact of each gas to the atmosphere: As mentioned at previous sub-charter, some greenhouse gases contribute more to the greenhouse effect than other. In order to further analyze the impact of each greenhouse gas, scientists have calculated a Global Warming Potential (GWP) for each greenhouse gas, a measure of the radiative effect (i.e. the strength of their greenhouse effect) of each unit of gas (by weight) over a specified period of time, expressed relative to the radiative effect of carbon dioxide (CO_2). This is often calculated over 100 years, though it can be done for any time period. Gases with high GWPs will warm the Earth more than an equal amount of CO_2 over the same time period. A gas with a long lifetime, but relatively low radiative efficiency, may end up exerting more warming influence than a gas that leaves the atmosphere faster than the time window of interest but has a comparatively high radiative efficiency, and this would be reflected in a higher GWP (C2ES, Center for Climate and Energy Solutions).

The table below depicts the Global Warming Potential (GWP) values and Atmospheric Lifetime for major greenhouse gases from the Fifth IPCC Assessment Report (AR5) released in 2014.

Global Warming Potential and Atmospheric Lifetime for Major Greenhouse Gases

Greenhouse gas	Chemical formula	Global Warming Potential, 100-year time horizon	Atmospheric Lifetime (years)
Carbon Dioxide	CO2	1	100*
Methane	CH4	25	12
Nitrous Oxide	N2O	265	121
Chlorofluorocarbon-12 (CFC-12)	CCl2F2	10,200	100
Hydrofluorocarbon-23 (HFC-23)	CHF3	12,400	222
Sulfur Hexafluoride	SF6	23,500	3,200
Nitrogen Trifluoride	NF3	16,100	500

Table 1: Global Warming Potential and Atmospheric Lifetime for Major Greenhouse gases [Fifth Assessment Report (Intergovernmental Panel on Climate Change, 2014)].

* No single lifetime can be given for carbon dioxide because it moves throughout the earth system at differing rates. Some carbon dioxide will be absorbed very quickly, while some will remain in the atmosphere for thousands of years.

1.3.1 Water Vapors

The greenhouse gas with the most remarkable impact on the greenhouse effect is by far this of water vapor, contributing on average about 60 per cent of the warming effect. In addition, water vapor is the most abundant greenhouse gas overall both by weight and by volume in the atmosphere. The majority of the scientific reports state that water vapors are not directly linked to anthropogenic sources, but are referred as a positive feedback loop. The water vapor feedback mechanism works in the following way: as the atmosphere warms due to human-caused increases in carbon dioxide, methane, nitrous oxide, and chlorofluorocarbons, water vapor increases, trapping more heat in the atmosphere, which in turn causes a further increase in water vapor (ScienceDaily), amplifying this way the process of global warming. According to American Chemistry Society though, human sources have only a small direct influence on tropospheric water vapor concentrations, because they are largely controlled by local temperatures. Furthermore, water vapors remain in the atmosphere for a much shorter time-period in comparison with the rest of the greenhouse gases. More specifically, its atmospheric lifetime is calculated to be from hours to days, before precipitating out. However, due to poor measurements of global water vapor, the percentage of increase of concentration of water vapors in the atmosphere in recent decades or centuries is still uncertain.

1.3.2 Carbon Dioxide (CO_2)

Carbon dioxide emissions are the primary driver of global climate change and account for about 76 per cent of total greenhouse gas emissions. As previously mentioned Carbon Dioxide (CO_2) can occur from naturally processes as well as from activities related to the industrialization of human societies. Main carbon dioxide (CO_2) natural sources include the decomposition of organic matter, the photosynthesis of plants and respiration of animals and the gas exchange between the atmosphere and the ocean. To a lesser extent, a very small amount of CO_2 (roughly 1 per cent of the emission rate from fossil fuel combustion) is also emitted in volcanic eruptions. This is balanced by an equivalent amount that is removed by chemical weathering of rocks (The Royal Society). On the other hand, the augmenting need for burning of fossil fuels, oil, coal and natural gas, for road, rail, air and marine transportation, industrial and manufacturing processes, cement and petroleum production or even agriculture practices plays a crucial role for the increase of the world's carbon footprint. Additionally, the deforestation in combination with the alteration of land usage, occurring for human purposes' related reasons, constitute significant causes of the increased concentration of the carbon dioxide (CO_2) in the atmosphere. In general, human sources of carbon dioxide emissions are much smaller than natural emissions but they have upset the natural balance that existed for many thousands of years before the influence of humans. This is because natural sinks remove around the same quantity of carbon dioxide from the atmosphere than are produced by natural sources. This had kept carbon dioxide levels balanced and in a safe range. But human sources of emissions have upset the natural balance by adding extra carbon dioxide to the atmosphere without removing any (CO_2 Human Emissions). Carbon dioxide emissions are increasing faster in some parts of the world than in others. The majority of emissions come from three regions: East Asia and Pacific, Europe and Central Asia, and the United States, which together accounted for 74 per cent of total global emissions in 2018. (EPA). The atmospheric lifetime of carbon dioxide CO_2 is not precise. A part of the excess carbon dioxide will be quickly naturally absorbed by natural sinks, such as oceans and land, while the time residence of others could extend to thousands of years, inducing a severe long-term impact to the climate system. The rising trend of the concentrations of carbon dioxide in the atmosphere throughout the years is depicted at below figure.

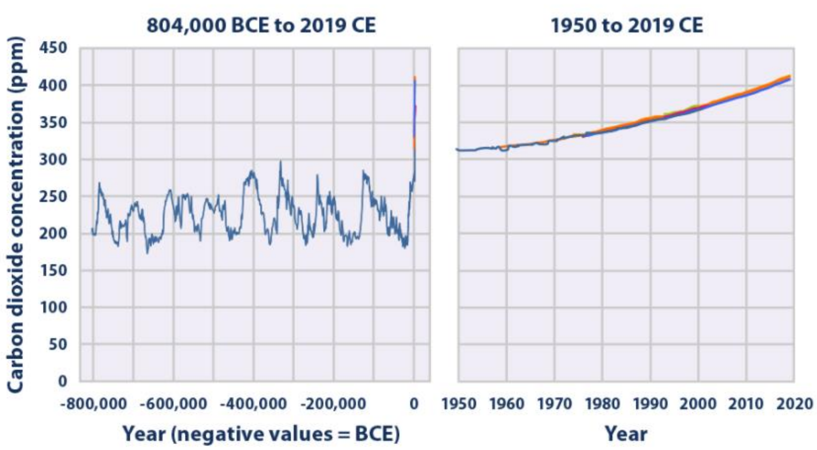

Figure 3: The rising trend of carbon dioxide CO_2 throughout the years

1.3.3 Nitrous Oxide (N_2O)

Nitrous Oxide (N_2O) is also a greenhouse gas with significant contribution to the enhancement of the greenhouse effect, as it is estimated that comprises approximately 6 per cent of greenhouse gas emissions. Moreover, according to IPCC the impact of 1 pound of N_2O on warming the atmosphere is almost 300 times that of 1 pound of carbon dioxide (CO_2) (IPCC 2007). In addition, it is a chemical inert but relatively short-lived gas in the troposphere (lower atmosphere) in comparison to carbon dioxide CO_2 and some fluorinated gases. In particular nitrous oxide molecules stay in the atmosphere for an average of 120 years before moving into the stratosphere where they ultimately lead to destruction of stratospheric ozone (EPA, SOEST). Thus, nitrous oxide (N_2O) apart from being a greenhouse gas is also an ozone destroyer. The said greenhouse gas is also emitted to atmosphere from several natural and anthropogenic sources. Natural production of nitrous oxide is from microbial activity in soils and in the ocean and after nitrous oxide production by the microbes the gas goes to the atmosphere (SOEST). The emissions from natural sources have not changed much over the recent years. On the other hand, emissions from human factors show a rising trend. A 2020 review of nitrous oxide sources and sinks found that emissions rose 30 per cent in the last four decades and are exceeding all but the highest potential emissions scenarios described by the IPCC (BBC, The world's forgotten greenhouse gas). In particular, according to the World Meteorological Organization (WMO), atmospheric concentrations of N_2O reached 331 parts per billion in 2018, 22 per cent above levels around the year 1750, before the industrial era began. The human-related nitrous oxide emissions come from the agriculture, land usage, fuel combustion, industry and waste. The major contributor is by far the agricultural activities, causing almost 70 per cent of global N_2O emissions in the decade to 2016 (Sustainability Times), with the use of synthetic and organic fertilizers and other cropping practices that induce emission from microbial processes in soils.

1.3.4 Methane (CH_4)

Methane (CH_4) is a hydrocarbon that is a primary component of natural gas and is the second most important greenhouse gas in terms of concentration and impact on the climate change, accounting for about 20 per cent of global emissions from anthropogenic sources. Its concentrations by volume in the atmosphere are generally measured in parts per billion (ppb) rather than parts per million (ppm) (Britannica). Although it exists in far lower concentrations than carbon dioxide in the atmosphere, methane, pound for pound, is more than 25 times as potent as carbon dioxide at trapping heat in the atmosphere, over a 100-year period and more than 80 times more powerful over a 20-year timescale. Methane has on average a shorter residence time in the atmosphere than the rest greenhouse gases, this of approximately ten years. However, due to the fact that there are a lot of sources of methane, the atmospheric load is constantly being regenerated or increased. The sources of methane emissions are also both natural and human-related. The main natural sources include the wetlands and green plants. Anthropogenic sources include livestock farming (methane is generated in the stomachs of ruminants), the decomposition of organic matter in landfills, rice cultivation, manure, the combustion of biomass, coal mining, natural-gas production and transmission. Although methane is gradually destroyed in reactions with other gases in the atmosphere, it is being added to the atmosphere faster than it can be broken down (Britannica, Environmental Science, toward a sustainable future). Since the Industrial Revolution, methane concentrations in the atmosphere have more than doubled, and about 20 per cent of the warming the planet has experienced can be attributed to this gas (National Geographic).

1.3.5 Ozone (O_3)

Ozone (O_3) is a greenhouse gas that is naturally present and plays a different role whether it is found in the higher or the lower level of the atmosphere. On the one side, the ozone at the higher elevations in the atmosphere, the stratosphere, forms a layer that blocks ultraviolet (UV) light, which is harmful to plant and animal life, from reaching the earth’s surface (U.S. Energy Information Administration). On the other side, the ozone that is found at lower elevations of the atmosphere, the troposphere is a harmful air pollutant that is a major component of urban smog, and also enhances the greenhouse effect. Tropospheric ozone at ground level occurs naturally only in small amounts. In particular some descends from the stratosphere and some is released by the plants and soil. However, the greatest sources of tropospheric ozone are related to human activities. It does not have any direct emissions sources, rather it is a secondary gas formed by the interaction of sunlight with hydrocarbons – including methane – and nitrogen oxides, which are emitted by vehicles, fossil fuel power plants, and oil refineries, the agriculture sector and a number of other industries (Climate & Clean Air Coalition). Even though tropospheric ozone has a short atmospheric lifetime of hours to weeks, it has a detrimental impact on human health, agriculture, ecosystems and the climate change.

1.3.6 Fluorinated gases (F-gases)

Fluorinated gases are a group of powerful greenhouses gases that do not result from any natural source, are entirely man-made and their emissions are rising strongly. The main four fluorinated gases, also known as F-gases, are the hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), sulphur hexafluoride (SF_6) and nitrogen trifluoride (NF_3). The F-gases are used in a range of industrial applications, such as aluminum and semiconductor manufacturing and as substitutes for ozone-depleting substances for refrigeration and air-conditioning, because they do not damage the atmospheric ozone layer. However, the F-gases have very high global warming potentials (GWPs) over a 100-year time horizon in comparison to the rest of greenhouse gases, with a severe effect on global temperatures, even in small atmospheric concentration. In particular, the global warming potential of this family of gases starts from 12.400 and reaches up to 23.500 times greater than carbon dioxide. Furthermore, the perfluorocarbons and sulphur hexafluoride also have a long residence time in the atmosphere, which could last thousands of years. In case of hydrofluorocarbons, a new subset has been developed, which is characterized by shorter atmospheric lifetimes, between 15 and 29 years in the atmosphere, and lower GWPs. Generally, the F-gases are the most potent and longest lasting type of greenhouse gases emitted by anthropogenic sources. For that reason, their use has been set under regulation in order to phase them down.

1.4 The need for international act

Even in the late 1960s and '70s the climatologists worldwide have started expressing concerns for the rising emissions of greenhouse gases and especially the concentration of carbon dioxide (CO_2) that would progressively lead to the climate crisis, as it is known nowadays. However, it was not until 1988 when the World Meteorological Organization and the United Nations Environment Programme (UNEP) decided to establish the Intergovernmental Panel on Climate

Change (IPCC) in order to further examine the global warming and climate change. Two years later, in 1990, the first assessment report of the IPCC was issued, which reflected the opinions of 400 scientists worldwide, identifying the climate change as a global problem of unique and urgent character and urging for immediate action to be taken. It also called for negotiations to begin on a framework convention without any further delay. Consequently, in 1992 the United Nations Conference on Environment and Development was held in Rio de Janeiro, also known as "Earth Summit", where the United Nations Framework Convention on Climate Change (UNFCCC) was ratified, initially by 166 countries and came into force on 21 March 1994. It is the first global treaty to address climate change, setting a framework for cooperation among nations to tackle this global issue. In particular, its objective is "to stabilize greenhouse gas concentrations in the atmosphere at a level that will prevent dangerous human interference with the climate system, in a time frame which allows ecosystems to adapt naturally and enables sustainable development." (UNFCCC, Article 2). As of today, it has been signed by 197 countries, including United States of America. The UNFCCC also established an annual forum, known as the Conference of the Parties, or COP, for international discussions aimed at stabilizing the concentration of greenhouse gases in the atmosphere. These meetings produced the Kyoto Protocol and the Paris Agreement (Council on Foreign Relations).

The first subsidiary agreement to the UNFCCC was Kyoto Protocol, which was adopted in 1997, and entered into force on 16 February 2005, seven years after it was negotiated by over 160 nations. It was the first ever legal binding treaty that required 37 high-income countries and the European Union (EU) to reduce their greenhouse gases' emissions on average by 5 per cent below 1990 levels during 2008-2012. It precluded greenhouse gases' mitigation obligations for developing countries, including major carbon emitters, such as China and India. The United States of America signed the agreement in 1998 but never ratified it and later withdrew its signature (Congressional Research Service, Council on Foreign Relations). Specific guidelines for the proper implementation of the Protocol were adopted at in Marrakesh in 2001, also known as "Marrakesh Accords". The Protocol's first commitment period lasted from 2008 until 2012, while the second started in 2013 and ended in 2020. During the second commitment period the parties agreed an enhanced reduction target of greenhouse gases' emissions, aiming by at least

18 percent below 1990 levels. The Kyoto Protocol contains provisions for reducing greenhouses gases' emissions from international aviation and shipping and treats these sectors in a different way to other sources due to their global activities that is, pursuing though the International Civil Aviation Organization (ICAO) and the International Maritime Organization (IMO) respectively. Emissions from domestic aviation and shipping are included in national targets for Annex I countries. The International Civil Aviation Organization and the International Maritime Organization (IMO) regularly report progress on their work to UNFCCC (IMO).

On 12 December 2015, the second major subsidiary agreement under the UNFCCC was adopted in Paris. The historic Paris Agreement is by far the most significant treaty established, setting the adequate framework for its parties in order to perform a limit policy on greenhouse gases. Initially, it was intended to be legally binding, though not all provisions in it are compulsory. More specifically, under the Paris Agreement, the below have been agreed (Australian Government, Department of Foreign Affairs):

- A global goal to limit average temperature increase to well below 2°C above pre-industrial levels and pursue efforts to keep warming below 1.5°C
- All countries will make nationally determined contributions to reduce emissions, and review their efforts every five years, to build ambition over time
- Robust transparency and accountability rules that will provide confidence in countries' actions and track progress towards targets
- The importance of adaptation and resilience to climate impacts
- Developing countries will receive financial, technological and capacity building support.

It is important to underline that there is not any direct reference to the International Maritime Organization at the articles of the Paris Agreement. However, the International Maritime Organization (IMO) through MEPC 69 in 2016 welcomed the Paris Agreement and acknowledged the major achievement of the international community in concluding the agreement and recognized that further efforts need to be pursued for the mitigation of the impact of emissions from international shipping (IMO).

CHAPTER TWO: THE IMPACT OF SHIPPING TO CLIMATE CHANGE

2.1 Air pollutants emitted from ships

Even in primary forms of population groups and human societies, the maritime transportation of people and goods was identified as the most safe and time-efficient way, regardless the dependence from the weather conditions. In the following years of Industrial Revolution, steam-powered sea-going vessels were larger and faster, with increased efficiency in order to pace and satisfy the augmenting needs arising from the population and economic growth. The global activity that characterizes shipping industry was created and international trade was established. In the recent years, steam engines have been replaced by oil-powered marine engines, burning fuel oils, consisted mainly of hydrocarbons and suplhur compounds that vary depending on fuel type. The most common used kinds of fuel oils by the shipping industry nowadays are: marine diesel oil (MDO), intermediate fuel oil (IFO), marine fuel oil (MFO), and heavy fuel oil (HFO). The propulsion of ocean-going ships is accomplished by the combustion of marine fuels, developing thermal energy and transforming it to mechanical energy. More specifically, the fuel is injected to the marine engine at a controlled amount at high pressure and mixed with air. This process results to an explosion due to compression that releases heat, which powers the engine system. This is a continuous procedure, that upon its completion each time, exhaust gases are drawn out and emitted and fresh air is provided for the following combustion. Exhaust gases emitted from marine diesel engines comprise nitrogen (N_2), oxygen (O_2), carbon dioxide (CO_2) and water vapor (H_2O) as well as other pollutants in smaller quantities, including nitrogen oxides (NO_x), sulphur oxides (SO_x), carbon monoxide (CO), partially reacted and non-combusted hydrocarbons (HC), and particulate matter (PM).

In addition to carbon dioxide (CO_2), which is the primary driver of climate change, the emission of sulphur oxides (SO_x), particulate matter (PM) and nitrogen oxides (NO_x) also constitute notable coefficients of the air pollution and global environmental issue. Therefore the presentation of these three most important exhaust gases is cited below.

Oxides of Sulphur (SO_x)

Sulphur Oxides' emissions are caused by the content of sulphur compounds in the marine fuels used in marine engines onboard vessels. During the process of combustion, the sulphur is oxidized principally forming sulphur dioxide (SO_2) and, to a much lesser extent, sulphur trioxide (SO_3) (Kristenen, 2015). It is easily understood that the lower the presence of the sulphur is in the marine fuel, the lower the emission rate of SO_x shall be. Concerns over the sulphur oxides are based on the harmful influence their emission has on human health. In particular, the emission of SO_x contributes in formation of secondary inorganic aerosol gases, fine particles creating numerous health issues, such as intense problems of respiratory system, cardiovascular and lung disease. Moreover the release of SO_x in the atmosphere has another determined effect environment-wise, because SO_x induce acid rain, which impacts the deforestation, the aquatic species and is a contributor of the acidification of the oceans. (IMO)

Oxides of Nitrogen (NO_X)

Atmospheric Nitrogen is characterized as an inactive gas. At normal temperatures, oxygen and nitrogen gases do not react together. However, this reaction occurs forming the Oxides of Nitrogen, under certain operating conditions within the combustion chamber, favored at high temperatures and at optimal air-to-fuel ratios inside the internal combustion engines. The Oxides of Nitrogen formed are nitrogen monoxide (nitric oxide or NO) and nitrogen dioxide (NO_2) and are referred under the collective term of NO_x. The emission of NO_x also raises particular concern for remarkable impact on human respiratory system and the environmental problem of acid rain. In addition, NO_x emissions, together with volatile organic compounds (VOC), are also involved in a series of photochemical reactions leading to an increase in tropospheric ozone, which in turn, may adversely affect human health, crop yield and natural vegetation (Kristenen, 2015).

Particulate Matter

Particulate Matter are composed of a complicated synthesis of organic and inorganic substances, including mainly elemental carbon, ash minerals, heavy metals and various either non or partially combusted fuel and lubricating oils' hydrocarbon components. The size of particles is directly linked to their potential for causing health problems. Particulate Matter less than 10 micrometers in diameter are inhaled, affecting the lungs and the heart. They can remain in the human system and are absorbed into the bloodstream that can lead to several lung and heart-related disease, including cancers. According to a research for mortality from ship emissions, particulate matter are considered to contribute to the death of 60000 people worldwide. Furthermore, higher level or mortality due to particulate matter is found in Asia and in Europe, where the shipping activity and by extension particulate matter emission is more intense (Corbett, 2007).

2.2 The contribution of shipping industry to atmospheric pollution and climate change

According to UNCTAD Review of Maritime Transport 2020, regardless the severe pressure conditions and the health and economic fallout from the spread of CoVID-19 pandemic, the maritime transport sector remains the backbone of the international trade and globalization, since almost 90 per cent of volume of world merchandise trade, including a wide variety of goods and raw materials, from food and household items to iron, coal, fuels and chemicals, are carried by sea. The total world fleet grew by 4.1 per cent in 2019, numbering at the beginning of 2020 approximately 100.000 merchant vessels of 100 gross tons and above, sailing the world's oceans and marine shipping is still considered to provide the most cost-effective and energy-efficient means of transporting of large volume of cargo in comparison to road and rail. Nevertheless, emissions from shipping-related activities impact on air quality of continental coastlines and proximal urban fabric, with direct effects on public health. Recent scientific researches indicate that 400.000 premature deaths from lung cancer and cardiovascular disease were caused due to atmospheric pollution from ship emissions, before the use of cleaner fuels (Sofiev, Winebrake, Johansson, et al., 2018). Moreover the release of exhaust gases, both greenhouse gases and non-greenhouse gases, enhance directly or indirectly the greenhouse effect and global warming as well as contribute to the terrestrial and ocean acidification, amplifying the climate change. On top of these scientifically proven facts, more concerns are rising from the latest GHG Study published by International Maritime Organization (IMO) in 2020 which presents increasing trends of greenhouses gases of total shipping, including carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O), expressed in CO_2e, as well as of SO_x, NO_x and Particulate Matter. More specifically, the emissions of greenhouse gases (GHG) of total shipping have increased, showing a raise of 9.6 per cent over the period under examination, from 977 million tonnes in 2012 to 1,076 million tonnes in 2018. In regard to the specific category of CO_2 emissions, the same increasing tendency is observed, with the amount of CO_2 emissions growing by 9.3 per cent, from 962 million tonnes in 2012 to 1,056 million tonnes in 2018. Furthermore, according to the Fourth IMO GHG Study, the share of total shipping CO_2 emissions in global anthropogenic emissions has increased from 2.76 per cent in 2012 to 2.89 per cent in 2018.

At this point, it should be underlined the principal difference between the Fourth IMO GHG Study and the previous Study of IMO published in 2014. At the Third IMO GHG Study international and domestic GHG inventories were distinguished by a different method, referred to as vessel-based, which used vessel type and size characteristics to group ships, assuming to operate either domestically or internationally. This method resulted to assumptions for fleets of similar ship type and characteristics and was found to be quite defective. Thus, the Fourth IMO GHG Study presented an innovative method, called as voyage-based, which defines emissions distinguishing international from domestic operation, being at the same time exactly consistent with the IPCC guidelines, according to the consortium. However, for terms of comparison, further analysis and understanding of the international shipping emissions' trends, both of these methods are included at the last IMO GHG Study. The below cited table represents the total shipping CO_2 emissions, which is the dominant source of shipping's impact to climate change, for the period under examination from 2012 until 2018, including both voyage-based and vessel-based perspective.

Year	Global anthropogenic CO_2 emissions	Total shipping CO_2	Total shipping as a percentage of global	Voyage-based International shipping CO_2	Voyage-based international shipping as a percentage of global	Vessel-based International shipping CO_2	Vessel-based international shipping as a percentage of global
2012	34,793	962	2.76%	701	2.01%	848	2.44%
2013	34,959	957	2.74%	684	1.96%	837	2.39%
2014	35,225	964	2.74%	681	1.93%	846	2.37%
2015	35,239	991	2.81%	700	1.99%	859	2.44%
2016	35,380	1,026	2.90%	727	2.05%	894	2.53%
2017	35,810	1,064	2.97%	746	2.08%	929	2.59%
2018	36,573	1,056	2.89%	740	2.02%	919	2.51%

Table 2: Total shipping and voyage-based and vessel-based international shipping CO_2 emissions 2012-2018 (million tonnes) (Fourth IMO GHG)

In light of this new voyage-based method by Fourth GHG Study, it is observed that the total CO_2 emissions from international shipping has also increased, though to a lower growth of rate compared to total shipping emissions, fluctuating around approximately 2 per cent. The vessel-based allocation of Third GHG Study, presents a shipping emissions' raise of 8.4 per cent, from 848.000 million tonnes in 2012 to 919.000 million tonnes in 2018.

It is worth mentioning that container shipping, bulk carriers and oil tankers are the three main ship types that constitute the major sources of international shipping's greenhouse gases' emissions, which combined with chemical tankers, general cargo ships and liquefied gas tankers accounted for 86.5 per cent of international shipping's total emissions, when calculated on a voyage-based allocation. Additionally, the rate of the greenhouse gases' emission of each ship type varies depending on their operational status and needs. Indicatively, chemical tankers and oil tankers have on average the largest part of their total greenhouse gases' emissions, greater than 20 per cent, related to activities near the ports, while the liquefied gas tankers and other liquid tankers have their largest share of greenhouse gases' emission under conditions of normal cruising. The figure below depicts the proportion of international greenhouse gases per four different operation phases, normal cruising, on passage (slow transit), maneuvering and at berth / anchorage for a wide variety of vessels.

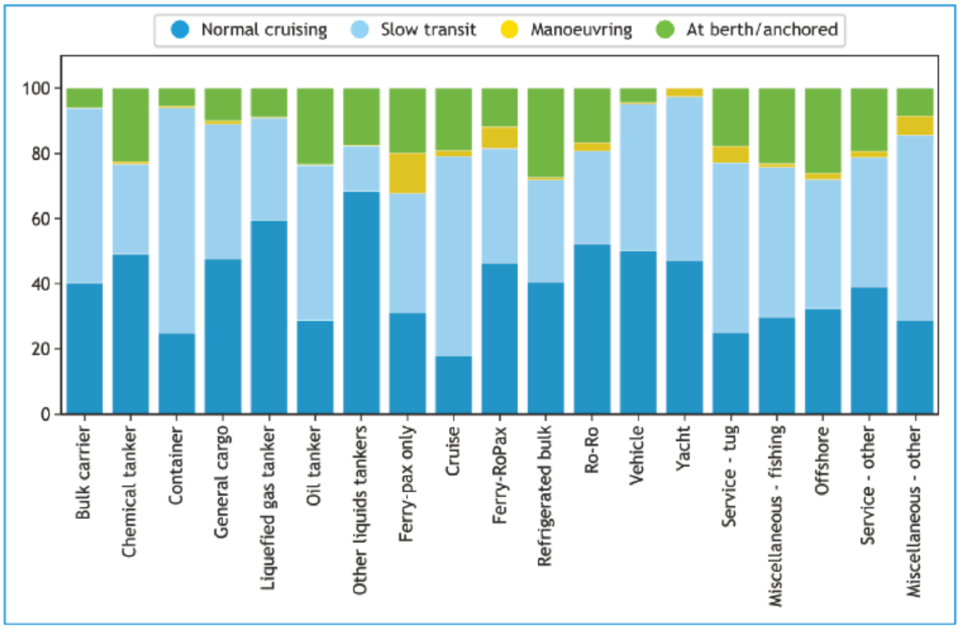

Figure 4: Proportion of international GHG emissions (in CO2e) by operational phase in 2018, according to the voyage-based allocation of emissions. Operational phases are assigned based on the vessel's speed over ground, distance from coast/port and main engine load (Fourth IMO GHG Study 2020)

On the other hand, fuel consumption as well as the different types of fuel remain the factors of the highest importance in relation to ship energy efficiency and the greenhouse gases' emissions, due to their direct influence on rate of emission induced from the combustion of fuel. Primarily the largest part of fuel consumption is used for propulsion purposes as accomplished by the main engine, followed by the need of electrical power generated by the auxiliary engines and the heat produced by boilers onboard.

With regard to the remaining major air pollutants, in the Third IMO GHG Study is stated that international shipping is annually responsible for approximately 13 per cent of global nitrogen oxides (NO_x) emissions and 12 per cent of global sulphur oxides (SO_x) emissions. The latest Study of IMO reveals an increase for both exhaust gases over the reference period; in spite of the actions already taken aiming their reduction. The overall increasing tendencies for numerous emissions species across the period of the Study, including greenhouse gases and air pollutants, are depicted with both vessel-based and voyage-based methods at below cited figure.

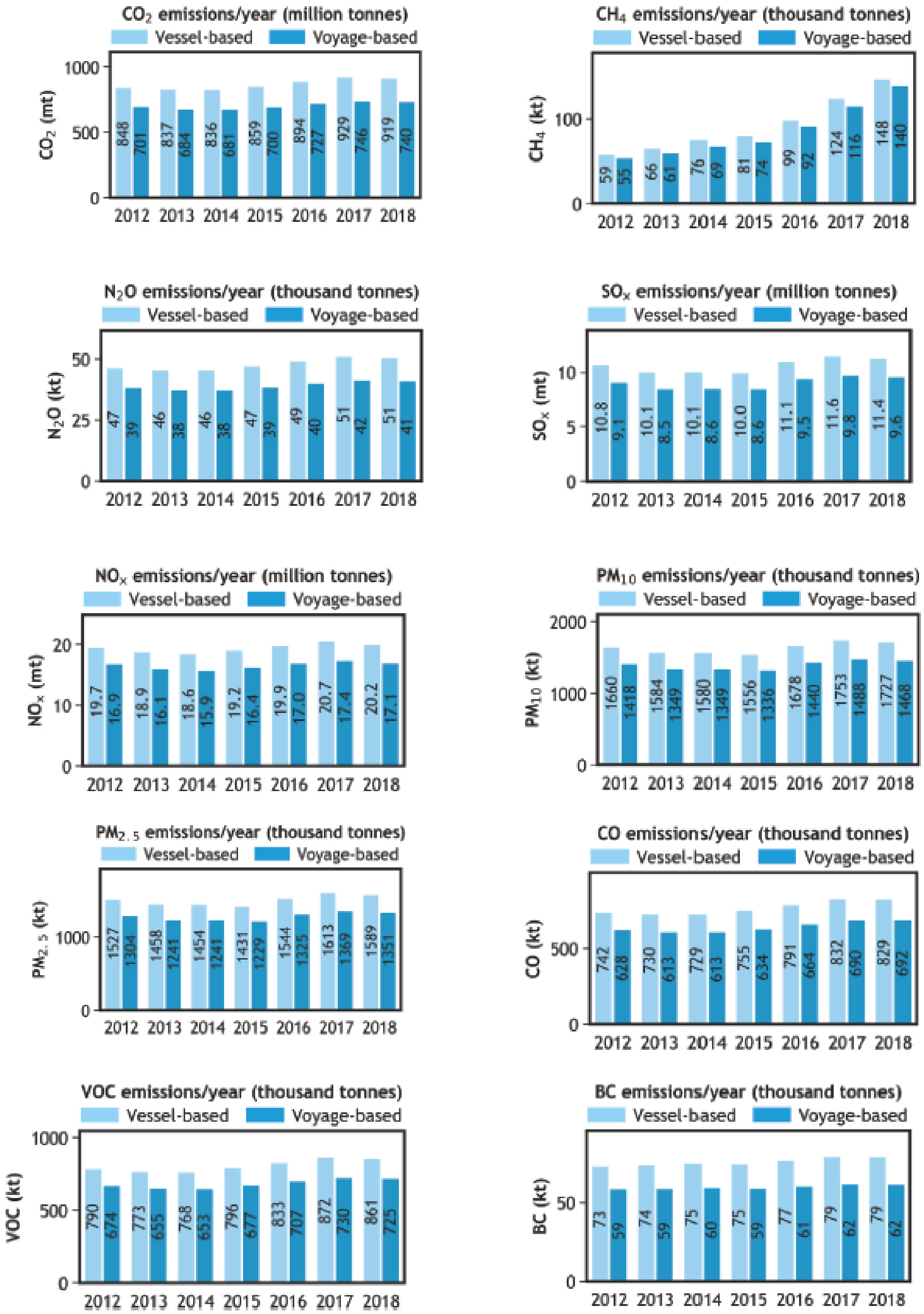

Figure 5: Emissions species trends, for voyage-based and vessel-based international shipping emissions (Fourth GHG Study 2020)

Seaborne trade is expected to grow more and more the upcoming years, maximizing the international shipping activity worldwide. According to the Fourth IMO GHG Study, based on long-term socio-economic and energy business-as-usual scenarios, the emissions sourced by vessels shall be further increased from 1,000 Mt CO_2 in 2018 to 1,000 to 1,500 Mt CO_2 in 2050. This represents an increase of 0 to 50 per cent over 2018 levels and is equal to 90-130 per cent of 2008 levels. It is easily understood that the increase of economic growth will induce more intense maritime transport for the satisfaction of the arising needs. “Emissions could be higher (lower) than projected when economic growth rates are higher (lower) than assumed here or when the reduction in GHG emissions from land-based sectors is less (more) than would be required to limit the global temperature increase to well below 2 degrees centigrade” is mentioned at the Fourth GHG Study. In such case the emissions produced by shipping sector will play an even more catalytic role into shaping the climate change. That being said, the intervention of global authorities on controlling merchant shipping emissions, leaded by the International Maritime Organization (IMO), has been and will remain of vital importance, from an environmental and human health perspective. These coupled aspects raise both ecological and social implications because impact of the shipping activity is out of geographical limits, operating along major trading routes and as a consequence distributing these changes worldwide, even heterogeneously. Therefore, it has been absolutely impulsive to impose schemes of regulation, with aim of controlling the shipping-emerged emissions and the improvement of ship energy efficiency, both in terms of proactivity and sustainable development.

2.3 The regulatory framework

International shipping activity is formed based on a wide variety of directives, regulations and specific processes as provided by international conventions, agreements and protocols, that establish the global regulatory framework relative to the reduction of the atmospheric pollution, the emissions from ships and their determined effect on public health, natural and built environment, both directly and indirectly. The following instruments are listed among the most important for this purpose: the United Nations Convention on the Law of the Sea (UNCLOS),1982, the International Convention for the Safety of Life at Sea (SOLAS),1974, the

1979 Geneva Convention, the 1985 Vienna Convention, the 1987 Montreal Protocol and the 1976 Barcelona Convention. However, without a doubt, the one with the higher significance that outlines the main international policy is Annex VI of the International Convention for the Prevention of Pollution from Ships (MARPOL).

On 2 November 1973 the International Convention for the Prevention of Pollution from Ships, with the shortened name of MAPROL 73, was adopted at the International Maritime Organization (IMO), in response to the Torrey Canyon accident in 1968, aiming at the prevention of pollution of the marine environment caused by ships' operation and accidents. Following the Amoco Cadiz accident in 1977, a Protocol was agreed by the International Conference on Tanker Safety and Pollution Prevention (TSPP) in February 1978 and was absorbed by the parent convention, renaming it to MARPOL 73/78. Initially, it was composed of V Annexes that cover different aspects of marine pollution. In 1997 the Convention was amended by the adoption of a Protocol, resulting to the addition of Annex VI concerning the prevention of air pollution from ships, which entered into force on 19 May 2005. After the adoption of the last Protocol, it was decided to refer to the Convention just as MARPOL.

MARPOL (International Convention for the Prevention of Pollution from Ships)		
Annex I	Regulations for the Prevention of Pollution by Oil	into force as from 2 October 1983
Annex II	Regulations for the Control of Pollution by Noxious Liquid Substances in Bulk	into force as from 2 October 1983
Annex III	Prevention of Pollution by Harmful Substances Carried by Sea in Packaged Form	into force as from 1 July 1992
Annex IV	Prevention of Pollution by Sewage from Ships	into force as from 27 September 2003
Annex V	Prevention of Pollution by Garbage from Ships	into force as from 31 December 1988
Annex VI	Prevention of Air Pollution from Ships	into force as from 19 May 2005

Table 3: Annexes of MARPOL

In particular Annex VI includes regulations addressing directly to the reduction and control of air pollution from ships' exhaust gases of NO_x, SO_x and Particulate Matter and prohibits deliberate emissions of Ozone depleting substances (ODSs) as well as characterizing designated emission control areas with much stricter limits on the emission of the aforementioned air pollutants. Currently, it is achieved to regulate air emissions from 96.6 per cent of the global shipping tonnage. In 2011, a new chapter 4 was added in MARPOL Annex VI, entitled Regulations on energy efficiency for ships, that comprises technical and operational energy efficiency measures, targeting the limitation or reduction of GHG emissions from international shipping. These measures entered into force on 1 January 2013. Chapter 4 of Annex VI introduced to the shipping industry two crucial new measures, this of Energy Efficiency Design Index – EEDI – and that of Ship Energy Efficiency Management Plan – SEEMP –, altering once and for all the conditions of ship operation and the perspective of the maritime industry on the handling of greenhouse gases emissions' issue. It was the first ever mandatory regulatory plan worldwide for an international industry sector or transport mode. Over the years, Annex VI of MARPOL has been amended several times in order to set new goals, meeting the necessity for prompt action on climate change, to keep pace with the technological development, incorporating new "tools" provided by the improvement of technology, and to further deploy the implementation experience gained.

CHAPTER THREE: REGULATORY MEASURES FOR AIR POLLUTANTS

3.1 Introduction

Even though air pollution induced from ships does not have the direct cause and effect as an oil spill incident, the International Maritime Organization (IMO) has adopted in 1997 the Annex VI in MARPOL, entering into force as from 2005, for the prevention of air pollution from ships in order to tackle the cumulative effect to the overall air quality problems and mitigate the impacts of international shipping on the environment. From this point of view, at the 53rd session of the Marine Environment Protection Committee (MEPC) in July of 2005, the revision of MARPOL Annex VI was agreed with much stricter regulations on the emission limits both in open sea area and in Emission Control Areas (ECAs). The revised MARPOL Annex VI and the associated NOx Technical Code 2008 were adopted in October of 2008 with the Resolution MEPC.176(58), which entered into force on 1 July 2010, and various amendments followed accompanied by the respective guidelines for the proper implementation of the regulatory measures taken and compliance of the international shipping industry with the same. For ships of 400 gross tons and above, if the compliance to the regulations of Resolution MEPC.176(58) is accomplished, then an International Air Pollution Prevention Certificate (IAPP) shall be issued by the Administration, with a validity of five years.

In this chapter the regulatory measures concerning the SO_x, Particulate Matter and NO_x measures shall be further presented.

3.2 SO_x and PM Regulations

The regulation 14 for the Sulphur Oxides (SO_x) and Particulate Matter (PM) of the Resolution MEPC.176(58), addressing to the control of these emissions from ships, determined the sulphur content limits that apply to all fuel oil used onboard, for both main and auxiliary engine as well as boilers and gas generators. Furthermore, the said regulation imposed two different sets of gradually tighter limits based on the operation area of the ships, i.e. one for the occasion of vessels sailing in the open sea area and another one for sailing within Emission Control Areas (ECAs). These fuel oil sulphur limits, expressed in terms of per cent m/m (mass by mass) are depicted below:

Outside an ECA established to limit SOx and particulate matter emissions	Inside an ECA established to limit SOx and particulate matter emissions
4.50% m/m prior to 1 January 2012	1.50% m/m prior to 1 July 2010
3.50% m/m on and after 1 January 2012	1.00% m/m on and after 1 July 2010
0.50% m/m on and after 1 January 2020*	0.10% m/m on and after 1 January 2015

Figure 6: Limit of SO_x and Particulate Matter (PM) emission outside and inside an ECA (IMO)

More specifically, in case of cruising outside of ECAs, the International Maritime Organization (IMO) has established a strengthened limit from 4.5 per cent m/m prior to 2012 to 3.5 per cent m/m on and after 01 January 2012. As from 01 January 2020 the limit of sulphur content of marine fuels used has been further reduced to 0.50 per cent m/m, after the review of the availability of the required fuel oil and the adoption of resolution MEPC.280(70) in 2016. Below figure illustrates the gradual application of strengthened limits.

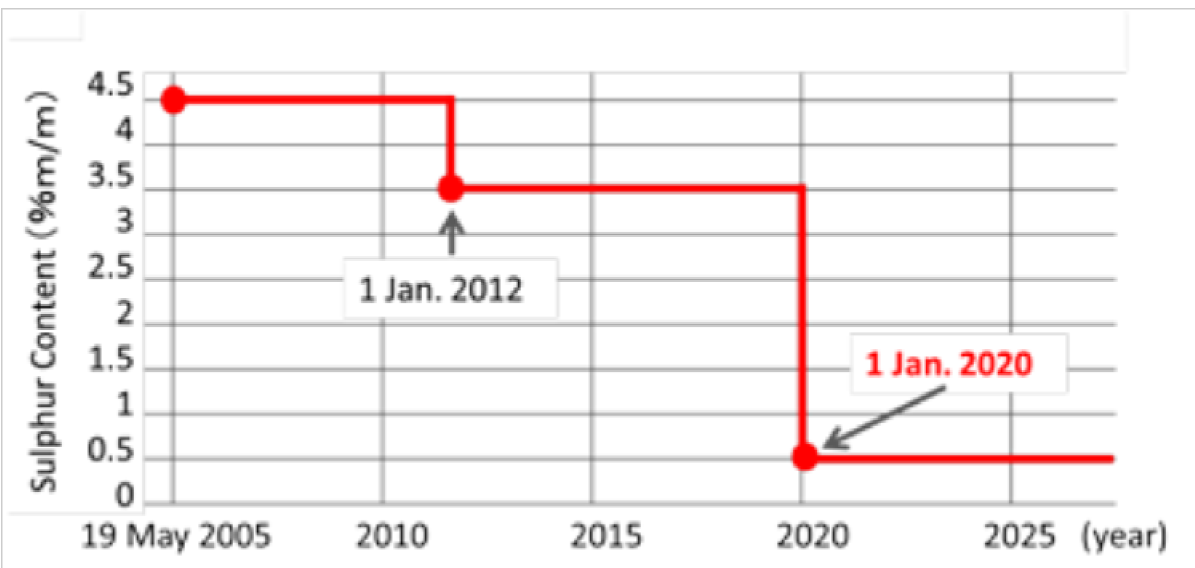

Figure 7: Sulphur content limits at Open Sea Area (Class NK)

Concerning ships of 400 gross tons or above engaged in international voyages, bunker delivery notes and the corresponding fuel oil samples (more than 400ml) should be kept on board for a period of more than 3 years and for more than 12 months respectively according to Regulation

18 of MARPOL Annex VI. Guidelines for sampling and storage of fuel oil are provided in IMO Resolution MEPC.182(59) (Class NK).

The new global upper limit on the sulphur content of ships' fuel oil, also known as “IMO 2020”, will mean a 77 per cent drop in overall SO_x emissions from ships, equivalent to an annual reduction of approximately 8.5 million metric tonnes of SO_x. Particulate matter will also be reduced (IMO).

With respect to the control applicable inside the ECAs, the established limit has come into force earlier, from 1.5 per cent m/m prior to 01 July 2010 to 1.0 m/m on and after 01 July 2010. After 01 January 2015, the limit imposed is 0.10 per cent m/m for ships operating within these designated areas. In particular, according to the International Maritime Organization (IMO), the ECAs established are:

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

The below table shows the gradual strengthened limit of sulphur content of fuel oils used inside ECAs.

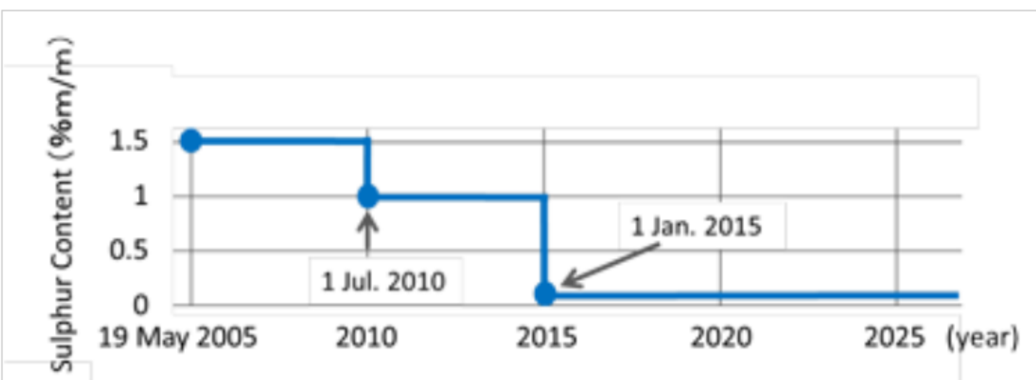

Figure 8: Sulphur content limits inside an ECA (Class NK)

The majority of ships, engaged in international voyages, operate both in the designated ECAs as well as the open sea area. Consequently, it is required to comply with the regulations adopted for both cases. In particular, the total switch to the fuel oil compliant with ECA limit is needed to be accomplished prior to entering the respective designated area and the change to fuel oil compliant with the open sea area limit shall start only after the exit of the vessel from the ECA. With aim of proper implementation, a written procedure must be followed, keeping records in the logbook as prescribed by the Flag Administration, concerning the quantities of the ECA compliant fuel oils onboard, the date, time and location of change-over.

Finally, in 2018, MEPC has adopted an additional Resolution, MEPC.305(73), in order to enhance the IMO 2020 Regulation. The aforementioned Resolution, that entered into force in 01 March 2020, prohibits the carriage of non-compliant fuel oil on board a ship (fuel oil with a sulphur content higher than 0.5 %), for any propulsion or operation purposes, unless the ship is fitted with an approved Exhaust Gas Cleaning System (EGCS).

3.3 NO_x Regulations

The Regulation 13 for Nitrogen Oxides (NO_x) of the Resolution MEPC.176(58) and the NO_x Technical Code 2008 refer to the measures decided for the control of NO_x emissions from ships with an installed marine diesel engine with a power output of more than 130 kW, other than those used only in emergency cases, irrespective of the tonnage of the vessel onto which such engines are installed. A three-tier approach has been established for the purpose of mitigation of NO_x emissions, depending on the construction date of the ship and the engine maximum operating speed. The table below depicts the progressively stricter NO_x limit value, which is determined from the parameter n, i.e. the engine’s rated speed (crankshaft revolutions per minute):

Tier	Ship construction date on or after	Total weighted cycle emission limit (g/kWh) n = engine's rated speed (rpm)		
		n < 130	n = 130 - 1999	n ≥ 2000
I	1 January 2000	17.0	$45 \cdot n^{(-0.2)}$ e.g., 720 rpm – 12.1	9.8
II	1 January 2011	14.4	$44 \cdot n^{(-0.23)}$ e.g., 720 rpm – 9.7	7.7
III	1 January 2016	3.4	$9 \cdot n^{(-0.2)}$ e.g., 720 rpm – 2.4	2.0

Table 4: NOx limit values based on engine's rated speed (IMO)

In particular, Tier I applies to marine diesel engines of all ships built on or after 1 January 2000. The same Tier applies for marine diesel engines of all ships built on or after 1 January 1990 but prior to 1 January 2000, if an approved method for that engine has been certified by an Administration. Moreover, marine diesel engines installed on all ships constructed on or after 2011 must comply with Tier II emission limit. The first two Tiers are implemented globally. Under Tier III limit standards are included all installed marine engines on ships constructed on or after 1 January 2016. In this case, the limit value must be reduced to 3.4 g/kWh and applies to all ships operating only inside an ECA (IACCSEA). According to the International Maritime Organization, the following ECAs are defined for the respective compliance with Tier III NO_x standard:

1. the North American ECA and the United States Caribbean Sea ECA, as from 01 January 2016;
2. the Baltic Sea ECA or the North Sea ECA, as from 1 January 2021.

It is highly important to mention that the Tier II corresponds to about 20 per cent reduction from the IMO Tier I NO_x emission standard and the Tier III NO_x emission level reflects an 80 per cent reduction from the IMO Tier I emission standard accordingly (Wartsila). This notable difference is shown at below figure:

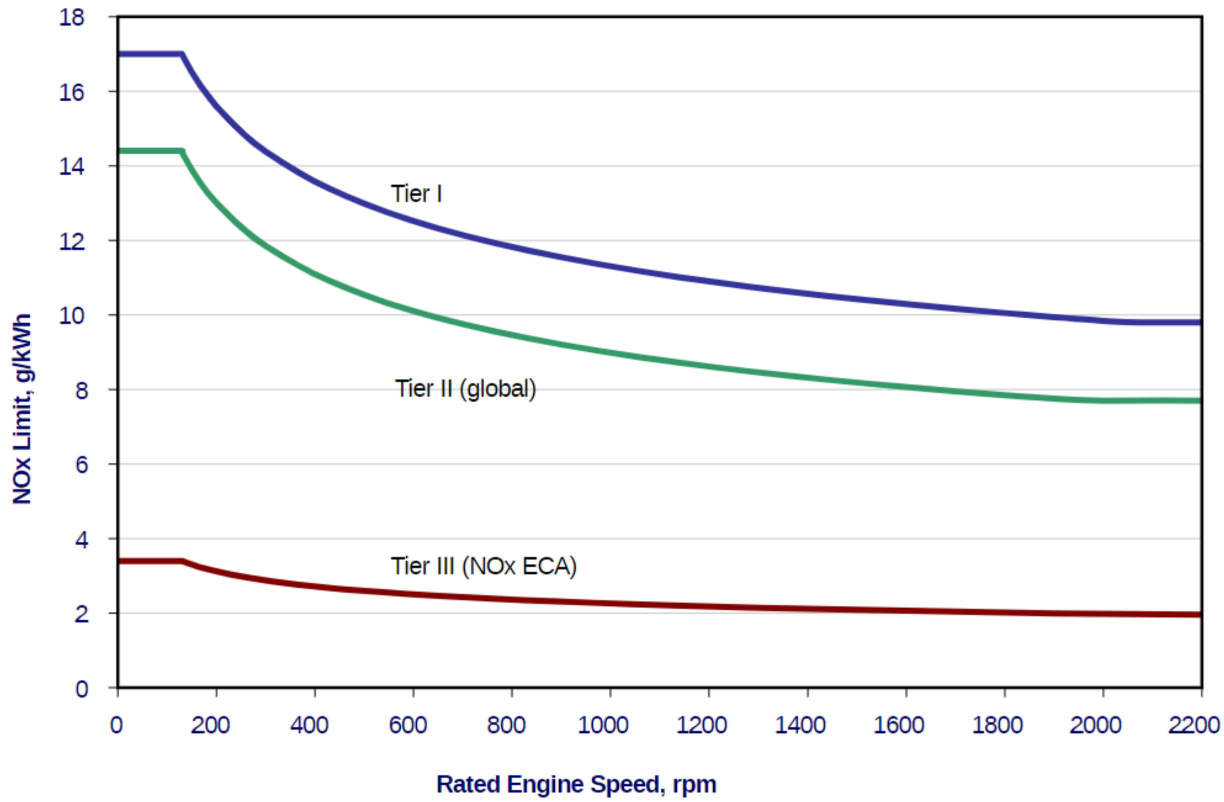

Figure 9: MARPOL Annex VI NO_x emission limits (Wartsila)

In case an installed marine engine on a ship meets the standards as determined in the three aforementioned Tiers and consequently complies with Regulation 13 for NO_x emission limits, an Engine International Air Pollution Prevention (EIAPP) Certificate shall be issued by the Administration, followed by the required survey.

CHAPTER FOUR: REGULATORY MEASURES FOR SHIP ENERGY EFFICIENCY

4.1 Introduction

Following global trends on tackling the climate change and intense emphasis given by numerous international organizations and fora on this topic, the International Maritime Organization (IMO) began as well to center its interest on creating a regulatory framework in order to mitigate the contribution of shipping sector to the anthropogenic sources of greenhouse gases emission. More than two decades ago, in 1997, when the Annex VI for the prevention from air pollutants was adopted, CO_2 ship emissions were extensively discussed, though not included in that amendment of MARPOL. However, two resolutions were adopted, Resolution 8 and Resolution A.963(23) in 1997 and in 2003 respectively, based on which the Marine Environment Protection Committee (MEPC) draw the lines for the final suite of ship energy efficiency regulatory measures. On the one hand Resolution 8 targeted to identify the percentage of CO_2 from ships emissions as part of the global inventory of CO_2 emissions and to examine the feasibility of strategies for reduction of emission, in correlation with other air and marine pollutants. This led to publication of the First IMO GHG Study on greenhouse gases emissions from ships in 2000, stating shipping activity contributed to 1.8 per cent of the world total human-related CO_2 emissions. On the other hand, Resolution A.963(23) aimed a series of mechanisms to be developed in order the rate of CO_2 emissions from the maritime transport to be drastically decreased in the upcoming years. After six years, the final package of technical and operational energy efficiency measures was completed and circulated for voluntary use.

Based on the conclusions of the Second IMO GHG Study, also released in 2009, the International Maritime Organization (IMO) amended ANNEX VI of MARPOL in 2011, with the inclusion of chapter 4 and proceeded to the adoption of the below mentioned energy efficiency measures through Resolution MEPC.203(62):

- the Energy Efficiency Design Index (EEDI) for new ships
- the Ship Energy Efficiency Management Plan (SEEMP) for all ships

neBoth measures entered into force on 1 January 2013 and apply to all ships of 400 gross tonnage and above, irrespective of the national flag they fly or the nationality of the owner.

4.2 Energy Efficiency Design Index (EEDI)

Energy Efficiency Design Index, known and referred to by the acronym EEDI, is a mandatory technical measure addressing to the design and construction of new ships, with the aim of improving the energy efficiency of new-build vessels over time, by lowering the fuel consumption, using less polluting equipment and engines on board and consequently reducing the CO_2 emissions, induced by the combustion process. According to MEPC.203(62), the definition of “new ship” means a ship: a. for which the building contract is placed on or after 1 January 2013; or b. in the absence of a building contract, the keel of which is laid or which is at a similar stage of construction on or after 1 July 2013; or c. the delivery of which is on or after 1 July 2015. The EEDI, even though is a legally binding regulation, does not impose prescriptive standards in order the minimum required level of energy efficiency to be met, offering this way on the one hand the chance to the ship-building stakeholders to decide the most cost-efficient means for a ship to be in compliance with this regulation and on the other hand stimulating the technological innovations within this sector in continuous search of better energy efficient systems. However, MEPC has adopted various guidelines with the ultimate goal of the proper implementation of EEDI.

In a general sense, EEDI expresses the ratio from the impact to environment divided by the benefit to society from the maritime transport and could be depicted as per below formula:

EEDI = Impact to environment/Benefit to society

More specifically, EEDI is an energy efficiency tool that measures the amount of CO_2 emitted in grams per transport work (e.g. tonne-mile of work).

The simplified mathematical formula for the calculation of EEDI is cited below:

EEDI = CO_2 Emissions (in grams)/Transport Work

Where Transport Work = Deadweight (in tonnes) × Distance travelled (in nautical miles)

A more complicated mathematical formula for the calculation of EEDI is based on several technical design parameters concerning emissions from main engine and auxiliary engine, energy efficient technologies as well as capacity and speed of the vessel to be built:

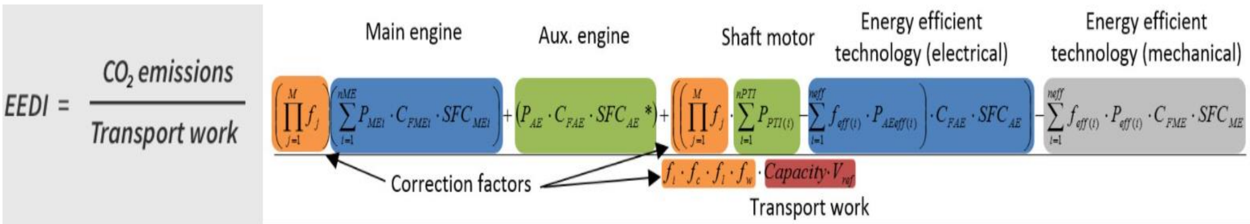

Figure 10: EEDI Mathematical Formula (Global Maritime Energy Efficiency Partnerships)

According to the Global Maritime Energy Efficiency Partnerships' analysis, the top line of the EEDI formula can be divided into four key parts:

1. CO_2 emissions due to propulsion power, PME + PPTI
2. CO_2 emissions due to auxiliary power, PAE
3. CO_2 emissions reduction through energy efficient technologies reducing the auxiliary power by generating electricity for normal maximum sea load, PAEeff.
   Examples include waste heat recovery and photovoltaic power generation.
4. CO_2 emission reduction through energy efficient technologies reducing the propulsion power, Peff.
   Examples include air lubrication systems and wind propulsion systems.

The bottom line of EEDI formula consists of capacity and reference speed Vref, which represent the transport work capacity of the vessel.

It is easily understood that the smaller the EEDI resulting from this formula, the more energy efficient ship design would be.

Hence, based on this formula, the shipbuilding industry is able to calculate properly the EEDI to be attained for each new ship and/or each ship that has undergone such an extensive conversion that is considered to be a newly-built ship by the Administration. The calculation must be accomplished on the basis of specific guidelines as released by the side of MEPC and must be contained in the EEDI technical file, showing all relative information as well as the calculation process.

In terms of establishing the minimum energy efficient level to be attained for different ship type and size segments, MEPC.203(62) also imposes the Required EEDI for each new ship and/or each ship that has undergone such an extensive conversion that is considered to be a newly-built ship by the Administration, as derives from below mathematical formula:

$$\text{Attained EEDI} \leqq \text{Required EEDI}$$

$$\text{Required EEDI} = (1\text{-}X/100) \times \text{Reference line value}$$

Where X is the reduction factor for the required EEDI compared to the EEDI Reference line

The initial regulatory regime provided a plan of three phases for mitigation of CO_2 level, upon completion of an initial two year phase zero, for the following seven ship types: bulk carriers, tankers, gas carriers, general cargo ships, container ships, refrigerated cargo carriers and combination carriers. The reduction factor of phase one was set to 10 per cent and would incrementally become stringer every five years in accordance to each ship type and size and the date of ship’s delivery. In this case, the reduction rate for phase three, as from 2025 and onwards, would be 30 per cent for all ships types and sizes falling under the EEDI regulation. In 2014, in light of extending the application of EEDI, MEPC decided to amend the relative regulation, including five more ship types: LNG carriers, ro-ro cargo ships (vehicle carriers), ro-ro cargo ships; ro-ro passenger ships and cruise passenger ships having non-conventional propulsion, incorporating this way the ship types responsible for approximately 85 per cent of the CO_2 emissions from international shipping. In 2020, during the 75th session of MEPC, the Committee adopted amendments to MARPOL Annex VI that will further tighten the EEDI regulatory measure, expected to enter into force as from 1 April 2022. In particular, these amendments bring forward the entry into effect date of phase three to 2022, from 2025, for several ship types, including gas carriers, general cargo ships and LNG carriers (IMO) and enhance the EEDI reduction rate for container ships, significantly for these with higher DWT capacity, reaching even the 50 per cent, as follows (IMO):

- For a containership of 200,000 DWT and above, the EEDI reduction rate is set at 50% from 2022
- For a containership of 120,000 DWT and above but less than 200,000 DWT, 45% from 2022
- For a containership of 80,000 DWT and above but less than 120,000 DWT, 40% from 2022
- For a containership of 40,000 DWT and above but less than 80,000 DWT, 35% from 2022
- For a containership of 15,000 DWT and above but less than 40,000 DWT, 30% from 2022

Consequently, the latest reduction factors for all applicable ship types and sizes, to be used for the calculation of the Required EEDI, are depicted at below table, adopted with Resolution MEPC.324(75):

Ship Type	Size	Phase 0 1 Jan 2013 – 31 Dec 2014	Phase 1 1 Jan 2015 – 31 Dec 2019	Phase 2 1 Jan 2020 – 31 Mar 2022	Phase 2 1 Jan 2020 – 31 Dec 2024	Phase 3 1 Apr 2022 and onwards	Phase 3 1 Jan 2025 and onwards
Bulk carrier	20,000 DWT and above	0	10		20		30
	10,000 and above but less than 20,000 DWT	n/a	0-10*		0-20*		0-30*
Gas carrier	15,000 DWT and above	0	10	20		30	
	10,000 and above but less than 15,000 DWT	0	10		20		30
	2,000 and above but less than 10,000 DWT	n/a	0-10*		0-20*		0-30*
Tanker	20,000 DWT and above	0	10		20		30
	4,000 and above but less than 20,000 DWT	n/a	0-10*		0-20*		0-30*
Containership	200,000 DWT and above	0	10	20		50	
	120,000 and above but less than 200,000 DWT	0	10	20		45	
	80,000 and above but less than 120,000 DWT	0	10	20		40	
	40,000 and above but less than 80,000 DWT	0	10	20		35	
	15,000 and above but less than 40,000 DWT	0	10	20		30	

Ship Type	Size	Phase 0 1 Jan 2013 – 31 Dec 2014	Phase 1 1 Jan 2015 – 31 Dec 2019	Phase 2 1 Jan 2020 – 31 Mar 2022	Phase 2 1 Jan 2020 – 31 Dec 2024	Phase 3 1 Apr 2022 and onwards	Phase 3 1 Jan 2025 and onwards
	10,000 and above but less than 15,000 DWT	n/a	0-10*	0-20*		15-30*	
General Cargo ships	15,000 DWT and above	0	10	15		30	
	3,000 and above but less than 15,000 DWT	n/a	0-10*	0-15*		0-30*	
Refrigerated cargo carrier	5,000 DWT and above	0	10		15		30
	3,000 and above but less than 5,000 DWT	n/a	0-10*		0-15*		0-30*
Combination carrier	20,000 DWT and above	0	10		20		30
	4,000 and above but less than 20,000 DWT	n/a	0-10*		0-20*		0-30*
LNG carrier***	10,000 DWT and above	n/a	10**	20		30	
Ro-ro cargo ship (vehicle carrier)***	10,000 DWT and above	n/a	5**		15		30
Ro-ro cargo ship***	2,000 DWT and above	n/a	5**		20		30
	1,000 and above but less than 2,000 DWT	n/a	0-5*,**		0-20*		0-30*
Ro-ro passenger ship***	1,000 DWT and above	n/a	5**		20		30
	250 and above but less than 1,000 DWT	n/a	0-5*,**		0-20*		0-30*
Cruise passenger ship*** having non-conventional propulsion	85,000 GT and above	n/a	5**	20		30	
	25,000 and above but less than 85,000 GT	n/a	0-5*,**	0-20*		0-30*	

Table 5: Reductions factors for the calculation of required EEDI (Resolution MEPC.324(75))

* Reduction factor to be linearly interpolated between the two values dependent upon ship size. The lower value of the reduction factor is to be applied to the smaller ship size.

** Phase 1 commences for those ships on 1 September 2015.

*** Reduction factor applies to those ships delivered on or after 1 September 2019, as defined in paragraph 43 of regulation 2.

A ship delivered on or after 1 September 2019 means a ship:

.1 for which the building contract is placed on or after 1 September 2015; or

.2 in the absence of a building contract, the keel of which is laid, or which is at a similar stage of construction, on or after 1 March 2016; or

.3 the delivery of which is on or after 1 September 2019.

Note: n/a means that no required EEDI applies.

In addition, Reference line value (baseline), included in the calculation of Required EEDI shall be calculated with below mathematical formula:

$$\text{Reference line value} = a \times b^{-c}$$

Where a, b and c parameters are provided by MEPC and presented below:

Ship type defined in regulation 2		a	b	c
2.25	Bulk carrier	961.79	DWT of the ship	0.477
2.26	Gas carrier	1120.00	DWT of the ship	0.456
2.27	Tanker	1218.80	DWT of the ship	0.488
2.28	Container ship	174.22	DWT of the ship	0.201
2.29	General cargo ship	107.48	DWT of the ship	0.216
2.30	Refrigerated cargo carrier	227.01	DWT of the ship	0.244
2.31	Combination carrier	1219.00	DWT of the ship	0.488
2.33	Ro-ro cargo ship (vehicle carrier)	$(DWT/GT)^{-0.7} \cdot 780.36$ where $DWT/GT<0.3$	DWT of the ship	0.471
		1812.63 where $DWT/GT \geq 0.3$		
2.34	Ro-ro cargo ship	1405.15	DWT of the ship	0.498
2.35	Ro-ro passenger ship	752.16	DWT of the ship	0.381
2.38	LNG carrier	2253.7	DWT of the ship	0.474
2.39	Cruise passenger ship having non-conventional propulsion	170.84	GT of the ship	0.214

Table 6: a, b, c parameters for the calculation of Reference Line Value (Module 2 - Ship Energy Efficiency Regulations and Related Guidelines, IMO)

The parameters for ro-ro cargo ships, ro-ro passenger ships and bulk carriers have been further amended in 2018 with Resolution MEPC.301(72) and in 2020 with Resolution MEPC.324(75) respectively:

Ship type defined in regulation 2	a	b	c
2.34 Ro-ro cargo ship	1405.15	DWT of the ship	0.498
	1686.17*	DWT of the ship where DWT≤17,000* 17,000 where DWT > 17,000*	
2.35 Ro-ro passenger ship	752.16	DWT of the ship	0.381
	902.59*	DWT of the ship where DWT≤10,000* 10,000 where DWT > 10,000*	

Table 7: Amended a, b, c parameters for the calculation of Reference Line Value for ro-ro cargo ships, ro-ro passenger ships (Resolution MEPC.301(72))

* to be used from phase 2 and thereafter 1

"2.25 Bulk carrier	961.79	DWT of the ship where DWT≤279,000 279,000 where DWT > 279,000	0.477"

Table 8: Amended a, b, c parameters for the calculation of Reference Line Value for bulk carriers (Resolution MEPC.324(75))

The strengthening of maximum of the Required EEDI, arising from latest amendments, aims to further lowering the Attained EEDI to be calculated by ship designers and builders. The International Maritime Organization (IMO) in order to secure the integrity of the aggregated data included in the EEDI technical file for the proper calculation of EEDI, has also developed a verification process that is conducted in two stages: preliminary verification at the design stage and final verification at the sea trial. Both verification stages are conducted in accordance to the relative guidelines adopted by MEPC in 2014. Finally, the verification of the Attained EEDI is realized by the Administration or by any duly authorized organization by it. Upon successful completion of this procedure, the respective certificate is issued.

4.3 Ship Energy Efficiency Management Plan (SEEMP)

The Ship Energy Efficiency Management Plan, known and referred to by the acronym SEEMP, is a mandatory operational measure applying to all ships over 400 gross tonnage, both new and existing ships of international shipping. The SEEMP has a twofold purpose and structure. On the one hand, the first part provides a four-steps process for all involved parties in order to improve the level of a ship’s energy efficiency as well as promote and apply energy efficiency measures that are feasible and effective cost-wise. On the other hand, the second part includes the methodology used for the proper record of fuel consumption of a ship of 5000 gross tonnage and above as well as the processes for the relative report to the ship's Administration or any organization duly authorized by it, as derives from the resolution MEPC.278(70).

PART I

The part I of SEEMP should be adjusted to each company’s practices, in order to constitute an adequate mechanism for the control and monitoring of the environmental performance of its vessels and also develop energy efficiency measures. In many cases, companies already have an adopted Environmental Management System for the selection of best measures for their fleets and a Safety Management System for their ships, of which SEEMP may forms part. Additionally, SEEMP should be ship-oriented, i.e. it should be created based on each vessel’s special characteristics and needs as well as its trade, sailing area and operation conditions. Consequently, the ship-operator or ship-owing company should develop a unique plan for each vessel of its fleet on basis of these parameters, that would include a package of measures for the improvement of energy efficiency, such as fuel efficient operations, weather routing, draft and trim optimization, propeller and hull inspection/cleaning, speed optimization (slow steaming), in-time engine maintenance etc.

In particular, the SEEMP describes a continual improvement process, consisted of the four following steps:

1. Planning
2. Implementation
3. Monitoring

4. Self-evaluation and improvement

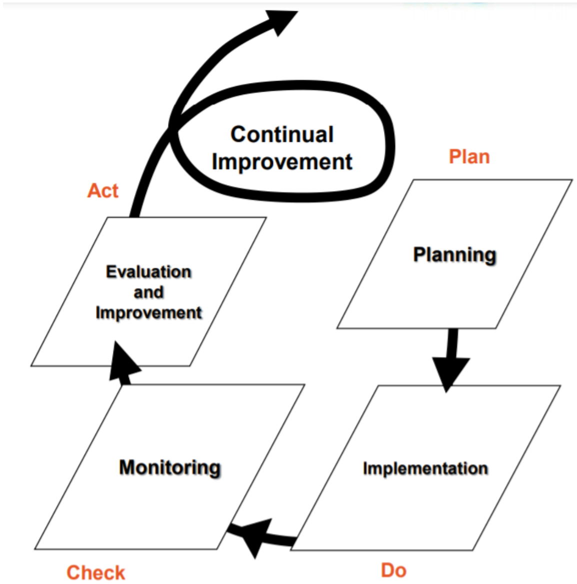

Figure 11: SEEMP (Module 2 - Ship Energy Efficiency Regulations and Related Guidelines, IMO)

Each one of these components has notable contribution and importance to the desired execution of the SEEMP. During this repeated cyclic process, some elements may remain the same while others will be necessarily modified.

Planning

The initial step of planning plays a critical role for the proper implementation of the SEEMP, because during this phase, it must be determined the current status of the energy used by the ship and the means for the optimization of the ship's energy efficiency. Therefore, it is proposed the devotion of sufficient time for this step in order the energy consumption of the ship to be identified by different forms, to evaluate the efficiency of potential measures already undertaken and to decide a proper suite of specific measures for further improvement of the energy efficiency on the base of the ship's type and operation. This planning process should also take into consideration the good communication and coordination of the involved stakeholders affecting a ship's operation, namely, ship-owners or ship-operators, ship repair yards, charterers, cargo owners, ports and traffic management services. The company is called to manage successfully this coordination, establishing an energy management plan. Moreover, another key-factor for the planning and implementation of the measures is the human resources development, both ashore and on board. The need for raising awareness and providing a suitable training for the personnel cannot be neglected. Within the same context, the company should set measurable and easily understood goals to be achieved, even voluntarily, in order to create motives for implementation and commitment for the enhancement of the energy efficiency.

Implementation

Upon completion of the planning phase, follows the step of implementation. During this phase, an implementation system should be defined, including implementation methods, tasks and periods (start and end dates) for selected measures as well as assigned personnel to deliver these duties. This system should be determined at planning stage for smoother implementation of SEEMP. Also record-keeping is highly advised while performing the chosen energy efficiency measures. This way the collected data shall constitute a useful and beneficial material for the later stage of self-evaluation.

Monitoring

Once the selected energy efficiency measures are implemented, the stage of monitoring begins, in order to observe their effectiveness. Again, the monitoring system should be previously indicated at the planning stage. The monitoring system is based on procedures for the collection of continuous and consistent data, as they result from the monitoring tools, and the assigned personnel, mainly shore-staff. The most commonly used monitoring tool by the shipping industry is the Energy Efficiency Operational Indicator, known and referred to as EEOI, which constitutes an internationally established method by the International Maritime Organization (IMO) for this purpose. Nevertheless, other monitoring tools can be used, either at the same time with EEOI or without its utilization, as long as their method is established preferably by an international standard and they are determined at the step of planning.

Self-evaluation and improvement

Self-evaluation and improvement is the last stage of the management cycle and concerns the evaluation of data resulting from previous phase of monitoring. This final step is essential due to the fact that it provides all required information for the commencement of the new improvement cycle to follow. More specifically, the rate of effectiveness of the decided measures is examined over the period of operation in accordance to the ship's characteristics. This way a completed evaluation report is produced for the development of an optimized management plan for the next cycle.

PART II

The part II of the SEEMP is a mandatory requirement for ships of 5000 gross tonnage and more, following the adoption of resolution MEPC.278(70) on Data Collection System for fuel oil consumption of ships, that entered into force on 1 March 2018. According to this resolution, ships of 5000 gross tonnage and above (representing approximately 85 per cent of GHG emissions from ships) must collect data in regard to the consumption of each fuel oil used as well as other specific data and to report the same to the Flag State at the end of each calendar year. Once the Flag State verifies that the report of the submitted data has been executed in accordance with the requirements, issues the respective Statement of Compliance to the ship. In their turn, the Flag State should transfer the aggregated data to an IMO Ship Fuel Oil Consumption Database in order the International Maritime Organization (IMO) to produce an annual report to MEPC. Additionally, on or before 31 December 2018, the SEEMP of vessels of 5000 gross tonnage and above should include the determined methodology for the collection of the aforementioned data and the procedures to be followed for the report to be delivered to the Flag State.

More specifically, the relative guidelines by the International Maritime Organization (IMO) propose that a ship-specific method should be developed for the data required to be collected, aggregated and reported, regarding the priority areas of fuel oil consumption, distance travelled and hours underway. Moreover, more essential factors are underlined to be taken into consideration for the proper report, such as the conversion factor, the quality of data and the possession of a standardized data reporting format.

Finally, the compliance of a ship with the energy efficiency regulations, both EEDI for new ships and SEEMP for all ships, leads to the issuance of the International Energy Efficiency Certificate, known and referred to by the acronym IEE, whose validity does not expire throughout the life of the ship, unless there is a major conversion of the ship or a transfer of flag to another State.

4.4 Energy Efficiency Operational Indicator (EEOI)

The Energy Efficiency Operational Indicator, known and referred to by the acronym EEOI, is part of the monitoring step of the SEEMP and is considered to be the primary monitoring tool, that is widely used in the maritime sector for identifying the level of a ship's energy efficiency in operation with the aim of its improvement. Specifically, the EEOI is a voluntarily used indicator by ship-owners and ship-operators that calculates the actual amount of emission of CO_2 for the actual cargo carried for a determined voyage or number of voyages or a period in question.

The simplified version of EEOI calculation depicts the ratio of mass of CO_2 emitted per unit of transport work:

$$\boxed{EEOI = MCO_2/\text{Transport Work}}$$

Where MCO_2 = Fuel Consumption × $C_{f,}$

C_f = Fuel Mass to CO_2 mass conversion factor

Transport Work = Cargo Carried × Distance Travelled (in nautical miles)

Cargo Carried could be expressed in tonnes, TEU, person etc., based on ship type and work done.

The basic mathematical formula for the calculation of EEOI for a single voyage is defined as:

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

When the average of the indicator is needed for a period or for a number of voyages, then the EEOI is calculated as:

$$\text{Average EEOI} = \frac{\sum_i \sum_j (FC_{ij} \times C_{Fj})}{\sum_i (m_{cargo,i} \times D_i)}$$

Where:

• j is the fuel type;

• i is the voyage number;

• FC_{ij} is the mass of consumed fuel j at voyage i;

• C_{Fj} is the fuel mass to CO2 mass conversion factor for fuel j;

• m_{cargo} is cargo carried (tonnes) or work done (number of TEU or passengers) or

gross tonnes for passenger ships; and

• D is the distance in nautical miles corresponding to the cargo carried or work done.

It is easily understood that the smaller the EEOI is, the more energy efficient a ship's operation would be.

Even though both EEDI and EEOI show the emission of CO_2 per tonne-mile, the first is used for the stage of ships' design and building by the shipbuilding sector while the last examines how efficiently the ships are operated by the companies.

It is preferable the calculation and monitoring of the EEOI to be executed by the shore-staff, in order to limit any extra burden for the crew onboard, using all necessary data for each fuel consumed, type, quantity and other fuel information that may affect the consumption, distance sailed and cargo type, as obtained from required records kept on board, such as the official bridge, deck and engine log-books and other oil record books. The majority of the companies are measuring EEOI, implemented as part of their Environmental Management System, for each ship and for each fleet every three months, seizing this way the chance for a performance-based evaluation which could drive also to the identification of areas in need of further actions for correction and improvement of the ship's energy efficiency in operation.

4.5 Latest Regulatory Measures

On 13 April 2018, the International Maritime Organization (IMO) adopted the Initial IMO Strategy on the reduction of greenhouse gas emissions from ships, through resolution MEPC.304(72), in order to expedite the procedures for the limitation of greenhouse gases' emissions from international shipping, as a matter of urgency. The adopted Strategy sets out a vision that confirms the commitment of the Organization towards that goal and to phase them out as soon as possible within the present century. More concretely, the Strategy envisages among else (IMO):

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

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 per cent by 2030, pursuing efforts towards 70 per cent by 2050, compared to 2008

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 per cent 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.

In line with this Strategy, MEPC has also adopted amendments to MARPOL Annex VI this June during its 76th session, composed of a suite of new measures, both of technical and operational approaches, aiming to meet the set of these goals, by further optimizing the level of a ship's energy efficiency. The aforementioned amendments, adopted with MEPC.328(76), introduced the technical requirement of the Energy Efficiency Existing Ship Index (EEXI) and the operational requirement of the Carbon Intensity Indicator (CII). These amendments are expected to enter into force on 01 November 2022, while certification for both new requirements will come into effect as from 01 January 2023. The International Maritime Organization (IMO) will review their effectiveness and implementation until 01 January 2026 in order to evaluate the same and proceed with the development and adoption of new amendments, if needed.

4.5.1 Energy Efficiency Existing Ship Index (EEXI)

The Energy Efficiency Existing Ship Index, known and referred to by the acronym EEXI, is a technical measure that applies to all cargo and passenger ships of 400 gross tonnage and above engaged in the international voyages, falling under MARPOL Annex VI. The EEXI is considered to be the extension of EEDI for existing ships, regardless their delivery date. In addition the simplified version of the EEXI mathematical formula also depicts the ratio of CO_2 emissions per unit of transport work. In particular, the EEXI is a design index that determines the standardized CO_2 emissions related to installed engine power, transport capacity and ship speed (DNV).

EEXI = [gCO_2/tonne × nautical mile]

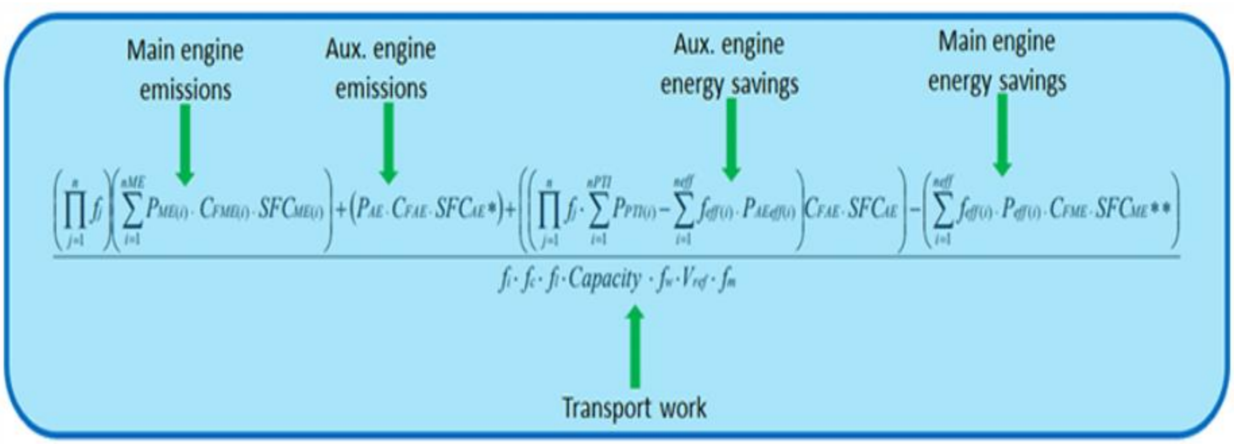

Figure 12: EEXI Mathematical Formula (DNV GL)

The method of calculation is similar to this of EEDI, since the value of EEXI should also be calculated for each individual ship resulting to the Attained EEXI of the vessel. In accordance to EEDI philosophy, a Required EEXI is also imposed, setting the limit for the minimum level of the new Index, specified for each ship type and size. It is easily understood based on previous analysis for the EEDI that the Attained EEXI should also be equal or less to the required EEXI, utilizing EEDI reference lines and reduction factors for ships with a certain size of a specified ship type, related to Phases 2 and 3 of EEDI.

$$\text{Attained EEXI} \leqq \text{Required EEXI}$$

$$\text{Required EEXI} = (1\text{-}Y/100) \times \text{EEDI Reference line value}$$

Where y is specified in below table:

Ship type	Size	Reduction factor
Bulk carrier	200,000 DWT and above	15
	20,000 and above but less than 200,000 DWT	20
	10,000 and above but less than 20,000 DWT	0-20*
Gas carrier	15,000 DWT and above	30
	10,000 and above but less than 15,000 DWT	20
	2,000 and above but less than 10,000 DWT	0-20*
Tanker	200,000 DWT and above	15
	20,000 and above but less than 200,000 DWT	20
	4,000 and above but less than 20,000 DWT	0-20*
Containership	200,000 DWT and above	50
	120,000 and above but less than 200,000 DWT	45
	80,000 and above but less than 120,000 DWT	35
	40,000 and above but less than 80,000 DWT	30
	15,000 and above but less than 40,000 DWT	20
	10,000 and above but less than 15,000 DWT	0-20*
General cargo ship	15,000 DWT and above	30
	3,000 and above but less than 15,000 DWT	0-30*

Refrigerated cargo carrier	5,000 DWT and above	15
	3,000 and above but less than 5,000 DWT	0-15*
Combination carrier	20,000 DWT and above	20
	4,000 and above but less than 20,000 DWT	0-20*
LNG carrier	10,000 DWT and above	30
Ro-ro cargo ship (vehicle carrier)	10,000 DWT and above	15
Ro-ro cargo ship	2,000 DWT and above	5
	1,000 and above but less than 2,000 DWT	0-5*
Ro-ro passenger ship	1,000 DWT and above	5
	250 and above but less than 1,000 DWT	0-5*
Cruise passenger ship having non-conventional propulsion	85,000 GT and above	30
	25,000 and above but less than 85,000 GT	0-30*

Table 9: Reduction factors (in percentage) for the EEXI relative to the EEDI reference line

An EEXI Technical file, containing all basic information required for the calculation of EEXI, must be issued to be submitted to the Administration and/or any other organization duly authorized by it in order to be verified and the IEE Certificate to be re-issued. In case of ships already complying with EEDI phase 2 and 3 and this value is equal to or less to the Required EEXI, an EEXI Technical File is not necessary and the IEE Certificate shall be renewed without any further approval.

4.5.2 Carbon Intensity Indicator (CII)

The Carbon Intensity Indicator, known and referred to by the acronym CII, and the according rating scheme are requirements addressing to the operational efficiency and applying to all cargo, Ro-Ro Pax and cruise ships of 5000 gross tonnage and above trading internationally, already subject to the requirement of the IMO Data Collection System for fuel oil consumption of ships. The calculation of CII is performed annually based on reported IMO Data Collection System data and the performance level should be recorded in the ship's SEEMP. The International Maritime Organization (IMO) has adopted 4 sets of guidelines for the proper implementation of CII concerning the operational Carbon Intensity Indicators and the calculation methods (G1), the reference lines for use with operational Carbon Intensity Indicators (G2), the operational Carbon Intensity reduction factors relative to reference lines (G3) and eventually the operational Carbon Intensity rating of ships (G4).

The basic calculation method depicts the CO_2 emitted in grams per cargo-carrying capacity and nautical mile.

$$\boxed{CII = CO_2/Deadweight \times Distance\ Sailed}$$

On the basis of this formula an annual Attained CII is measured that needs to be documented and verified against the annual Required CII, resulting from below mathematical formula:

$$Required\ CII = \frac{1 - Z}{100} CII_{Ref}$$

Where:

• Z is the reduction factor, set by the G3;

• Ref is the reference line, set by G2 in accordance to ship type and size

The reduction factor Z is a key element, since it is envisaged to follow a progressive increment of 2 per cent yearly, starting as from 5 per cent in 2023, strengthening the limit of Required CII. The reduction factors for the years of 2027 to 2030 will be determined following the evaluation of the measure.

Year	Reduction Factor (Z)
2023	5%
2024	7%
2025	9%
2026	11%
2027	**
2028	**
2029	**
2030	**

Table 10: Reduction Factors for the calculation of CII (NKK)

Moreover, the reference lines are calculated from below mathematical formula in accordance with the ship types and sizes, as included in G2,:

$$CII\ ref = a\ Capacity^{-C}$$

Source: NKK

Where a and c parameters are defined by below table, mentioned in MEPC.337(76):

Ship Type		Capacity	a	c
Bulk Carrier	DWT ≥ 279,000	279,000	4745	0.622
	DWT < 279,000	DWT	4745	0.622
Gas Carrier	DWT ≥ 65,000	DWT	14405E+7	2.071
	DWT < 65,000	DWT	8104	0.639
Tanker		DWT	5247	0.610
Container ship		DWT	1984	0.489
General cargo ship	DWT ≥ 20,000	DWT	31948	0.792
	DWT < 20,000	DWT	588	0.389
Refrigerated cargo carrier		DWT	4600	0.557
Combination carrier		DWT	40853	0.812
LNG Carrier	DWT ≥ 100,000	DWT	9.827	0
	100,000 > DWT ≥ 65,000	DWT	14479E+10	2.673
	DWT < 65,000	65,000	14479E+10	2.673
Ro-ro cargo ship (VC)		GT	5739	0.631
Ro-ro cargo ship		DWT	10952	0.637
Ro-ro passenger ship		GT	7540	0.587
Cruise passenger ship		GT	930	0.383

Table 11: a, b, c parameters for the calculation of CII (NKK)

Upon completion of this process, the operational carbon intensity rating can be determined for each ship, within a scale from A to E (where A is the best), indicating a major superior, minor superior, moderate, minor inferior, or inferior performance level. In case a ship receives the D rating for three consecutive years or the rating E for a single year, then it is required a corrective action plan to be submitted as a part of the SEEMP and approved, in order to be shown the ways for the required rating (C or above) to be achieved. It is significant to underline that all stakeholders, including Administrations, port authorities etc., are encouraged to provide incentives to ships rated as A or B.

The CII measure is a continuous process that has to be annually measured, evaluated and targeted for optimization, based on tightening emission limits, in order to meet the criteria set for the adequate ratings of C and above.

CHAPTER FIVE: CONCLUSIONS

It is true that the International Maritime Organization (IMO) has adopted since 1997, with the inclusion of Annex VI in MARPOL, a wide list of regulations for the prevention of pollution from ships. The urgent call for prompter action in order to tackle the climate change has led the International Maritime Organization (IMO) to impose more and more strict measures of both technical and operational approach and develop strategies in order to reduce the emissions of different kinds of gases and simultaneously improve the energy efficiency of the international fleet. Hence, the regulatory measures have been updated by the adoption of amendments over the years, setting a clearer plan for proper execution. In addition, fresh requirements will enter into force the ensuing years, following the 76^{th} session of MEPC in June 2021.

The technological developments and innovations surely play a crucial role, allowing the reduction limits to be met through the appropriate design, engine systems and equipment. However, the human element remains an important factor to be taken into consideration for the optimization of a vessel’s energy efficiency level. The crew on board and the shore-staff should be adequately and constantly trained in order to co-operate successfully for the delivery of the desired result while a ship is operating, by either minimizing the fuel usage and emissions with practices, such as these of slow steaming or weather routing, or following all procedures deriving from the SEEMP.

The actual implementation of green shipping is a hard and continuous process, which requires the effective collaboration and according contribution of all involved parties to the seaborne trade. The International Maritime Organization (IMO) has drawn the lines with the established regulatory framework for the mitigation of international shipping impact to the climate change, though the active participation of all stakeholders, ship-owners, ship-operators, ship designers and builders, seafarers etc., is needed, even if economic costs or other operational difficulties are faced. It is compulsory to understand that the compliance to these regulations in combination with the market-based measures is the only way to cut down on the increasing trends of the emissions of the marine shipping.

Without the regulatory initiatives of the International Maritime Organization (IMO), the addressed issues would be uncontrollable, due to the global character and nature of this industry’s activities. Although there are opposing voices criticizing the Organization’s agenda for the measures adopted and their feasibility, it is irrational to deny the significance of the same as a global regulator that drives the change towards greener shipping in the shipping industry as a whole and not divided based on certain commercial or national interests.

Closing this dissertation, it is underlined by its author that the alarming condition of our planet does not allow any delay for the implementation of the existing measures and even more actions is needed to be taken as soon as possible in order tackle the climate change.

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