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"Atmospheric pollution from Shipping."

Dissertation by Valentini Lykargyri

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Supervisor: Prof. Sakellariadou Fani

Abstract

Air pollution is a global issue that is developing and has terrible consequences for both people and the environment. The purpose of this thesis is to address the role that the shipping industry plays in air pollution and the measures taken to minimize it. The primary factor contributing to pollution from ships is the fuel used for their propel. Specifically, the combustion of fossil fuel elements such as Sulphur and Nitrogen is triggering the extent of environmental issues. As sea trade is the major means of trading goods, actions were taken to eliminate its impact. Over the years, more directives and regulations emerged on global, local and national scale, in order to address this problem. Alongside, to be compliant, the shipping sector had to undergo some technical and/or operational adjustments, as well as the development of substitute and environmentally friendly fuels.

Key words: Air pollution, fossil fuel, environmental issues, directives, regulations, environmentally friendly fuels.

Greetings

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Also, I want to thank my family and friends who made this journey come true and who always were there to motivate and support me.

This thesis, is tributed to my beloved sister Penny.

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Chapter 1. Introduction.

1.1. Purpose of this dissertation.

This thesis sought to examine how maritime transportation affects air pollution, in addition to the illustration of how pollutant gas emissions can be reduced. The associated fuels used in shipping are discussed, together with the air pollutants that ship engines release and the institutional structure that has been established to control them.

Specifically, the objectives are:

➔ To explore the contribution and impacts of maritime transport to the global problem of air pollution.

➔ To identify the present and evolving institutional framework related to the management and regulation of the aforementioned issue at international, local, and national levels.

➔ Analyze and evaluate the extent to which merchant ships contribute to air pollution.

➔ To develop conclusions regarding the scope and gravity of the shipping-related air pollution issue, as well as the likelihood of a sustainable solution.

➔ To make technical suggestions for growth and mitigation in the area of ship-related air pollution.

➔ To alert all related parties - the national and global official organizations of shipping and shipping enterprises - to the obligations placed on them as well as the requirements imposed on them with regard to the conservation of the environment.

➔ To provide a base for future research approaches.

1.2 Methodology.

The collection of information and data from secondary sources, such as books, academic papers, publications, newspapers, e - journals and websites, is the foundation for this thesis**.** The research for this thesis, that was conducted within the aforementioned approach, mostly relied on secondary sources, such as books and academic papers on transport and the environment, as well as material from online newspapers, magazines, and other websites. When the material was gathered, everything was processed once again in order to identify the most credible and valuable sources for the study. Each chapter of the thesis's information was then divided into thematic divisions related to its topic.

1.3 Structure.

Chapter 1 is listing the main purpose of this dissertation. Chapter 2 is referred to atmospheric pollution from the shipping industry and the components of this significant global issue. Chapter 3 presents the institutional framework governing atmospheric pollution from ships, referring to both the provisions and conditions of the IMO (International Maritime Organization), as well as those of the UN, the EU, and on a national level. Chapter 4 discusses the ways and techniques that could contribute to combating the problem of atmospheric pollution, or at least reducing the percentage caused by shipping transportation. Chapter 5 summarizes the research findings, presents the requirements and suggestions for shipping companies and administrations, and proposes directions for future research.

Chapter 2. Atmospheric pollution.

2.1. Types and definitions of atmospheric pollution generated by shipping.

Air emissions, existed since the beginning of our planet. The outcomes, from an eruption of a volcano exhausting cinders and smoke, to an outbreak of a fire releasing ashes and smoke, to wave energy causing desalination, all are considered as air emissions/pollutants. Air pollutants are small particles and gasses - easy to travel through the air - that when appearing in concentrations, can affect the weather and climate, but also jeopardize the well-being of organisms and ecosystems, degrade material goods, limit or interfere with enjoying nature, as well as other legitimate environmental purposes. Nevertheless, since the human accession to the planet, air pollution has been continuously increased. Emissions from ships are one of the most significant causes of air pollution, since the majority of ships utilize fuels that are composed of carbon and hydrogen. The pollutants from anthropocentric activity can be split into two categories: Primary and Secondary. The difference between the two categories is that primary pollutants are formed and emitted directly from distinct sources, while secondary ones are formed in the lower atmosphere by chemical reactions with the chemical compounds of primary pollutants in the atmosphere. Following are the most common primary and secondary air pollutants from ships:

Primary pollutants:

- Sulfur oxides: **SO**x **-** One of the most significant pollutants produced by marine engines and the combustion of fossil fuels. During fuel combustion and with the presence of oxygen sulfur dioxide is generated. The higher the sulfur content in the fuel, the more oxides are released into the atmosphere.
- Nitrogen oxides: **NO**x **-** Are produced during combustion, once oxygen and nitrogen are present and in high-temperature and high-pressure conditions. Such oxides take part in specific chemical processes that, when triggered by solar radiation, produce ozone. Along with SOx, NOx are significant pollutants as well.
- Carbon monoxide: **CO -** Is generated when there is insufficient oxygen for the production of carbon dioxide. Thus, is the outcome of incomplete combustion of coal and coal-containing chemicals. The fact of CO is that it is not immediately detected, because it has no color or smell, but it is also quite poisonous.
- Volatile organic compounds: **VOCs -** They standout out for their toxicity along with their power to evaporate into the atmosphere and cause ozone haze. They are also related to both cancer and respiratory issues in humans.
- Particulate Matter: **PM_{10} , $PM_{2.5}$ -** These particles can be made up of hundreds of different compounds and come in a wide variety of sizes and forms. As primary pollutants, that means, they are released directly from a source, meaning the ship's chimney. They consist of minuscule solid or liquid particles, which are so tiny that they can be inhaled and result in severe health issues. Particles with a diameter of less than 10 micrometers have the potential to travel deep into your lungs and potentially enter your bloodstream. The greatest threat to health comes from fine particles, which have

a diameter of less than 2.5 micrometers. Fine particles are also responsible for reduced visibility (haze).

Secondary pollutants:

- Ground-level ozone: **O_3 -** In contrast to its existence in the upper atmosphere, ozone is a strong air-polluting substance when detected at sea/ground level and has adverse effects on every living thing's respiratory system. It is an unstable gas that is extremely poisonous and has a distinct smell.
- Sulfuric acid: **$H2SO_4$** and Nitric acid: **HNO_2 -** $H2SO_4$ is a mineral acid composed of the elements hydrogen, oxygen, and sulfur. It is a thick liquid that is soluble in water. It has no color or smell. HNO_2 The ozone budget of the troposphere includes nitrous acid. Nitrous acid is created by the uneven interaction of nitric oxide (NO) with water.
- Particulate Matters: **PMx -** When a secondary pollutant, PMs are created in the atmosphere by complicated chemical reactions involving substances like sulfur dioxide and nitrogen oxides. They have the same severe effects on organisms.
- Nitrogen dioxide: **NO_2 -** Is a gaseous air pollutant produced, when fossil fuels like coal, oil, gas, or diesel are burned in high-temperature. It is one of six commonly occurring air pollutants for which there are federal air quality regulations that limit their presence in outdoor air. On human health, there are many negative effects of nitrogen dioxide on the lungs and respiratory system.
- Peroxyacyl nitrates: **PANs -** Strong respiratory and vision irritants from photochemical smog. They are produced due to thermal decomposition of VOCs. They are more toxic than Ozone, since they are diluted easily in water. They severely harm flora when present in higher amounts.

Air quality and air pollution in an area can be identified by the measurement of local air emissions to the atmosphere. Introducing wind conditions in the equation though, is a factor that can cause changes in air quality. Wind can be divided in three kinds with strength as a factor, contributing in different changes in air quality:

1. Weak winds that cannot dissolve the emitted pollution.

2. Strong winds blending the air with pollutants, in a force to make them spread in long distance.

3. Steady winds that cannot mix pollutants with air when in higher levels of the atmosphere.

As an outcome, air pollutants are sensitive when it comes to weather patterns. When primary pollutants cannot be dissipated due to inversion layers in the atmosphere, they become "trapped" forming smog, a type of pollution often seen over densely populated cities remaining fairly low over a city and it cannot be dissipated easily, resulting in the population and nature feeling the effects of its pollutants.

2.2. Effects of pollutants emitted from shipping.

When pollutants travel in greater levels outside the atmosphere, they get trapped and affect the stratosphere worldwide, with compounds contributing to the existence of persistent pollutants. Persistent pollutants have been detected to have affected the surroundings of both poles. Those pollutants, besides adding up to the global inventory, also lead to ice melting in the poles, as they contribute to global warming. This applies to additional and restricted measures for emissions in vulnerable areas, such as the Arctic routes and ECA areas.

A major pollutant, that can affect both human health and climate change and is detected as both primary and secondary pollutant, is particulate matter (**PM_x**). Particulate matter varies in size, as its diameter ranges from 0.002 to 100 μm. While larger in size, they can be rejected easily from the atmosphere. But, those with a diameter between 0.002-10 μm, are the ones that can cause severe health problems - connecting mainly with the respiratory system - and contribute to climate change - global warming - so they are of great attention.

Nitrogen oxides and more specifically nitrogen oxide and dioxide (**NO** & **NO_2**) are emitted from the combustion of fossil fuels and when exposed to UV radiation, they react with hydrocarbons and produce a mixture of **O_3**, **HNO_2**, aldehydes, **PANs** and other secondary pollutants. Even small amounts of these chemicals are able to affect the vision and respiratory system of both humans and animals, and damage crops and trees. This mixture of pollutants are the compounds of photochemical smog; a visible brown haze that is most discrete during morning and afternoon hours, in densely populated, warm areas. Due to its existence in areas with warmer temperatures, photochemical smog is most common during summer. As more and more urban populations appear around the world, this problem is expected to increase and many more people may encounter its adverse health effects.

Another important secondary pollutant that can damage human health is ground level **O_3**. It is formed by the reaction of the emissions - especially **VOCs** - and those chemical changes increase the level of **O_3** in the lower levels or the atmosphere. Photochemical smog - described above - is a cause of preventing ground level ozone depletion. Ozone is harmless when in the stratosphere, contributing to our protection from UV radiation. However, when existing in the atmosphere, it can harm the lungs through breathing it, but also damage agriculture and flora.

2.3. Environmental issues.

Shipping is a crucial aspect of international trade and commerce, enabling goods to be transported around the world efficiently and cost-effectively. However, the shipping industry also has a significant impact on the environment, contributing to various environmental issues, such as air and water pollution, climate change, and biodiversity loss. The environmental impact of shipping has become a growing concern in recent years, as the volume of global trade continues to increase, and the negative effects of shipping on the environment are becoming more apparent. This has led to increased efforts to address the environmental impact of shipping, both through regulatory measures and industry-led initiatives, to promote more sustainable and environmentally-friendly shipping practices.

2.3.1. Climate change.

When people think of climate change, they only think of the rise in temperature. But climate change is more complex than that. It includes not only global warming, but also changes in weather patterns - sometimes extreme such as drought or floods - sea level rise, glacier shrinking and changes in every aspect of our lives. However, those impacts differ in volume around the world. That means different regions and more specifically the poles, are more affected by climate change. Although research on climate showed its variability over the decades, it also proved that in recent years, Earth’s climate is changing because of the human impact on it. We may believe that climate change is going to be a future phenomenon, but we are now experiencing its effects both in our health and surrounding ecosystems. That calls for immediate action to minimize those negative outcomes and reduce our emissions as there is still time.

2.3.2. The greenhouse effect.

Greenhouse effect is connected with solar energy entering the Earth. It is a natural process in which the planet's atmosphere traps heat, keeping the temperature at the surface at suitable levels in which the living beings can live and grow. The major element contributing to this phenomenon is Carbon dioxide (**CO_2**), a gas that easily absorbs radiation. UV radiation enters Earth's atmosphere. Some of it is used to warm the surface and it is vital, since it supports life on our planet. The excess radiation bounces back and exits our planet. The greenhouse effect is happening, when a portion of the radiation leaving the Earth is absorbed by atmospheric **CO_2** and being remitted back to the surface. The planet's increased temperature is a factor of this particular event. The shipping industry is adding to the increase of GHGs concentrations in the atmosphere, emitting large amounts of **CO_2** through incomplete combustion of fuels and more radiation gets trapped to Earth as a result. The destructive effects of this phenomenon is the rise of sea level, extended by the melt of polar ice caps, the desertification of the temperate zone areas, as the rainbands move northward and the extinction of certain species. It was estimated that shipping was responsible for about 2.5% of global greenhouse gas emissions in 2020 (IMO 2020), and this figure is expected to increase as global trade continues to grow. Therefore, restrictions and initiatives are developing to manage - or if possible, eliminate - the carbon footprint globally. The shipping industry is also looking to transition to greener fuels - lower in sulfur-, creating a new market and a new world for global protection.

2.3.3. The ozone depletion.

Ozone exists both in the atmosphere and stratosphere in different concentrations. The majority subsist in the stratosphere, creating the commonly known Ozone Layer, playing an important role in life existence on our planet. This membrane of ozone in the stratosphere, absorbs most of the harmful UV radiation that reaches the Earth and prevents it from passing through the atmosphere. Without this natural filtration of UV light from the sun, the Earth would be an inhabitable planet. UV light is divided into three types: UV-A UV-B and UV-C: The latter is the one that is absorbed by ozone in the stratosphere and therefore, is the most dangerous ultraviolet radiation, as:

A. It is the leading cause of melanoma, a deadly form of skin cancer.

B. UV-C radiation is strong enough to pass through the retina of the eye that is a cause of cataracts.

C. Lastly, and possibly the main effect of UV-C on living organisms is to mutate their DNA. It is used by scientists in laboratories and under suitable conditions to achieve gene mutations. Specifically, UV-C alters DNA to such an extent that it gradually loses its ability to divide and multiply. As for plant organisms, it obstructs photosynthesis, alters growth rates, and obliterates DNA.

Thus, the ozone hole allows ultraviolet radiation to enter the Earth's atmosphere, causing all these problems in living organisms. At the same time, the effects of the phenomenon also concern the environment. The prevailing view is that if ozone, which absorbs some of the sun's radiation, is reduced, more heat will enter the Earth, which in combination with the also serious greenhouse effect, will contribute to global warming. The thinner ozone layer appears to be above the north pole and the region of the Arctic. Since 1985, when the ozone depletion phenomenon was first observed, countermeasures such as the Montreal Protocol were made in order to treat and ease the depletion.

2.3.4. Photochemical smog.

Shipping pollution can contribute to the formation of photochemical smog, which is a type of air pollution that can have harmful effects on human health and the environment. When nitrogen oxides (NOx) and volatile organic compounds (VOCs) from ship emissions react with sunlight, they can form ground-level ozone and other pollutants, such as particulate matter (PM) and sulfur dioxide (SO2). These pollutants can cause a variety of health problems, including respiratory issues such as coughing, wheezing, and asthma, as well as eye irritation and headaches.

Figure 1: Photochemical smog in the Los Angeles area. Source: United States Geological Survey.

In addition to its effects on human health, photochemical smog from shipping pollution can also have environmental impacts. For example, it can damage crops and other vegetation, harm wildlife, and contribute to the acidification of soils and water bodies. Furthermore, ozone and other pollutants that contribute to photochemical smog can also exacerbate climate change, as they are greenhouse gasses that contribute to global warming. To mitigate the effects of photochemical smog from shipping pollution, regulatory measures such as Emission Control Areas (ECAs) and stricter emission standards for ships have been implemented. Additionally, increasing the use of cleaner fuels and developing more efficient shipping technologies can also help reduce the amount of NOx, VOCs, and other pollutants emitted by ships, and therefore help to mitigate the impact of photochemical smog.

2.3.5. Acid rain.

Shipping emissions can contribute to the formation of acid rain, which is a type of precipitation that has a lower pH than normal rainwater. When sulfur dioxide (SO2) and nitrogen oxides (NOx) from ship emissions are released into the atmosphere, they can react with water, oxygen, and other chemicals to form sulfuric acid (H2SO4) and nitric acid (HNO3), respectively. These acids can then be transported over long distances by wind and other atmospheric processes, leading to the formation of acid rain in areas far from the original emission source. In recent years this phenomenon is becoming more and more frequent. Depending on its pH level and the period of time exposed, acid rain can degrade historical monuments, corrode metals, burn plant leaves, harm buildings etc. Also, many aquatic species die or have trouble reproducing due to damage to their young and their eggs because of a reduction in pH in surface waters. It also destroys aquatic flora and degrades water quality. The same applies to ground flora and fauna. As for humans and animals, it increases the chances of cancer and burdens the respiratory function.

2.4. Conclusions

This segment offered some general information, regarding the environmental problems interconnected with human activity. Specifically, it stated the effects of air pollution from ships, in human health and nature. Since shipping is the most common means of global trade, representing up to 90% of transporting goods, it shares a great responsibility for the existence and the ongoing increase of these problems. These concerns have long been addressed by Nations, International bodies and organizations, and several acts were taken such as protocols, conventions and constantly updating regulations as we will see further. But this is not enough. There is always room for improvement. The best and only way is for everyone to be informed regarding these problems and consequences and the part that the shipping industry plays in this, in order to reduce the human footprint on the planet.

Chapter 3. The evolution of regulations on marine pollution from ships.

Humanity has long recognized the value of utilizing the seas, as it has played a critical role in supporting societies and sustaining life for centuries. Consequently, there has been a historical necessity to regulate and manage marine activities. The origins of sea regulations can be traced back to the trade that occurred in the Mediterranean Sea many centuries ago, during the B.C. era. However, over the past few decades marine pollution from ships has been a growing concern, as it can have significant impacts on the health of marine ecosystems and human societies that rely on them. In response, various regulations and policies have been developed to control and reduce marine pollution from ships. The evolution of these regulations can be traced back to the 1950s, when concerns over oil spills and other forms of marine pollution began to emerge.

One of the key milestones in the evolution of regulations on marine pollution from ships was the adoption of the International Convention for the Prevention of Pollution from Ships (MARPOL) in 1973. This convention was designed to prevent and control pollution from ships by setting standards for the discharge of pollutants, including oil, chemicals, sewage, and garbage. The convention has since been amended several times, with the most recent amendment coming into force in 2020.

Another important development in the evolution of regulations on marine pollution from ships was the creation of Emission Control Areas (ECAs) in certain regions around the world. These areas were established to reduce the emissions of sulfur oxides (SOx), nitrogen oxides (NOx), and particulate matter (PM) from ships by requiring them to use fuels with lower sulfur content or to install emission control technologies. The first ECA was established in the Baltic Sea in 2005, and additional ECAs have since been designated in other regions, including the North Sea, the English Channel, and the coastal areas of North America (Figure 2).

Figure 2 : Existing Emission Control Areas around the world. Source: DNV GL 2015, updated by ICCT.

Overall, the evolution of regulations on marine pollution from ships reflects a growing recognition of the importance of protecting marine ecosystems and human societies from the negative impacts of ship pollution. While there is still much work to be done in this area, the development of international conventions like MARPOL and the establishment of ECAs represent important steps towards a more sustainable and environmentally responsible maritime industry.

3.1. International Maritime Organization (IMO).

The International Maritime Organization (IMO) is a specialized agency of the United Nations that is responsible for regulating shipping and maritime affairs worldwide. Established in 1948, the IMO's main mandate is to promote the safety and security of international shipping, prevent marine pollution, and facilitate trade by setting global standards and regulations for the shipping industry. The IMO's work covers a wide range of issues, including ship design and construction, navigation and communications, crew training and certification, environmental protection, and maritime security. The organization also provides technical assistance and capacity building to its member states (Annex 1), which include more than 170 countries, and collaborates with other international organizations and stakeholders to address emerging challenges facing the maritime sector. The IMO plays a crucial role in promoting sustainable and efficient shipping, which is essential for global trade and economic development while minimizing the impact on the environment and human health.

3.1.1. Evolution of strategies and regulations adopted by IMO.

The International Maritime Organization (IMO) has adopted various strategies over the years to address marine pollution from ships. Some of the key strategies adopted by IMO include:

MARPOL Convention: The International Convention for the Prevention of Pollution from Ships, also known as the MARPOL Convention, is one of the most important IMO treaties aimed at preventing marine pollution from ships. It was first adopted in 1973 and has been amended several times since then to address emerging environmental concerns.

The MARPOL Convention consists of six annexes, each addressing a specific type of marine pollution. Annex I deals with the prevention of pollution by oil, Annex II deals with the prevention of pollution by noxious liquid substances, Annex III deals with the prevention of pollution by harmful substances in packaged form, Annex IV deals with the prevention of pollution by sewage from ships, Annex V deals with the prevention of pollution by garbage from ships, and Annex VI deals with the prevention of air pollution from ships.

It has been ratified by over 150 countries and is enforced by port state control inspections, which check that ships comply with the convention's requirements. The convention has been instrumental in reducing marine pollution from ships and continues to be a key instrument in promoting sustainable shipping.

Annex VI: Annex VI of MARPOL, deals specifically with air pollution from ships. It was added to the convention in 1997 and came into force in 2005. The annex sets limits on the emissions of sulfur oxides (SOx) and nitrogen oxides (NOx) from ships and aims to reduce air pollution from ships by promoting the use of cleaner fuels and technologies.

Under Annex VI, ships are required to use fuel with a sulfur content of no more than 0.5% in certain areas, known as sulfur emission control areas (SECAs). In these areas, the maximum sulfur content is further reduced to 0.1%. Annex VI also sets limits on NOx emissions from diesel engines and requires new ships to meet Tier II or Tier III NOx emission standards.

Annex VI also encourages the use of alternative fuels and technologies to reduce air emissions from ships. For example, ships can use liquefied natural gas (LNG) as a fuel, which emits fewer pollutants than traditional marine fuels. The annex also promotes the use of exhaust gas cleaning systems (EGCS), also known as scrubbers, to remove pollutants from exhaust gasses before they are released into the atmosphere.

Ballast Water Management Convention: Is an international treaty aimed at preventing the spread of harmful aquatic organisms and pathogens from one region to another through ballast water carried by ships. The convention was adopted by the International Maritime Organization (IMO) in 2004 and came into force in 2017.

Ballast water is taken on board by ships to provide stability and balance, and is discharged when cargo is loaded or unloaded. However, ballast water can contain a range of aquatic organisms, including bacteria, microbes, small invertebrates, and even fish and marine mammals. When ballast water is discharged in a new region, these organisms can be introduced to local ecosystems and cause harm to native species and habitats.

The Ballast Water Management Convention requires ships to manage their ballast water to minimize the risk of introducing harmful organisms to new regions. This can be done through a range of measures, including exchanging ballast water in the open ocean, treating ballast water using approved technologies, or using a combination of both. The convention sets out specific requirements for the treatment of ballast water, including standards for the number and size of organisms allowed in discharged water. Ships are required to carry a ballast water record book and a ballast water management plan, and may be subject to additional inspections and surveys.

Sulfur Emission Control Areas (SECAs): Sulfur Emission Control Areas (SECAs) are specific geographic areas designated under Annex VI of the International Convention for the Prevention of Pollution from Ships (MARPOL) where ships are required to use fuel with a maximum sulfur content of 0.1%, compared to the global limit of 0.5%.

The SECAs were introduced to reduce the emissions of sulfur oxides (SOx) from ships, which can have a harmful impact on human health and the environment. The current SECAs include the Baltic Sea, the North Sea, and the English Channel, as well as the coastal areas of the United States and Canada.

Ships operating within SECAs are required to use low-sulfur fuel or alternative fuels such as liquefied natural gas (LNG) or methanol. Alternatively, they may use exhaust gas cleaning systems (EGCS) to remove sulfur oxides from the ship's exhaust gasses before they are released into the atmosphere.

The establishment of SECAs has been an important step towards reducing air pollution from ships, and has contributed to improved air quality and public health in the designated areas. It has also encouraged the development and adoption of cleaner technologies and fuels in the shipping industry.

Hong Kong Convention: The Hong Kong International Convention for the Safe and Environmentally Sound Recycling of Ships, commonly known as the Hong Kong Convention, is an international treaty aimed at ensuring that ships are recycled in a safe and environmentally sound manner.

The convention was adopted by the International Maritime Organization (IMO) in 2009, and it sets out requirements for the design, construction, operation, and maintenance of ship recycling facilities, as well as the handling of hazardous materials and the protection of workers' safety and health.

Under the Hong Kong Convention, ships are required to have an inventory of hazardous materials (IHM) that lists all the hazardous materials on board, such as asbestos, heavy metals, and toxic chemicals. The IHM must be updated throughout the ship's life cycle and be available to ship recycling facilities at the end of the ship's life.

Ship recycling facilities are required to have a valid license to operate and comply with the convention's safety and environmental standards. They must also develop a ship recycling plan (SRP) that outlines the procedures for the safe and environmentally sound recycling of each ship.

Energy Efficiency Design Index (EEDI): The EEDI is a technical measure adopted by IMO in 2011 to improve the energy efficiency of new ships. It sets minimum design standards for new ships based on their size and type, and aims to reduce greenhouse gas emissions from shipping.

Polar Code: The Polar Code for ships was developed by the International Maritime Organization (IMO) in 2014 to enhance the safety and environmental protection of ships operating in the harsh and remote polar regions. The regulations cover various aspects of ship design, construction, equipment, and operation, including:

Structural requirements: Polar Code mandates that ships operating in polar waters must have strengthened hulls and other structural features to withstand the harsh polar conditions.

Environmental protection: The code sets out rules for preventing pollution from ships, including restrictions on discharging oil, garbage, and sewage in polar waters.

Navigation and communication: Polar Code requires ships to have appropriate navigation and communication equipment, such as radar, GPS, and satellite communications, to ensure safe navigation in polar waters.

Crew training: The code mandates that ships' crew members must be adequately trained and familiar with polar operations and emergency procedures.

Polar Code for ships is essential to ensure the safety and sustainability of shipping activities in polar regions, where environmental conditions are challenging and can be hazardous for ships and crew. By following the regulations and guidelines set out in the Polar Code, ships can operate safely and responsibly in these remote and sensitive areas.

Global Sulfur Cap: The Global Sulphur Cap refers to the new regulations set by the International Maritime Organization (IMO) to limit the amount of sulfur oxide emissions from ships. The regulation requires ships to use fuels with a lower sulfur content to reduce their impact on the environment and human health.

The Global Sulphur Cap came into effect on January 1st, 2020, and mandates that ships must use fuel with a maximum sulfur content of 0.50% by mass when operating outside designated emission control areas. This is a significant reduction from the previous limit of 3.5% sulfur content and is expected to result in a significant reduction in sulfur oxide emissions from ships.

Ships can comply with the Global Sulfur Cap by using low-sulfur fuel, installing emissions abatement technologies, such as scrubbers, or switching to alternative fuels, such as liquefied natural gas (LNG) or biofuels. The regulation applies to all ships, regardless of their flag, size, or type, and failure to comply can result in penalties and fines.

Emission Control Areas (ECAs): ECAs were established by the International Maritime Organization (IMO) under MARPOL Annex VI, which regulates air pollution from ships. Currently, there are four designated ECAs worldwide: the Baltic Sea, the North Sea, the North American ECA, and the United States Caribbean Sea ECA. These ECAs have stricter sulfur limits than the global sulfur cap, with a maximum sulfur content of 0.10% for ships operating within the ECAs.

There have been discussions about establishing new Emission Control Areas (ECAs) in other regions of the world. One potential area being considered is the Mediterranean Sea, where there are concerns about air pollution and its impact on human health.

In addition to the Mediterranean Sea, there have been calls to establish ECAs in other regions, such as the South China Sea, the English Channel, and the Strait of Hormuz (Figure 3). The establishment of these new ECAs would require the support of IMO member states and industry stakeholders, as well as a comprehensive analysis of the potential environmental and economic impacts.

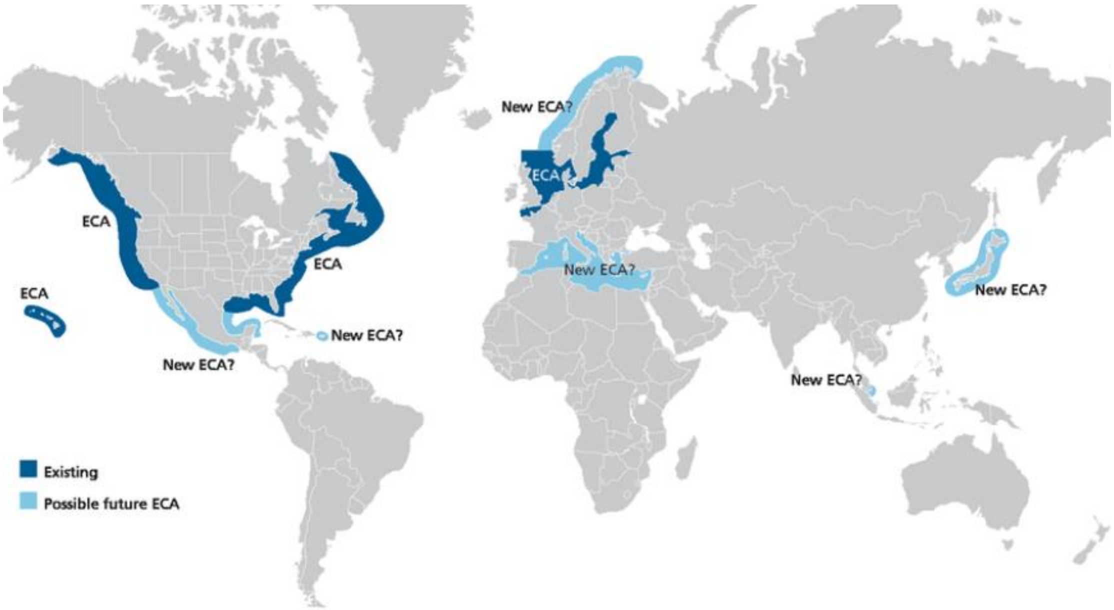

Figure 3 : Emission control areas (ECA) for Tier III and possible future ECA as indicated by DNV GL.

IMO has also been working to strengthen the existing ECAs by reviewing and updating the regulations under MARPOL Annex VI. In 2020, IMO adopted amendments to MARPOL Annex VI that will also include provisions for the evaluation of the effectiveness of the ECAs and the potential establishment of new ECAs in the future.

These are just some examples of the strategies adopted by IMO to address marine pollution from ships. IMO continues to work towards developing new measures and strengthening existing ones to protect the marine environment and reduce the impact of shipping on human health and the environment.

3.1.2. Recent developments in IMO.

The International Maritime Organization (IMO) has been working on several recent developments to address emerging environmental and safety issues in shipping, including:

Reduction of greenhouse gas emissions: In 2018, IMO adopted an initial strategy to reduce greenhouse gas (GHG) emissions from shipping. The strategy aims to reduce GHG emissions from shipping by at least 50% by 2050 compared to 2008 levels, and to phase out GHG emissions from shipping as soon as possible in this century.

Cyber risk management: IMO has developed guidelines for the management of cyber risks in shipping. The guidelines provide recommendations for the prevention, detection, and response to cyber incidents in order to enhance the safety and security of ships and the protection of the environment.

Autonomous ships: IMO has developed guidelines for the testing and deployment of autonomous ships, which are expected to be increasingly used in shipping in the coming years. The guidelines address safety, security, and environmental concerns related to the use of autonomous ships.

Digitalization of shipping: IMO has been working on the digitalization of shipping, including the use of electronic shipping documents and the development of standardized data exchange formats. The goal is to improve efficiency and safety in shipping while reducing the environmental impact.

Implementation of IMO regulations: IMO has been working on the implementation of existing regulations, including the implementation of the sulfur cap, which limits the sulfur content in marine fuel to 0.5%, and the implementation of the Ballast Water Management Convention, which sets out regulations for the management of ballast water to prevent the spread of invasive species.

These developments are aimed at promoting sustainable and safe shipping practices, while addressing emerging environmental and safety issues in shipping.

The Monitoring, Reporting and Verification (MRV) Regulation: The EU has introduced a mandatory system for monitoring, reporting and verifying CO2 emissions from ships operating in EU waters. This regulation aims to provide transparent and reliable data on the amount of CO2 emitted by ships, which can help to inform future policy decisions and encourage shipping companies to reduce their emissions.

Port-based Measures: The EU has implemented port-based measures, such as shore power facilities and cold ironing, to reduce the emissions of ships while they are docked in port. These measures help to reduce the use of auxiliary engines, which are a significant source of emissions when ships are in port.

Financial Incentives: The EU has introduced financial incentives, such as reduced port fees and emissions trading schemes, to encourage shipping companies to reduce their emissions. These incentives can help to offset the cost of investing in cleaner technologies and encourage the adoption of more sustainable practices.

Overall, the EU's strategies for mitigating air emissions from ships aim to reduce the impact of shipping on air quality and climate change while maintaining the competitiveness of the European shipping industry. These strategies are an important part of the EU's efforts to transition to a more sustainable and low-carbon economy.

3.2. Strategies by E.U

Apart from IMO, on local scale, the European Union has implemented a range of strategies to mitigate air emissions from ships, including:

The Monitoring, Reporting and Verification (MRV) Regulation: The EU has introduced a mandatory system for monitoring, reporting and verifying CO2 emissions from ships operating in EU waters. This regulation aims to provide transparent and reliable data on the amount of CO2 emitted by ships, which can help to inform future policy decisions and encourage shipping companies to reduce their emissions.

EU Emissions Trading System (EU ETS) – It is a cap-and-trade system for greenhouse gas emissions that covers certain sectors, including shipping. From January 1, 2022, ships over 5,000 gross tonnage (GT) that call at EU ports will be required to monitor and report their carbon emissions under the EU MRV (Monitoring, Reporting, Verification) regulation. From 2023, the EU ETS will be expanded to cover emissions from ships that are voyaging between EU ports.
Port-based Measures: The EU has implemented port-based measures, such as shore power facilities and cold ironing, to reduce the emissions of ships while they are docked

in port. These measures help to reduce the use of auxiliary engines, which are a significant source of emissions when ships are in port.

Financial Incentives: The EU has introduced financial incentives, such as reduced port fees and emissions trading schemes, to encourage shipping companies to reduce their emissions. These incentives can help to offset the cost of investing in cleaner technologies and encourage the adoption of more sustainable practices.

ECO ports: Eco Ports is a network of European ports that aims to promote and support environmental sustainability in port operations and management. The network includes more than 100 ports in Europe and beyond. The Eco Ports network provides a framework for sharing knowledge and best practices on environmental management and sustainability in ports. It also offers a certification scheme, the Eco Ports PERS (Port Environmental Review System), which assesses and recognizes port environmental performance.

In general, the EU's strategies for mitigating air emissions from ships aim to reduce the impact of shipping on air quality and climate change while maintaining the competitiveness of the European shipping industry. These strategies are an important part of the EU's efforts to transition to a more sustainable and low-carbon economy, while also improving its port competitiveness, attracting new business, and enhancing their reputation as responsible and sustainable partners in the supply chain.

3.3 National strategies.

On a national level, each nation developed its own regulations and strategies for air preservation. Below are some examples:

China: In 2015, China implemented an Emission Control Area (ECA) in the Pearl River Delta, Yangtze River Delta, and Bohai Rim region, where ships are required to use low-sulfur fuel. In 2018, the ECA was expanded to cover the entire coastline of China. China has also implemented a national standard for marine fuel, which limits the sulfur content to 0.5%.

United States: The United States has implemented an ECA covering the waters within 200 nautical miles of its coasts. This ECA requires ships to use low-sulfur fuel and has resulted in significant reductions in sulfur oxide emissions. The United States has also implemented national standards for marine fuel, which limit the sulfur content to 0.5%.

European Union: The European Union has implemented the Sulphur Directive, which requires ships to use low-sulfur fuel in designated ECA areas within its waters. The EU has also established an emissions monitoring and reporting system for ships, which requires ships to monitor and report their emissions of carbon dioxide, sulfur oxide, nitrogen oxide, and particulate matter. These limits are significantly lower than those required by international standards and have helped to reduce air pollution from shipping in these areas.

Japan: Japan has implemented an ECA covering the waters within 200 nautical miles of its coasts, where ships are required to use low-sulfur fuel. Japan has also implemented a voluntary energy efficiency standard for ships, which encourages the use of more fuel-efficient technologies and practices.

These are just a few examples of the many strategies and regulations implemented by nations to mitigate air pollution from ships. By working together and sharing best practices, nations can continue to make progress towards a more sustainable and environmentally friendly maritime industry.

Chapter 4. Transition to a more sustainable future.

The shipping industry - as mentioned -, is a significant contributor to global greenhouse gas emissions and environmental pollution. To address these concerns, the International Maritime Organization (IMO) has developed several measures and regulations aimed at reducing the environmental impact of shipping. The Energy Efficiency Design Index (EEDI) and the Energy Efficiency Operational Indicator (EEOI) are mandatory technical standards that set minimum energy efficiency requirements for new ships and measure the energy efficiency of ships in operation, respectively. The Ship Energy Efficiency Management Plan (SEEMP) is a non-mandatory framework that provides guidelines and best practices for optimizing ship operations and management. Together, these measures have helped the shipping industry make progress in reducing its environmental impact and mitigating pollution. Apart from these measures, and in the spirit of modernization and environmental awareness, the shipping industry is introduced to various changes that can be made on ships to eliminate its footprint. From the funnels and the ship's design to its fuel and maintenance, all these updates on the ship's operation and care can add to air preservation and provide a base for future developments. All the above will be analyzed in the following paragraphs in order to see how they contribute to the industry's environmental impact.

4.1 The Energy Efficiency Design Index (EEDI).

The Energy Efficiency Design Index (EEDI), is a mandatory technical standard developed by IMO that sets the minimum energy efficiency requirements for new ships. The goal is to promote the use of more sustainable ship designs and reduce greenhouse gas emissions from shipping.The EEDI is calculated based on a ship's design and takes into account factors such as its size, speed, and engine power. Ships must meet a minimum EEDI requirement to be certified for operation. The minimum is calculated based on a ship's design, and it is expressed in grams of CO_2 per tonne-mile (gCO_2/tonne-mile).

The EEDI calculation takes into account the ship's fuel consumption and emissions, as well as its transport work, which is the amount of cargo it can carry per unit of time. Its formula is:

$$\mathbf{EEDI = (C \times K) / (D \times L)}$$

Where:

C = the estimated daily fuel consumption of the ship in tons per day

K = the conversion factor for the type of fuel used by the ship

D = the transport work of the ship, which is the product of its deadweight tonnage (DWT) and its design speed

L = the length of the ship in meters.

The conversion factor (K) takes into account the carbon content and the energy content of the fuel. The transport work (D) is calculated based on the cargo capacity of the ship and its design speed. (Annex 2)

To have a reference level, against which the Energy Efficiency Design Index (EEDI) requirements are calculated, IMO established the baseline level. (IMO 2008) (Annex 3). The baseline level represents the average energy efficiency of ships that were built between 2000 and 2010 The EEDI requirements are set as a percentage reduction from the baseline level. For example, the minimum EEDI requirement for a new ship built in 2020 is 30% lower than the baseline level. By 2025, the minimum requirement will be 50% lower than the baseline level. This means that a new ship built in 2025 will need to be 50% more energy-efficient than the average ship built between 2000 and 2010. The baseline level is periodically reviewed and updated by the IMO to reflect advances in technology and changes in the shipping industry.

The EEDI has been effective in promoting the development of more environmentally friendly - high performance - energy saving ships. Ship designers and builders have had to adapt to the stricter requirements, resulting in the creation of more competent ship designs. For example, many new ships now feature next-generation engines, advanced propulsion systems, and innovative hull designs that reduce drag and improve fuel efficiency.

4.2 Energy Efficiency Operational Indicator (EEOI).

The Energy Efficiency Operational Indicator (EEOI) is a voluntary technical standard developed by the IMO. Unlike the EEDI, which applies to new ships, the EEOI, is a tool used to measure the energy efficiency of a ship during its operation. It is a ratio of the amount of CO_2 emissions produced by the ship to the amount of cargo carried and the distance traveled. The EEOI, provides a metric for assessing a ship's environmental performance (Annex 4). Ship operators can use the EEOI to identify areas for improvement and track their environmental performance over time.

The EEOI is calculated using the following formula:

EEOI = (Total CO_2 emissions during voyage) / (Cargo carried x Distance traveled)

The total CO_2 emissions during a voyage include emissions from the ship's main engine, auxiliary engines, boilers, and other sources of energy consumption. The cargo carried is measured in tons, and the distance traveled is measured in nautical miles. It is expressed in grams of CO_2 per ton-mile and is used as a benchmark for measuring the energy efficiency of a ship. The lower the EEOI value, the more energy-efficient the ship is considered to be. It can also be used to compare the energy efficiency of a ship with other ships of similar size and type. If the EEOI value is high, it indicates that the ship is less energy-efficient and emits more CO_2 per unit of cargo and distance traveled. Conversely, a lower EEOI value indicates that the ship is more energy-efficient and emits less CO_2 per unit of cargo and distance traveled.

The EEOI has been effective in encouraging ship operators to adopt more viable operating practices. By tracking their environmental performance, operators can identify areas for improvement and implement changes to reduce fuel consumption and emissions. For example, operators can adjust their speed, optimize their routes, and improve their maintenance practices to reduce fuel consumption and improve efficiency. The EEOI has also encouraged the development of new technologies, such as emissions abatement systems and alternative fuels, that can further lower the level of harmful discharges and decrease the amount of pollutants released from ships.

4.3. Ship Energy Efficiency Management Plan (SEEMP).

The Ship Energy Efficiency Management Plan (SEEMP) is a framework developed by the IMO to help ship owners and operators improve the energy efficiency of their ships. It is a mandatory requirement for all ships of 400 gross tonnage and above. The SEEMP provides a set of guidelines and best practices for optimizing ship operations, maintenance, and management, and can help reduce fuel consumption, emissions, and operating costs.

The SEEMP has been effective in encouraging ship owners and operators to adopt more sustainable practices. Although it is not mandatory, many ship owners have implemented SEEMPs as part of their sustainability efforts. It is a document that outlines the measures that the ship operator will take to improve the energy efficiency of the ship during its operation. The SEEMP is based on the concept of continuous improvement in energy efficiency and provides a framework for identifying and implementing measures to reduce the environmental impact of the ship. It is not a prescriptive document, but rather a flexible tool that allows ship operators to tailor their energy efficiency measures to their specific vessel and operational needs.

The SEEMP is designed to promote a culture of energy efficiency in the shipping industry and encourage ship operators to adopt best practices for reducing fuel consumption and greenhouse gas emissions. The SEEMP includes a variety of measures, such as optimizing the ship's speed and route, implementing energy-efficient technologies, and reducing unnecessary energy consumption onboard.

The SEEMP is implemented in four phases: planning, implementation, monitoring, and self-evaluation. During the planning phase, the ship operator identifies potential energy efficiency measures and sets targets for improvement. In the implementation phase, the ship operator implements the identified measures and monitors their effectiveness. During the monitoring phase, the ship operator measures and analyzes the ship's energy efficiency performance. In the self-evaluation phase, the ship operator evaluates the effectiveness of the implemented measures and identifies areas for further improvement.

Finally, SEEMP is an important tool and an integral part of the regulatory framework for shipping, and its implementation is essential for compliance with international environmental regulations.

4.4 The Environmental Ship Index (ESI).

The Environmental Ship Index (ESI), is a voluntary tool that evaluates the environmental performance of ships based on their emissions of air pollutants (nitrogen oxides and sulfur oxides) and greenhouse gasses (carbon dioxide). The tool assigns a score to each ship based on its emissions performance, with higher scores indicating cleaner ships.

To calculate a ship's ESI score, the following steps are typically taken:

Data collection: The ship's emissions data is collected through various means, such as engine monitoring systems or onboard sensors. The data is then verified to ensure its accuracy.

Calculation (Annex 5): The ship's emissions data is entered into a calculation tool that uses a standardized methodology to calculate the ship's emissions performance. The calculation takes into account factors such as the ship's engine type, fuel consumption, and operating conditions. The ESI score is based on a set of reference levels for each pollutant, which are updated periodically. As of 2021, the reference levels for nitrogen oxides (NOx), sulfur oxides (SOx), and carbon dioxide (CO2) emissions are 17.2 grams per kilowatt hour (g/kWh), 1.5 g/kWh, and 22 grams per tonne-kilometer (g/t-km), respectively. The emissions reduction factor (ERF) is calculated for each pollutant by comparing the ship's emissions to the reference levels. The ERF is expressed as a percentage, with a higher percentage indicating greater emissions reduction. The formula for calculating the ERF is:

ERF = 100 x (1 - (ship emissions / reference emissions))

The ERFs for each pollutant are weighted according to their environmental impact. The current weighting factors for NOx, SOx, and CO2 emissions are 50%, 30%, and 20%, respectively.

Score assignment: Based on the ship's emissions performance, the ship is assigned an ESI score on a scale of 0-100. The overall ESI score is calculated by summing the weighted ERFs for each pollutant. A higher score indicates better emissions performance.

The ESI is intended to incentivize the use of cleaner ships in ports and other shipping-related activities. Ports and other stakeholders can use the tool to offer incentives (such as reduced port fees or preferential treatment) to ships with higher scores, thereby encouraging shipowners and operators to invest in cleaner technologies and practices.

One of the key benefits of the ESI is its ability to promote a level playing field for environmental performance in the shipping industry. By providing a standardized methodology for evaluating emissions performance, the tool can help to ensure that all ships are held to the same environmental standards. This can also help to create a market for cleaner technologies and practices, as shipowners and operators seek to improve their ESI scores to remain competitive. However, it's important to note that the ESI is a voluntary tool and not all ships participate in the program. Furthermore, the tool only evaluates emissions performance and does not account for other environmental impacts of shipping, such as noise pollution or impacts on marine ecosystems.

4.5 Energy Efficiency Existing Ship Index (EEXI).

The Energy Efficiency Existing Ship Index is a new regulation implemented by the International Maritime Organization's (IMO) MARPOL Annex VI to decrease greenhouse gas emissions from ships. EEXI calculates a ship's energy efficiency based on its carbon emissions per tonne-mile of transport work. All ships of 400 gross tonnage or more must comply with the EEXI requirement, which came into force on January 1, 2023 (Annex 6).

The primary objective of EEXI is to lessen the environmental impact of the shipping industry by encouraging more sustainable technologies and practices. To comply, ships must undergo an evaluation of their energy efficiency and show adherence to the required standards, which may require modifications to their engine, hull, or other systems, as well as the use of alternative fuels like liquefied natural gas (LNG) or biofuels. Although it is expected to be costly, the EEXI is considered an essential investment in the future of the maritime industry.

The formula is as follows:

$$\mathbf{EEXI = (CF * DWT) / [(CER * PME) + (0.01 * DWT)]}$$

Where:

CF is the carbon dioxide emissions factor, expressed in grams of CO_2 per kWh of energy consumed by the ship's main engines

DWT is the ship's deadweight tonnage

CER is the reference emissions value, expressed in grams of CO_2 per tonne-mile of transport work

PME is the power of the ship's main engines, expressed in kilowatts

The numerator of the formula (CF * DWT) represents the total carbon emissions of the ship in grams of CO_2 per hour, while the denominator represents the energy efficiency of the ship in kilowatts per tonne-mile of transport work.

The reference emissions value (CER) is determined based on the ship's type and size, and represents the average emissions value for a ship of similar characteristics. The reference value ensures that the EEXI takes into account the ship's unique characteristics and performance, as well as industry-wide standards.

The formula demonstrates that the EEXI is a measure of a ship's energy efficiency that considers both its carbon emissions and transport work. A more energy-efficient ship will have a lower EEXI value, indicating lower carbon emissions per tonne-mile of transport work. Conversely, a less energy-efficient ship will have a higher EEXI value, indicating higher carbon emissions per tonne-mile of transport work.

EEXI's implications extend beyond greenhouse gas emissions. It may lead to changes in vessel design, construction, and operation, as well as the development of new technologies and practices that improve energy efficiency and decrease environmental impact. The EEXI requirement could encourage more collaboration and knowledge-sharing among stakeholders in the maritime industry, as they strive to meet the standards and adapt to the industry's rapidly evolving landscape.

In summary, the EEXI requirement is a significant step towards reducing greenhouse gas emissions and improving sustainability in the maritime industry. Compliance will involve significant costs and challenges, but it is considered a necessary investment in the future of the industry. EEXI is expected to promote innovation and collaboration, leading to the development of more sustainable technologies and practices.

4.6. Carbon Intensity Reduction (CIR).

The IMO is developing the Carbon Intensity Reduction (CIR) rating system to encourage the reduction of carbon emissions from ships. This will create a standardized measure of emissions that can facilitate comparison and benchmarking between different ships and shipping companies. It is an important measure in the shipping industry, which is responsible for a significant portion of global greenhouse gas emissions.

Its formula is as follows:

CIR = (total carbon emissions in grams) / (total cargo transported in tonnes x distance transported in miles)

There are various ways in which shipping companies can achieve CIR, such as by adopting more energy-efficient technologies, improving vessel design and operations, and using low-carbon fuels such as LNG or biofuels. Additionally, some shipping companies have started to invest in carbon offsetting and carbon capture technologies as a means of reducing their carbon footprint.

CIR can also be used to compare the carbon efficiency of different shipping operations. It can also be used for specific routes or types of cargo, allowing shipping companies to identify areas where they can improve their carbon efficiency. For example, a shipping company may calculate CIR ratings for different routes or types of cargo and find that certain routes or cargoes have a higher carbon intensity than others. This can help the company to prioritize investments in more carbon-efficient technologies or to consider alternative routes or cargoes that have a lower carbon intensity.

A significant advantage of the CIR is that it provides a clear incentive for shipping companies to reduce their carbon emissions. Lower carbon intensity ratings will attract customers, investors, and other stakeholders who are increasingly concerned about sustainability and climate change. This can drive market demand for low-carbon shipping and spur innovation and investment in new technologies and practices.

Furthermore, the CIR is more accurate in measuring emissions than the Energy Efficiency Existing Ship Index (EEXI). While the EEXI sets a minimum energy efficiency standard for existing ships, it does not consider cargo-carrying capacity or distance traveled. In contrast, the CIR provides a comprehensive measure of emissions that factors in both of these elements. As pressure grows for the industry to take action on climate change, CIR is likely to become an increasingly important metric for measuring the environmental impact of shipping activities.

4.7. Carbon Intensity Indicator (CII).

The CII was developed by the IMO as part of its efforts to reduce greenhouse gas emissions from the shipping industry. The IMO has set a target to reduce the shipping industry's greenhouse gas emissions by at least 50% by 2050 compared to 2008 levels. The CII is expected to be a key tool in achieving this target by encouraging ships to improve their carbon efficiency. It is a measure of a ship's carbon emissions per unit of transport work, which is calculated as follows:

CII = (CO_2 emissions from fuel consumption during voyage) / (Transport work)

where CO_2 emissions are measured in metric tonnes and transport work is measured in tonne-miles. The transport work is calculated by multiplying the weight of cargo carried (in tonnes) by the distance traveled (in nautical miles). The resulting CII value provides a measure of a ship's carbon intensity, which is used to determine its rating on a scale of A to E under the IMO's Carbon Intensity Reduction (CIR) rating system.

Categories of rating:

Ships that receive a CII rating of A have a remarkably small amount of carbon emissions for each unit of transport work they carry out. This may be due to the use of more effective technologies like sails or hybrid engines, or using cleaner fuels such as biofuels. An example of this is a freighter that is outfitted with wind-assisted propulsion technology, which can harness wind power to supplement the engine's power. This kind of ship would likely receive an A rating for its CII, as it would emit fewer carbon emissions per unit of cargo transported, resulting in a lesser environmental impact than those with higher CII ratings.

Ships with a CII rating of B have low to moderate carbon emissions per unit of transport work. This could be because they are using moderately efficient technologies or cleaner fuels, but not to the same extent as ships with a rating of A. For example, a cargo ship using an efficient diesel engine and operating on LNG could have a CII rating of B. While this ship emits more carbon than a ship with a rating of A, it still has relatively low emissions per unit of transport work and is more sustainable.

Ships that receive a CII rating of C release moderate to high levels of carbon emissions per transport work unit. This could occur due to the usage of less efficient technologies or dirtier fuel sources. To illustrate, a cargo vessel that uses a conventional diesel engine and operates on heavy fuel oil may have a CII rating of C. Although this ship emits more carbon than those with A or B ratings, its emissions per transport work unit remain relatively moderate, and there is potential to enhance its sustainability by upgrading to cleaner or more efficient technologies.

Ships with a CII rating of D have high to very high carbon emissions per unit of transport work. This could be because they are using very old or inefficient technologies, or because they are using high-carbon fuels. For example, a cargo ship using an outdated two-stroke diesel engine and operating on heavy fuel oil could have a CII rating of D. This ship would emit much more carbon than a ship with a rating of A, B, or C, and would have a significant environmental impact.

Ships that receive a CII rating of E are characterized by very high levels of carbon emissions per unit of transport work. This could be attributed to the use of outdated and inefficient technologies or the utilization of high-carbon fuels. An example of such a ship would be a cargo vessel equipped with a coal-burning steam engine, which could easily earn a CII rating of E. Compared to ships that earn ratings of A, B, C, or D, this vessel would generate significantly higher levels of carbon emissions, resulting in a substantial environmental impact. To become more sustainable, ships with a rating of E would require significant upgrades or even complete overhauls.

Ships with higher CII ratings may face increased expenses due to carbon pricing schemes or other initiatives aimed at reducing emissions. Conversely, vessels with lower CII ratings may benefit from a competitive edge in the market, as they are viewed as more eco-friendly and may attract clients who prioritize reducing their carbon footprint.

The CII is expected to stimulate progress in the shipping industry by inspiring the creation and adoption of more carbon-efficient technologies and procedures. For instance, ships may invest in engines that are more fuel-efficient, transition to cleaner fuels, or implement more effective operating procedures to boost their CII score.

4.8. Container Ship Index (CSI).

The Container Ship Index is a recently developed environmental performance metric that focuses on container ships. The World Shipping Council collaborated with industry stakeholders to develop the CSI, which utilizes a set of environmental indicators to evaluate container ships' performance in terms of greenhouse gas emissions, air pollutants, and other environmental impacts.

The CSI uses a scoring system that awards points to different environmental indicators, such as sulfur oxides and nitrogen oxides emissions, energy efficiency, and waste management practices. The overall score is then used to assign the ship an A, B, C, or D rating, with A being the highest and D being the lowest.

The main objective of the CSI is to provide a standardized and transparent approach for shippers, customers, and other stakeholders to assess container ships' environmental performance. By offering a clear and comparable rating system, the CSI seeks to motivate container ship owners and operators to enhance their environmental performance and enable shippers and customers to make informed decisions about their shipping activities' environmental impact.

Container ships with high CSI ratings are more likely to attract customers who prioritize environmental sustainability in their shipping activities and may receive lower port fees or other financial incentives. Conversely, container ships with low CSI ratings may face higher costs or regulatory scrutiny and could find it challenging to compete in the marketplace.

4.9. Electronic Data Systems (EDS).

Electronic Data Systems have become an essential aspect of modern maritime transportation. EDS refers to a range of electronic tools and systems used in the maritime industry, such as electronic chart displays and information systems (ECDIS), vessel traffic management systems (VTMS), and automatic identification systems (AIS), among others. These systems have revolutionized the way the shipping industry operates, allowing for more efficient and safe management of vessels and cargoes, and reducing the risk of accidents and environmental damage.

One of the most critical functions of EDS in the maritime industry is to enhance navigational safety. ECDIS and AIS, for example, provide vessel operators with real-time information on the location, speed, and course of other vessels in their vicinity, allowing them to make more informed decisions and avoid collisions. VTMS, on the other hand, are used to manage vessel traffic in ports and other busy waterways, minimizing congestion and the risk of accidents.

In addition to improving navigational safety, EDS are also used to optimize vessel performance and improve environmental sustainability. For example, modern EDS can collect data on a vessel's fuel consumption, emissions, and other performance metrics, allowing operators to identify opportunities to improve efficiency and reduce environmental impacts. EDS can also help to monitor and manage cargoes, ensuring that they are handled safely and securely, and comply with various regulations and industry standards.

EDS have also been instrumental in enhancing security in the maritime industry. Advanced monitoring systems can detect and track suspicious vessels or activities, allowing authorities to intervene and prevent security incidents. EDS can also be used to monitor the movement of hazardous or high-value cargoes, reducing the risk of theft or other security breaches.

4.10. Exhaust Gas Cleaning Systems (EGCS).

Exhaust Gas Cleaning Systems, also known as scrubbers, are devices used to reduce harmful emissions from exhaust gasses released from engines. These systems have become increasingly important in recent years as the shipping industry looks for ways to reduce its impact on the environment. The main function of scrubbers is to remove sulfur oxides (**SOx**) and other pollutants from gas combustion, before they are released into the atmosphere. This is done by passing the exhaust gasses through a scrubbing tower that contains a scrubbing agent such as seawater, freshwater, or chemicals.

There are two types of exhaust gas cleaning systems: open loop and closed loop. In open loop systems, seawater is used as the scrubbing agent, and the resulting wastewater is discharged into the sea. This can be an advantage in terms of cost and simplicity since seawater is readily available, and there is no need for onboard storage or disposal of wastewater. Open loop systems also have lower energy consumption since they do not require additional water treatment or chemical production. However, the discharge of wastewater can be a concern since it may contain pollutants such as heavy metals, particulate matter, and other harmful substances. This can have adverse effects on marine ecosystems, and there is a risk of polluting sensitive coastal areas. Therefore, the use of open loop systems is subject to regulations and restrictions to minimize their environmental impact.

Closed loop systems, on the other hand, use fresh water or chemicals as the scrubbing agent, and the resulting wastewater is stored onboard for later disposal at a port facility. This can be an advantage in terms of environmental protection since the discharge of wastewater is controlled and monitored, and there is less risk of polluting coastal waters. Closed loop systems also allow for the recovery of valuable byproducts such as gypsum, which can be sold or reused. However, closed loop systems have higher energy consumption since they require additional water treatment and chemical production, and they have higher operating costs due to the need for wastewater storage and disposal. There is also a risk of chemical spills or leaks, which can have adverse effects on the environment and human health. Both types of systems have advantages and disadvantages, and the choice of system depends on various factors such as the ship's type, size, and operating conditions.

One of the main benefits of exhaust gas cleaning systems is their ability to reduce emissions of harmful pollutants, particularly sulfur oxides. Scrubbers can remove up to 98% of sulfur oxides from exhaust gasses, which can have a significant positive impact on air quality and human health. Additionally, scrubbers can also reduce particulate matter emissions and other pollutants such as nitrogen oxides and carbon dioxide. However, there are the aforementioned concerns regarding the environmental impact of the exhaust gas cleaning system. The discharge of wastewater from open loop systems can lead to the accumulation of pollutants in coastal waters, which can have adverse effects on marine ecosystems. Additionally, the production and disposal of chemicals used in closed loop systems can also have environmental impacts. Therefore, it is important to carefully consider the potential environmental impacts of these systems and to ensure that they are properly designed and operated to minimize their environmental footprint.

To sum up, exhaust gas cleaning systems are an important tool for reducing emissions from ships and improving air quality. However, it is important to balance the environmental benefits of these systems with their potential environmental impacts and to make sure that regulations and best practices are in place to ensure that these systems are used in a responsible and sustainable manner, and further research and innovation are needed to improve their efficiency and effectiveness.

4.11. Low Sulfur Fuel.

Low sulfur fuel is a type of fuel that has a lower sulfur content than conventional fuels. It is often used in the shipping industry to comply with environmental regulations that aim to reduce the emissions of sulfur oxides (SOx) from ships. The use of low sulfur fuel is mandatory in certain designated emission control areas (ECAs), which are areas where strict limits on sulfur emissions have been imposed by the International Maritime Organization (IMO). The main benefit of low sulfur fuel is its ability to reduce emissions of sulfur oxides and other harmful pollutants from ships. By using low sulfur fuel, ships can reduce their sulfur emissions by up to 97%, which can significantly improve atmospheric conditions and public health benefits.

On the other hand, the use of low sulfur fuel also has some challenges and drawbacks. One of the main challenges is the cost of the fuel, which is generally higher than conventional fuels due to the additional refining processes required to reduce the sulfur content. The availability of low sulfur fuel can also be a concern, especially in areas where it is not readily available or where there is high demand. This can lead to supply chain disruptions and higher costs for the shipping industry. Additionally, the use of low sulfur fuel can also have implications for engine performance and maintenance. Low sulfur fuel has different properties than conventional fuels, and it can lead to increased wear and tear on engine components such as fuel pumps, injectors, and valves. Therefore, it is important for ship operators to ensure that their engines are properly designed and maintained to operate on low sulfur fuel.

In general, the use of low sulfur fuel is a significant approach to minimize emissions from ships and enhance the condition of the air we breathe. Nevertheless, it is crucial to strike a balance between the environmental advantages of using low sulfur fuel and the potential economic and technical consequences. Responsible and sustainable use of this fuel is imperative. The shipping industry is exploring other alternatives - all analyzed in this chapter - to lower emissions. To develop more efficient and sustainable solutions, more research and innovation are required.

4.12. Alternative Fuels.

Alternative fuels refer to any non-conventional fuel that can be used to power vehicles and machinery. These fuels are often seen as more environmentally friendly than traditional fossil fuels, which produce harmful emissions when burned. Alternative fuels are typically derived from renewable sources such as biomass, solar energy, wind power, or geothermal heat.

There are several types of alternative fuels that are commonly used today, including biodiesel, ethanol, hydrogen, natural gas, propane, and electricity. Biodiesel and ethanol are derived from plant materials and are often blended with traditional diesel or gasoline to reduce emissions. Hydrogen can be used in fuel cells to power electric vehicles, while natural gas and propane can be used in vehicles designed to run on these fuels. Here are some details for each one of them:

- Biodiesel is a renewable fuel that is made from vegetable oils, animal fats, or recycled cooking oil. It can be used in diesel engines without any modifications, or it can be blended with traditional diesel fuel to reduce emissions. Biodiesel is biodegradable, non-toxic, and produces lower emissions of carbon monoxide, particulate matter, and other pollutants than traditional diesel.

- Ethanol is a biofuel that is produced by fermenting sugars and starches from plant materials such as corn, sugarcane, or switchgrass. It can be blended with gasoline to create a fuel known as E10 (10% ethanol) or E85 (85% ethanol). Ethanol produces fewer emissions of carbon monoxide, particulate matter, and other pollutants than gasoline.

- Hydrogen is a clean-burning fuel that can be used in fuel cells to power electric vehicles. Fuel cells generate electricity by combining hydrogen and oxygen to produce water and heat. Hydrogen is renewable and produces no harmful emissions, but it can be expensive to produce, transport, and store.

- Natural gas and propane are fossil fuels that are often used as alternative fuels in vehicles. Natural gas is typically compressed and stored in high-pressure tanks, while propane is stored in liquid form. Both fuels produce lower emissions of greenhouse gasses and pollutants than gasoline, but they are less energy-dense and can result in lower fuel economy.

- Electricity is a versatile and clean source of energy that can be used to power vehicles directly through batteries or indirectly through fuel cells. Electric vehicles produce no tailpipe emissions and can be charged using renewable sources such as solar or wind power. However, the production and distribution of electricity can produce emissions, and the range and charging infrastructure for electric vehicles is still developing.

Alternative fuels offer several benefits, such as decreased emissions, enhanced energy security, and reduced dependence on foreign oil. They also have the potential to diversify the energy mix and create new economic opportunities for various stakeholders, including farmers and entrepreneurs. In addition, they can play a crucial role in mitigating climate change by cutting down greenhouse gas emissions. Nonetheless, alternative fuels come with certain challenges such as higher costs, limited availability, and technical hurdles in their production, storage, and transportation. The infrastructure for alternative fuels, including refueling stations, is not as developed as that for traditional fuels, which can make it challenging for consumers to access these fuels. So, more research and investment are required to create efficient and cost-effective production and distribution systems.

4.13. Optimizing Ship Design.

Optimizing ship design is an essential approach to reduce air emissions from ships. The International Maritime Organization (IMO) has set up regulations for ships to lower their emissions, including the International Convention for the Prevention of Pollution from Ships (MARPOL). One of the critical design elements is the hull design. Improving hull design by using more streamlined shapes can significantly reduce drag and resistance. The reduced resistance results in lower fuel consumption, and consequently, lower emissions. For instance, adding a bulbous bow to the ship's hull can reduce drag and save up to 10% in fuel consumption, thereby reducing emissions.

Another design element is the propulsion system. The propulsion system is a crucial design element that has a significant impact on the ship's emissions. Using energy-efficient propulsion systems, such as hybrid propulsion systems, can significantly reduce emissions. Hybrid propulsion systems combine diesel engines with electric motors, enabling ships to use electricity at low speeds and diesel engines at high speeds. This approach helps to reduce emissions by up to 20% compared to traditional diesel engines. Moreover, adding a waste heat recovery system to the ship's propulsion system can help reduce emissions and fuel consumption. Waste heat recovery systems recover heat from the exhaust gas and use it to generate electricity or heat, reducing fuel consumption and emissions. This process recovers waste heat generated by the ship's engines and reuses it, resulting in a significant reduction in fuel consumption and emissions.

A second propulsion system that can reduce emissions is the use of electric propulsion. Electric propulsion systems use electric motors to propel the ship, reducing emissions by eliminating the need for diesel engines. However, electric propulsion systems require a significant amount of power, which can be challenging to generate using traditional fossil fuels. Therefore, electric propulsion systems are typically used in conjunction with alternative fuels, such as hydrogen or batteries.

To sum up, hybrid propulsion systems, waste heat recovery systems, and electric propulsion systems are effective methods for reducing emissions and fuel consumption. Ship manufacturers and designers can keep looking for innovative technologies and design components to enhance propulsion systems, resulting in even more significant decreases in emissions and a more environmentally friendly shipping industry.

4.14. Renewable Energy Sources.

It is known that the shipping industry is responsible for a significant amount of global greenhouse gas emissions. Therefore, there is a growing need to find alternative sources of energy that are more sustainable and environmentally friendly. Renewable energy sources such as wind, solar, and hydrogen fuel cells are becoming increasingly popular in the shipping industry.

Wind power has emerged as a promising alternative energy source in the shipping industry. Ships can harness the power of the wind by installing wind turbines on board to generate electricity. This approach has been found to significantly reduce a ship's fuel consumption and emissions, making it a more sustainable and eco-friendly mode of transportation. One of the advantages of wind power is that it is a free, abundant, and renewable source of energy. This means that there are no fuel costs associated with using wind power, which can significantly reduce a ship's operating costs. Wind turbines can also be installed on a ship's deck without taking up valuable cargo space, making it a practical and space-saving solution.

However, there are obstacles related to utilizing wind power as an energy source for ships. The primary issue is that wind power is exceedingly reliant on weather conditions and therefore not a dependable source of energy. As a result, when there is minimal or no wind, ships may still need to use conventional fuels to operate their engines. Also, the design and installation of wind turbines on ships can be complex and costly. There are also safety concerns associated with the installation and operation of wind turbines on board ships. Hence, ship designers and builders need to carefully consider the technical and economic feasibility of wind power before implementing it as a primary source of energy.

Overall, to reduce emissions and fuel consumption in the shipping industry, wind power has the potential to play a significant role in reducing emissions and fuel consumption in the shipping industry, given the fact we need to overcome the technical and economic challenges associated with the adoption of this technology.

4.15. Speed Reduction.

Slowing down the speed of the ship can significantly reduce emissions, especially in areas such as ports and coastal areas where air pollution can have a significant impact on public health. When ships reduce their speed, they burn less fuel and emit fewer pollutants into the atmosphere. This approach has gained traction in recent years as a means of meeting emissions reduction targets and complying with regulations such as the International Maritime Organization's (IMO) Energy Efficiency Design Index (EEDI).

Several studies have shown that speed reduction can significantly reduce emissions. For instance, a report from the European Parliament found that reducing the speed of ships by 10% could reduce CO_2 emissions by 27%, sulfur oxide emissions by 62%, and nitrogen oxide emissions by 31%. Similarly, a study by the IMO found that a 10%

reduction in speed could result in a 19% reduction in CO_2 emissions, a 30% reduction in nitrogen oxide emissions, and a 50% reduction in particulate matter emissions.

According to a report published by the World Health Organization (WHO) in 2018, air pollution is a leading environmental risk to health, causing an estimated seven million premature deaths worldwide every year. In urban areas, shipping emissions can contribute significantly to air pollution, particularly in and around ports. The same report states that reducing ship speeds in ports and their approaches can significantly reduce emissions and improve air quality. For example, in the Port of Rotterdam, a speed reduction program was implemented in 2012, resulting in a 30% reduction in nitrogen oxides and sulfur dioxide emissions. Similarly, in the Port of Los Angeles and Long Beach, a vessel speed reduction program was launched in 2009, leading to a 50% reduction in nitrogen oxide emissions in the area. WHO recognizes that speed reduction programs can be an effective strategy for mitigating the impact of shipping emissions on urban air quality and public health.

The Finnish Environment Institute estimated that a 10% reduction in ship speed in the Baltic Sea could result in a 25% reduction in NOx emissions and a 30% reduction in SOx emissions. A report by the International Transport Forum found that if the shipping industry adopted slow steaming practices (i.e., reducing speed to reduce fuel consumption and emissions), global greenhouse gas emissions from shipping could be reduced by up to 30% by 2030.

However, there are also trade-offs associated with speed reduction. Slower speeds can result in longer voyage times, which can impact supply chains and increase costs.

In addition, there may be safety concerns associated with reduced speeds, particularly in areas with high traffic volumes or challenging weather conditions. As such, speed reduction is one of several strategies that can be used to mitigate emissions in the shipping industry, but it must be balanced against other considerations such as safety and efficiency.

4.16. Regular Maintenance and Tuning.

Regular maintenance and tuning of ship engines can also play a significant role in mitigating emissions from ships. Proper maintenance can help ensure that engines are operating efficiently and effectively, reducing fuel consumption and emissions.

According to a study by the International Maritime Organization (IMO), regular maintenance and tuning of engines can lead to fuel savings of up to 30%, as well as a significant reduction in emissions of pollutants such as nitrogen oxides (NOx), sulfur oxides (SOx), and particulate matter (PM). The study found that regular maintenance, including cleaning of engine components and tuning of engine parameters, can help ensure that engines are operating at peak efficiency, reducing fuel consumption and emissions. In addition, regular maintenance can also help prolong the lifespan of engines and reduce the need for costly repairs and replacements. This can lead to significant cost savings for ship owners and operators over the long term.

In summary, maintaining and tuning ship engines on a regular basis is an essential approach to decreasing emissions and promoting the sustainability of the shipping sector. The implementation of efficient maintenance and tuning plans can guarantee that engines function optimally, resulting in a reduction of the environmental impact of shipping while simultaneously providing economic advantages to ship owners and operators.

In conclusion, the shipping industry has recognized the urgent need to address the environmental impact of its operations and has taken significant steps towards reducing greenhouse gas emissions and pollution. The implementation of regulations and measures such as the EEDI, EEOI, and SEEMP changes that can be made on ships, has played a crucial role in promoting sustainable practices in the shipping industry. However, more efforts are needed to fully realize the potential of these measures and to explore new technologies and design elements that can further reduce emissions and enhance the sustainability of the shipping industry. With continued research, innovation, and collaboration, the shipping industry can continue to make progress towards a more environmentally friendly and sustainable future.

Chapter 5. Final conclusions.

Based on the secondary research conducted as part of this thesis, maritime transportation has significant environmental impacts, primarily contributing to atmospheric pollution due to the substances found in their fuels and the increased demand for both commercial and tourist activities. The contribution of ships to atmospheric pollution is even greater in areas with frequent ship traffic.

The dissertation found that the institutional framework surrounding atmospheric pollution from maritime transport is adequate at a global, community, and national level, at least in terms of the fuels used by ships for their movements. However, given the significant participation rate of shipping, the dissertation proposed several ways to reduce atmospheric pollution at a global level. These included the use of biofuels, alternative fuels, and fuels with lower sulfur dioxide levels, as well as investment in better and more efficient combustion mechanisms for fuels, propulsion, and the reduction of emissions of volatile organic compounds.

Atmospheric pollution has severe consequences not only for the environment, flora, fauna, and crops, but primarily for human life. Therefore, it is necessary to find and apply solutions, both at the level of institutional frameworks and technological innovations, to mitigate the greenhouse effect, the ozone hole, and other consequences of atmospheric pollution.

In general, this thesis highlighted the responsibilities and the very important role of the authorities governing maritime transport, and especially the IMO, as well as the UN, the EU, and the respective countries.

This work brought attention to the responsibilities and significant role of governing authorities in the shipping industry, such as the IMO, UN, EU, and individual countries. Their role should extend beyond legislating ship operations and focus on monitoring and enforcing compliance with laws stemming from international treaties and national legislation by shipping companies. To achieve this, rigorous technical inspections should be conducted, and severe sanctions for non-compliance should leave no room for shipping companies to disregard regulations. Collaboration between these entities can lead to significant progress in reducing atmospheric pollution caused by ships.

Of course, it is a fact that compliance of shipping companies with international environmental and atmospheric protection rules is extremely expensive. The provision for the use of fuel with reduced sulfur dioxide content means an increase in the cost for shipping companies, given the higher price of these fuels, as well as the cost of investing in appropriate installations on their ships. On the other hand, the consumption of such fuels and their more efficient combustion will also result in greater efficiency and thus reduced operational costs for shipping companies. Therefore, the management of shipping companies should consider this increased cost as an investment for a more efficient and ultimately profitable future for their ships, while also contributing to the reduction of atmospheric pollution and the reputation that arises from it. This conclusion also applies to the implementation of the other solutions proposed in this thesis. Indeed, in addition to the use of fuels with lower sulfur oxide content, technical and operational measures can also be taken, which may have a high initial installation cost, but their contribution to reducing the operational cost of ships and simultaneously reducing fuel consumption and thus atmospheric pollution is significant.

It should also be noted that reducing emissions from ship engines does not solve the problem of atmospheric pollution as a whole. Despite this, considering that there is and will continue to be a growing demand for maritime transportation, their efforts to decrease atmospheric pollution will be crucial regardless. At the same time, upcoming studies could focus on air pollution generated by different types of transportation, industrial activities, and even households, to obtain a clearer and more holistic understanding of what actions are necessary to preserve the planet. Furthermore, future research might incorporate alternative technical remedies to further cut down fuel consumption that have not yet been identified.

Annexes.

Annex 1. Member States of IMO.

The following table states the member states of IMO.

Continent	COUNTRY	JOINING YEAR
Americas	Canada	1948
Europe	Netherlands	1949
Europe	United Kingdom of Great Britain and Northern Ireland	1949
Americas	United States of America	1950
Europe	Belgium	1951
Europe	Ireland	1951
Asia	Myanmar	1951
Oceania	Australia	1952
Europe	France	1952
Asia	Israel	1952
Americas	Argentina	1953
Americas	Dominican Republic	1953
Americas	Haiti	1953
Americas	Honduras	1954
Africa	Mexico	1954
Europe	Switzerland	1955
Americas	Ecuador	1956

Europe	Italy	1957
Africa	Egypt	1958
Europe	Greece	1958
Asia	Iran (Islamic Republic of)	1958
Asia	Japan	1958
Europe	Norway	1958
Asia	Pakistan	1958
Americas	Panama	1958
Europe	Russian Federation	1958
Asia	Türkiye	1958
Europe	Denmark	1959
Europe	Finland	1959
Europe	Germany	1959
Africa	Ghana	1959
Asia	India	1959
Africa	Liberia	1959
Europe	Sweden	1959
Europe	Bulgaria	1960
Africa	Côte d'Ivoire	1960
Europe	Iceland	1960
Asia	Kuwait	1960
Oceania	New Zealand	1960
Europe	Poland	1960
Africa	Senegal	1960
Asia	Cambodia	1961

Africa	Cameroon	1961
Asia	Indonesia	1961
Africa	Madagascar	1961
Africa	Mauritania	1961
Africa	Morocco	1962
Africa	Nigeria	1962
Asia	Republic of Korea	1962
Europe	Spain	1962
Africa	Algeria	1963
Americas	Brazil	1963
Asia	Syrian Arab Republic	1963
Africa	Tunisia	1963
Asia	Philippines	1964
Europe	Romania	1965
Americas	Trinidad and Tobago	1965
Americas	Cuba	1966
Asia	Lebanon	1966
Europe	Malta	1966
Asia	Singapore	1966
Asia	Maldives	1967
Americas	Peru	1968
Americas	Uruguay	1968
Asia	Saudi Arabia	1969
Americas	Barbados	1970
Europe	Hungary	1970

Africa	Libya	1970
Asia	Malaysia	1971
Americas	Chile	1972
Africa	Equatorial Guinea	1972
Asia	Sri Lanka	1972
Asia	China	1973
Europe	Cyprus	1973
Africa	Democratic Republic of the Congo	1973
Asia	Iraq	1973
Asia	Jordan	1973
Africa	Kenya	1973
Africa	Sierra Leone	1973
Asia	Thailand	1973
Americas	Colombia	1974
Asia	Oman	1974
Africa	Sudan	1974
Africa	United Republic of Tanzania	1974
Europe	Austria	1975
Africa	Congo	1975
Africa	Ethiopia	1975
Africa	Guinea	1975
Americas	Venezuela (Bolivarian Republic of)	1975
Americas	Bahamas	1976
Asia	Bahrain	1976
Asia	Bangladesh	1976

Africa	Cabo Verde	1976
Africa	Gabon	1976
Americas	Jamaica	1976
Oceania	Papua New Guinea	1976
Europe	Portugal	1976
Americas	Suriname	1976
Africa	Angola	1977
Africa	Guinea-Bissau	1977
Asia	Qatar	1977
Africa	Mauritius	1978
Africa	Seychelles	1978
Africa	Somalia	1978
Africa	Djibouti	1979
Americas	Dominica	1979
Africa	Gambia	1979
Africa	Mozambique	1979
Asia	Nepal	1979
ASia	Yemen	1979
Africa	Benin	1980
Americas	Guyana	1980
Americas	Saint Lucia	1980
Asia	United Arab Emirates	1980
Americas	Costa Rica	1981
Americas	El Salvador	1981
Americas	Saint Vincent and the Grenadines	1981

Americas	Nicaragua	1982
Oceania	Fiji	1983
Americas	Guatemala	1983
Africa	Togo	1983
Asia	Brunei Darussalam	1984
ASia	Viet Nam	1984
Americas	Antigua and Barbuda	1986
Asia	Democratic People's Republic of Korea	1986
Oceania	Vanuatu	1986
Americas	Bolivia (Plurinational State of)	1987
Oceania	Solomon Islands	1988
Africa	Malawi	1989
Europe	Monaco	1989
Americas	Belize	1990
Africa	Sao Tome and Principe	1990
Europe	Luxembourg	1991
Europe	Croatia	1992
Europe	Estonia	1992
Europe	Albania	1993
Europe	Bosnia and Herzegovina	1993
Europe	Czechia	1993
Africa	Eritrea	1993
Europe	Georgia	1993
Europe	Latvia	1993
Europe	North Macedonia	1993

Americas	Paraguay	1993
Europe	Slovakia	1993
Europe	Slovenia	1993
Asia	Turkmenistan	1993
Asia	Kazakhstan	1994
Africa	Namibia	1994
Europe	Ukraine	1994
Europe	Azerbaijan	1995
Europe	Lithuania	1995
Africa	South Africa	1995
Asia	Mongolia	1996
Oceania	Samoa	1996
Americas	Grenada	1998
Oceania	Marshall Islands	1998
Europe	Serbia	2000
Oceania	Tonga	2000
Africa	Comoros	2001
Europe	Republic of Moldova	2001
Americas	Saint Kitts and Nevis	2001
Europe	San Marino	2002
Oceania	Kiribati	2003
Oceania	Tuvalu	2004
Asia	Timor-Leste	2005
Africa	Zimbabwe	2005
Europe	Montenegro	2006

Oceania	**Cook Islands**	**2008**
Africa	**Uganda**	**2009**
Oceania	**Palau**	**2011**
Africa	**Zambia**	**2014**
Europe	**Belarus**	**2016**
Asia	**Armenia**	**2018**
Oceania	**Nauru**	**2018**
Africa	**Botswana**	**2021**

Table 1: Member states of IMO. Source: International Maritime Organization (IMO).

Annex 2. Example of EEDI calculation.

To calculate the EEDI for a new container ship with a capacity of 8,000-13,000 TEUs, assuming that the estimated daily fuel consumption of the ship (C) is 50 tonnes per day, and the length of the ship (L) is 400 meters, we do as follows:

EEDI = (C x K) / (D x L)

To calculate K, we need to know the carbon content and energy content of the fuel. Let's assume that the ship uses heavy fuel oil, which has a carbon content of 3.11 kg CO_2 per kg of fuel and an energy content of 42.7 MJ per kg of fuel. The conversion factor (K) for heavy fuel oil is:

K = (3.11 kg CO_2/ kg of fuel) / (42.7 MJ / kg of fuel) = 0.0728 kg CO_2/ MJ

To calculate D, we need to know the deadweight tonnage (DWT) and the design speed of the ship. Let's assume that the ship has a DWT of 120,000 and a design speed of 22 knots. The transport work (D) of the ship would be:

D = (DWT x design speed) = (120,000 x 22) = 2,640,000 tonne-knots

Now, we can calculate the EEDI for this ship using the formula:

EEDI = (C x K) / (D x L) = (50 x 0.0728) / (2,640,000 x 400) = 0.000001085 gCO_2/tonne-mile

This means that the new container ship must have an EEDI of no more than 0.000001085 gCO_2/tonne-mile to meet the minimum efficiency requirements set by the IMO.

Annex 3. Calculating the baseline level.

The baseline level calculation takes into account several factors, such as ship type, size, and power. For example, the baseline level for a large container ship would be different from that of a small tanker.

The formula for calculating the baseline level is as follows:

Baseline Level = a x (ln(b)) ^ c

Where:

a, b, and c are coefficients that depend on the ship type, size, and power.

For example, let's consider a large container ship with a deadweight tonnage (DWT) of 160,000 tons and a main engine power output (MEPO) of 45,000 kW. The coefficients for this ship type are:

a = 0.372

b = 1.304

c = -0.163

Using these coefficients, we can calculate the baseline level as follows:

Baseline Level = 0.372 x (ln(1.304)) ^ (-0.163) = 10.69 gCO_2/tonne-mile

This means that the minimum EEDI value for a new large container ship with a DWT of 160,000 tons and a MEPO of 45,000 kW must be no higher than 10.69 gCO_2/tonne-mile to meet the IMO's energy efficiency regulations.

Annex 4. Example of EEOI calculation.

Suppose a ship carries 10,000 tonnes of cargo and travels a distance of 5,000 nautical miles during a voyage. The ship's total fuel consumption during the voyage was 500 tonnes of heavy fuel oil, which resulted in the emission of 1,500 tonnes of CO_2.

To calculate the EEOI for this voyage, we would use the formula:

EEOI = (Total CO_2 emissions during voyage) / (Cargo carried x Distance traveled)

Plugging in the values, we get:

EEOI = 1,500 tonnes of CO_2 / (10,000 tonnes x 5,000 nautical miles)

EEOI = 0.03 grams of CO_2 per tonne-mile

This means that for every tonne of cargo carried one nautical mile, the ship emitted 0.03 grams of CO_2.

Annex 5. Example of ESI calculation.

Let's say we want to calculate the ESI score for a ship that emits the following pollutants:

Nitrogen Oxides (NOx) emissions: 30 grams per kilowatt hour (g/kWh).

Sulfur Oxides (SOx) emissions: 2.5 g/kWh.

Carbon Dioxide (CO_2) emissions: 80 grams per tonne-kilometer (g/t-km).

We can calculate the ESI score for this ship using the following steps:

Determine the reference emissions:

The ESI score is based on a reference level of emissions for each pollutant. The reference levels are based on the current regulatory requirements and are updated periodically. As of 2021, the reference levels for NOx, SOx, and CO_2 emissions are 17.2 g/kWh, 1.5 g/kWh, and 22 g/t-km, respectively.

Calculate the emissions reduction factor:

The emissions reduction factor (ERF) is calculated by comparing the ship's emissions to the reference level. The ERF is expressed as a percentage, with a higher percentage indicating greater emissions reduction. The formula for calculating the ERF is:

ERF = 100 x (1 - (ship emissions / reference emissions))

For our ship, the ERF would be calculated as follows:

NOx ERF = 100 x (1 - (30 g/kWh / 17.2 g/kWh)) = 42%

SOx ERF = 100 x (1 - (2.5 g/kWh / 1.5 g/kWh)) = 40%

CO_2 ERF = 100 x (1 - (80 g/t-km / 22 g/t-km)) = 73%

Calculate the overall ESI score:

The overall ESI score is calculated by weighting the ERFs for each pollutant according to their environmental impact. The current weighting factors for NOx, SOx, and CO_2 emissions are 50%, 30%, and 20%, respectively. The formula for calculating the ESI score is:

ESI score = (NOx ERF x 50%) + (SOx ERF x 30%) + (CO_2 ERF x 20%)

For our ship, the ESI score would be calculated as follows:

ESI score = (42% x 50%) + (40% x 30%) + (73% x 20%) = 45.6

Therefore, our hypothetical ship would have an ESI score of 45.6, which indicates moderate emissions reduction compared to the reference levels.

Annex 6. Example of EEXI calculation.

To calculate EEXI for we have a ship that has a length of 200 meters, a beam of 30 meters, a draft of 10 meters, and a gross tonnage of 50,000 GT. The ship has an engine power of 20,000 kW and a maximum speed of 20 knots.

To calculate the EEXI, we need to determine the required EEDI (Energy Efficiency Design Index) for the ship. The EEDI is calculated based on the ship's design, while the EEXI is calculated based on the ship's actual performance.

Assuming the ship was built in 2014, we can use the following EEDI reference line:

EEDI = (a x DWT) / (b x log(DWT) - c)

where:

a = 2100

b = 5.78

c = 19.0

DWT = deadweight tonnage (in tonnes)

Using the ship's gross tonnage to estimate its deadweight tonnage, we get:

DWT = 0.8 x GT = 40,000 tonnes

Plugging in the values, we get:

EEDI = (2100 x 40,000) / (5.78 x log(40,000) - 19.0) = 8.14 gCO2/tonne-mile

This is the required EEDI for the ship based on its design.

To calculate the EEXI, we need to determine the ship's actual CO2 emissions and compare it to the required EEDI. We can use the following formula:

EEXI = (actual CO2 emissions) / (a x DWT x distance traveled)

Assuming the ship travels 50,000 nautical miles per year and consumes 60,000 tonnes of fuel (with a carbon content of 3.114 kg CO_2/kg fuel), we can calculate its actual CO_2 emissions:

CO_2 emissions = 60,000 tonnes x 3.114 kg CO_2/kg fuel x 3.15 = 588,726 tonnes

where:

3.15 is a conversion factor from tonnes to metric tons (1000 kg)

Plugging in the values, we get:

EEXI = 588,726 / (2100 x 40,000 x 50,000) = 0.00699 gCO_2/tonne-mile

Since the calculated EEXI (0.00699 gCO_2/tonne-mile) is lower than the required EEDI (8.14 gCO_2/tonne-mile), the ship meets the EEXI requirements.

References.

1. Inversion (meteorology) - Wikipedia

2. Background on health effects of acid aerosols.

3. United Nations. (2018). Study of the impact of measures to reduce emissions of greenhouse gasses from ships.

4. International Maritime Organization. (2018). Prevention of air pollution from ships.

5. International Maritime Organization. (2016). Guidelines for the sampling of fuel oil for determination of compliance with MARPOL Annex VI.

6. International Council on Clean Transportation. (2018). Air pollution from ocean-going ships: An overview.

7. European Environment Agency. (2019). The impacts of shipping on air quality.

8. International Maritime Organization (IMO). (2020). Third IMO GHG Study 2020.

9. European Parliament. (2019). Reducing CO2 emissions from ships.

10. International Chamber of Shipping. (2021). Shipping and CO2: All you need to know.

11. United Nations Environment Programme (UNEP). (2018). Emissions Gap Report 2018.

12. Intergovernmental Panel on Climate Change (IPCC). (2018). Global Warming of 1.5°C.

13. European Environment Agency (EEA). (2020). Climate change, impacts and vulnerability in Europe 2020.

14. National Oceanic and Atmospheric Administration (NOAA). (2021). Ocean acidification.

15. "Air Pollution from Shipping: A Review of the Problem and Impacts on Atmospheric Chemistry and Climate" (Atmosphere, 2019).

16. "Ozone Depletion Due to Ship Emissions in the Arctic and Northern Hemisphere" (Environmental Science & Technology, 2016).

17. "Ozone Depletion from Shipping: Impacts on Health, Agriculture and Climate Change" (International Journal of Environmental Research and Public Health, 2018).

18. "Shipping Emissions and Their Impacts on Air Quality, Human Health, and Climate Change" (ACS Publications, 2018).

19. "Marine Shipping Emissions of Volatile Organic Compounds and Oxides of Nitrogen and Their Potential Impact on Ozone Formation in the Coastal Zone" (Environmental Science & Technology, 2016).

20. International Maritime Organization (IMO). (2021).

21. National Oceanic and Atmospheric Administration (NOAA). (2018).

22. European Commission. (2016). The EU's contribution to mitigating international aviation and maritime emissions: Effectiveness, environmental integrity and economic efficiency.

23. European Environment Agency. (2019). Monitoring, reporting and verification of CO2 emissions from ships in the EU: Annual report 2019.

24. EcoPorts. (2021).

25. European Sea Ports Organisation. (2021).

26. ESI, LNG and Scrubbers: A Comparative Study of Three Technologies for SOx and NOx Reduction in Shipping," a paper by M. Rodríguez-Rodríguez, M. Morales-Fernández, and A. Martín-Fernández.

27. Environmental Ship Index as an Economic Incentive for Sustainable Shipping," a paper by N. Besič and J. Žižmond.

28. The Environmental Ship Index: A Useful Tool to Encourage Reductions of Ship Emissions?" a paper by J. Hoffmann and T. Hagedorn.

29. International Maritime Organization. (2021)

30. Environmental Defense Fund. (2021)

31. European Maritime Safety Agency. (2021)

32. International Transport Forum. (2018). Reducing maritime emissions: policy options for the shipping sector.

33. Lloyd's Register. (2021). Maritime air pollution prevention.

34. Shipping and the Environment Improving Environmental Performance in Marine Transportation by Karin Andersson, Selma Brynolf, J. Fredrik Lindgren, Magda Wilewska-Bien (eds.) (z-lib.org).pdf

35. https://www.lr.org/en/insights/articles/eexi-explained-what-is-the-energy-efficiency-existing-ship-index/

36. https://www.imo.org/en/OurWork/Environment/PollutionPrevention/ShipEnergyEfficiency/Pages/Existing-ships.aspx

37. https://www.imo.org/en/OurWork/Environment/PollutionPrevention/AirPollution/Pages/Carbon-Intensity-Indicator-(CII)-rating-scheme.aspx

38. https://www.imo.org/en/OurWork/Safety/Navigation/Pages/VTS.aspx

39. https://www.carbonpricingleadership.org/wp-content/uploads/2021/02/Carbon-Shipping-Index-Report.pdf