Environmental Considerations in Maritime Transportation: CO_2 Emissions, Regulations, and Reduction Strategies

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1. INTRODUCTION

Together with the increase in the world population, it was also observed that there has been an increase in the consumption of goods in the past decades to fulfill the population's needs. From 2000 to 2019, the world's total domestic material consumption (DMC), which estimates the amount of material that an economy uses directly in order to fulfill the demand for products and services inside and outside a country, increased by more than 65%, reaching a total of 95.1 billion tons in 2019 (UN DESA, 2022).

The role of transportation is to connect goods to consumers and to link the products and services available to demand, and this sector is a significant consumer of energy. Both passenger and freight mobility consume an immense amount of energy; it is estimated that 25% of all energy consumption in the world is dedicated to transportation (IEA, 2022). And as energy use and production have a significant impact on the climate, this makes it one of the sectors that demand a lot of attention in terms of climate change mitigation.

There is no doubt that transportation is crucial for the social and economic development of a society (Rodrigue, 2020), and it is important to meet requirements to reduce the environmental degradation caused by the sector. Even though the consumer mindset is changing towards sustainable consumption, transportation is still one of the main polluter's sectors, responsible for 37% of the CO_2 emissions from end-use sectors in the year 2021, which accounted for 7.7 Gt of CO_2 emissions in 2021 against 7.1 Gt in 2020, mainly because of its high reliance on fossil fuels (IEA, 2022).

Road transportation, according to the Environmental European Agency, accounts for the highest percentage of transport greenhouse emissions in Europe, more than 70%, and is seen as a huge effort from the side of governments to reduce the emission of this share of transportation, with an expectation to decrease the numbers within the years. Contrariwise, the numbers from international maritime transport and the aviation sector are expected to increase until 2030 (EEA, 2022), considering that these transport modes are not prioritized by public policies.

Whether inland, coastal, or overseas shipping, maritime transport currently accounts for the movement of more than 80% of all cargoes in the world's trade, according to the United Nations Conference on Trade and Development (UNCTAD), and the exponential growth of international maritime trade over the years to meet local, regional, and international levels has forced ships to grow in size and sophistication.

Maritime transport brought a lot of advantages to the logistics and supply chain sectors, such as large capacity as it is one suitable transport option for carrying heavy and bulky goods over long distances, the ability to carry different types of goods, and a low cost because it consumes less fuel per quantity of goods transported (Bouman et al., 2017). This means of transport has a large global coverage, with about 70% of the earth's surface covered by ocean water, and can count on a higher level of security since a ship is less likely to be attacked and robbed than a land transport means.

However, there are limitations related to geography and time sensitivity of the cargo; this type of transport is slow compared to aviation, and it can take months to arrive at its destination. For example, a cargo from Brazil and its main trading partner, China, can take up to 45 days to arrive. It also requires high investments to make it feasible and to maintain it, such as maintenance of large ships, renovation, engineering updates in ports, dredging works, and the creation of channels (Matekenya & Ncwadi, 2022). And one of the huge disadvantages of this type of transportation is the environmental impact that it can cause.

The environmental impact caused by transportation is not restricted to greenhouse gas emissions; it is equally important to point out that the sector contributes to water pollution, for example, by run-off of pollutants into sources of water, noise pollution caused by the operation of the engines working directly or indirectly with transportation (Rodrigue, 2020), waste generation, including disposal of batteries that are produced with heavy metal elements such as nickel, cobalt, copper, and lithium, and impacts on biodiversity by the changes in the habitat to be able to support transportation infrastructure.

Despite being statistically the least environmentally harmful means of transportation, when taking into consideration the large capacity value (EEA, 2021), maritime transport has a key role to play in preventing pollution. The purpose of this study is to provide a comprehensive overview of the environmental impacts associated with maritime transportation. Specifically, this work analyzes the levels of CO_2 emissions in the European Union from 2018 to 2021 and provides an overview of relevant resolutions regarding air pollution. Additionally, this study presents potential strategies to reduce carbon emissions and mitigate the negative environmental impacts of the shipping industry.

2. LITERATURE REVIEW

2.1 MARITIME TRANSPORATION

The maritime transportation industry has a significant influence on the development of human civilization; the industry enabled the exchange of products such as spices and fabrics, cultural exchange, and the expansion of territories. The Phoenicians are credited with being the first people to achieve success in the field of navigation while also being the first people to create trade routes in the Mediterranean Sea (Lutfullaevich et al., 2023), which is believed to have occurred approximately 500 BC based on shipwrecks that have been discovered. At that point in time, navigation was mostly dependent on natural features along the coastline (Cartwright, 2022).

The development and use of instruments such as the compass, which provides a sense of location and direction, and the astrolabe, which helps with navigation using the position of celestial objects such as the moon and other planets, allowed the sailors to not only navigate close to the shore, as was happening before, but also to reach long distances across oceans (SDM, 2006).

These instruments greatly improved the precision and effectiveness of navigation, allowing sailors to map and explore previously uncharted places. Additionally, they made it possible for several countries to build their economies on maritime trade and also on the colonization and imperialism of many parts of the world. For instance, in the 15th century, Portugal made use of these instruments in order to build maritime trade routes to India and Brazil, which ultimately led to the expansion of Portugal's economy (SDM, 2006).

Over the course of history, the maritime industry has undergone significant transformations, particularly those that took place during the secondary Industrial Revolution. The adoption of steam engines for ship propulsion and the use of steel for its construction were upgrades that the industry had in this period. As steam engines could propel ships instead of relying on the direction and speed of the wind, navigational decisions could be made with greater precision (Rodrigue, 2020).

The shipping industry was responsible for enabling globalization and connecting products to demand. The industry is responsible for the delivery of a wide variety of products, including but not limited to oil, food, cereals, electronic goods, and vehicles, among many others (Bhattacharyya et al., 2023). Over the past five decades, there has been a significant increase in world seaborne trade, with only two notable declines occurring in 2009 following the Great Recession and in 2020 due to the COVID-19 pandemic, that had an impact on the economy of the entire world. Nowadays, maritime transportation is responsible for an overall shipment of approximately 11 billion tons annually as shown in Figure 1. (UNCTAD, 2022).

Figure 1 – International Maritime Trade (millions of tonnes)

Year	Tanker[a]	Main bulk[b]	Other dry cargo[c]	Total cargo
1970	1 440	448	717	2 605
1980	1 871	608	1 225	3 704
1990	1 755	988	1 265	4 008
2000	2 163	1 186	2 635	5 984
2005	2 422	1 579	3 108	7 109
2006	2 698	1 676	3 328	7 702
2007	2 747	1 811	3 478	8 036
2008	2 742	1 911	3 578	8 231
2009	2 641	1 998	3 218	7 857
2010	2 752	2 232	3 423	8 408
2011	2 785	2 364	3 626	8 775
2012	2 840	2 564	3 791	9 195
2013	2 828	2 734	3 951	9 513
2014	2 825	2 964	4 054	9 842
2015	2 932	2 930	4 161	10 023
2016	3 058	3 009	4 228	10 295
2017	3 146	3 151	4 419	10 716
2018	3 201	3 215	4 603	11 019
2019	3 163	3 218	4 690	11 071
2020	2 918	3 196	4 531	10 645
2021	2 952	3 272	4 761	10 985

Source: UNCTAD (2022)

According to UNCTAD:

"a Tanker includes crude oil, refined petroleum products, gas, and chemicals.

b Main bulk includes iron ore, grain, coal, bauxite/alumina and phosphate.

c Other dry cargo includes minor bulk commodities, containerized trade, and residual general cargo."

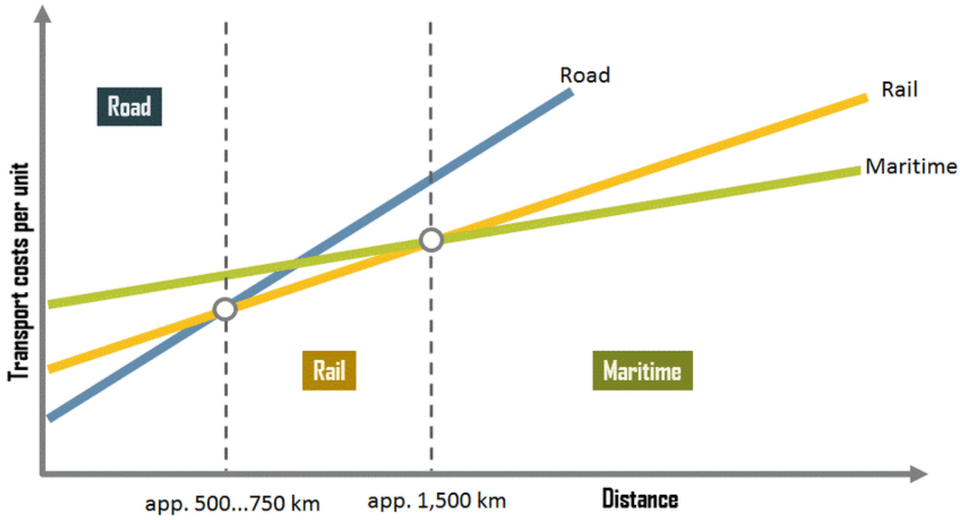
The COVID-19 pandemic brought many challenges to various industries, and the maritime industry was no exception. As a result of the implementation of health restrictions and the requirement to place a high priority on the safety of employees and crew members, the sector was affected in different layers, such as social, as ship workers were not able to disembark, causing a long period onboard and affecting the crew's mental health (Ward, 2020). In addition, a great number of shipyards had to shut down, which caused a disruption in the routine maintenance work that was being done.

As a direct consequence of this, non-critical work, such as regular maintenance, was not prioritized or put on hold in order to guarantee that only critical processes continued to run as efficiently as possible during all the restrictions. Moreover, non-essential inspections had to be delayed, which increased the difficulty of complying with international marine safety requirements and also affected the environment (ICS, 2020).

The maritime industry is subject to a vast array of international regulations and standards designed to promote safety, protect the environment, and ensure operations are conducted in an environmentally conscious way. The postponing of tasks that require inspection and maintenance can increase the risk of accidents and spills, both of which can have severe repercussions not only for human life but also for the environment in which they occur.

The industry brings a lot of advantages to the supply chain sector, starting with the lower costs per quantity of goods transported. For short distances, road transport cost per unit tends to be lower and as much the distance of transportation increases the cost of maritime transport decrease, making this means of transport the most cost-efficient for long distances (Peltokoski et al.,2016). Figure 2 shows that the distance where there is a switch in the most cost-efficient means of transport is between 500 to 750 km from the starting point of the trip and from approximately 1500 km the maritime transportation has the lowest possible operating costs.

Figure 2 - Comparison of road, rail and maritime transportation methods



Source : Peltokoski et al.(2016)

An additional advantage of the seat transport is that there is a diverse ship's fleet, which includes a large variety of ship types and sizes. The layout of the ship is determined by the kind of cargo that it is expected to carry, such as in the case of container ships and tankers, or by the kind of operation that it is expected to perform, as in the case of tugboats and supply vessels. The range of different designs allows the transport of large volume of goods, and it also gives the capability to work in different segments, including container ships, bulk carriers, oil tankers, platform supply vessels, and fishing (Psaraftis, 2021).

There are also disadvantages of transporting good by sea. The initial cost of maritime transportation is high because there is a significant investment in infrastructure, such as terminals and dredging work, as well as in the construction of ships. Additionally, there are instances in which maritime transportation is subject to extraordinary fees, such as a canal due, which is a price that ship operators pay in order to utilize the canals, as is the case with the Panama Canal (Pienaar, 2013). However, the authorities are concerned about pollution because most international transportation takes place in international waters, which makes it difficult to monitor, control, and tax the emissions of pollution (Parry et al., 2018).

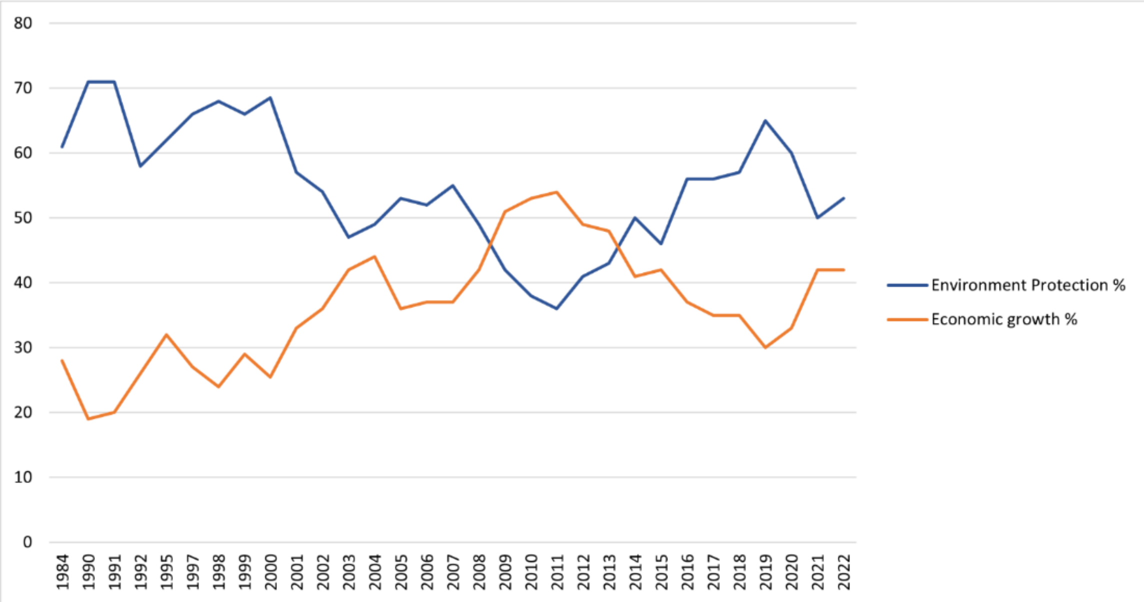
2.2 ENVIRONMENT IMPACTS

According to Yildiz et al., 2022, the Dover Strait, which separates Great Britain and the continent of Europe, is the busiest maritime route in all of Europe. This is due to the fact that 150,000 ships travel through the channel each and every year. Both the economy and the environment are severely impacted by the high volume of ship traffic that occurs not just in this region but also all over the world.

In terms of the economics, maritime transportation is referred to as "the backbone of global trade and the global economy," as stated by the Secretary-General of the United Nations Ban Ki-moon in his message for World Maritime Day in the year 2016. At the level of the environment, there are negative repercussions in a variety of dimensions, beginning with the daily operation of the ship itself and continuing through the installation and maintenance of infrastructure, including activities such as dredging and the construction of ports.

The maritime transportation sector, as well as the transportation sector as a whole, has to deal with the complex relationship between economic growth and environmental concerns and the change in its priorities depending on international economic conditions (Rodrigue, 2020). This was shown in the survey that was made by Gallup News (Figure 3), which was asked to U.S. adults from 1984 to 2022, which should be prioritized, economic growth or environmental protection, even with the risk of the other one being affected. In this research was observed that 53% of adults in the United States believe that protecting the environment should be a top priority, while over 42% believe that economic growth should take precedence (Jones, 2022).

Figure 3 - Public opinion on Environmental Protection vs Economic Growth Priorities Preferences



Source: GALLUP News (2022)

The concern with the impacts that the maritime industry has on the environment has increased over the past few years, but it took a different perspective in the 1970s due to significant maritime accidents, mostly related to oil tankers, that caused severe damage to the coastlines of European nations and the United States (Aslan et al., 2018). The primary obstacle faced by the industry is safeguarding the environment, and to achieve this, it is crucial to have a comprehensive understanding of the various forms of pollution that the sector can generate.

2.3 POLLUTION

NOISE POLLUTION

Transportation noise ranks as the second-largest environmental risk factor in Europe, just behind air pollution (Sørensen et al., 2020). In the past fifty years, there has been an increase in anthropogenic noise emissions in the marine environment (MEPC, 2018). The noise pollution from ships not only affects the environment of workers and passengers on board, or communities living near ports or areas with intense traffic of ships but also exerts a heavy influence on the marine fauna since many species of marine life, mainly mammals, rely on sound to communicate, navigate, and for feeding and mating purposes (Sørensen et al., 2020).

This type of pollution has as its main sources the normal operation of the engines and propellers, the flow around the ship's structure, as well by the breakdown of the flow pattern in the propellers, known as cavitation (Badino et al., 2012). If the ship's sizes and noises characteristics do not change, with the increase in the global fleet and shipping distances, it is expected an increase by 87-102% on average by 2030 of the underwater noise caused by container ships, tankers and bulk carriers (Kaplan & Solomon, 2016).

On 7 April 2014, the IMO, under the Marine Environment Protection Committee (MEPC), approved the MEPC.1/Circ.833 which is the guideline for the reduction of underwater noise from commercial shipping to address adverse impacts on marine life. The guideline has the aim of advice about underwater noise reduction for designers, shipyards, and ship operators, emphasizing the main causes and operational and maintenance recommendations, notwithstanding as a mandatory document.

According to Vakili et al. (2021), the efforts of companies to reduce Greenhouse Gases can positively affect underwater pollution as the strategies to reduce the emissions are also linked to underwater noise reduction. A set of technologies and operational practices, such as ship design optimization and reduced speed can be applied (Kaplan & Solomon, 2016). However, there is a lack of legal requirements or economic incentives for ships to reduce underwater noise which leads to a deficiency of investments on behalf of the cause (Smith & Rigby, 2022).

OIL POLLUTION

Oil pollution is characterized by the discharge into the environment of crude oil or its processed derivatives (Freedman, 1994). It can be caused by different sources, including fixed installations onshore and offshore, industrial and municipal waste, natural processes, and transport operations (Carpenter, 2019). Ships are potential sources of oil pollution in water since they utilize heavy oil for a variety of purposes, including as fuel, for the maintenance of machinery, and in some circumstances, such as tankers, as a product that is stored in the cargo holds of the ship.

It is commonly known that oil pollution, when originating from maritime transport, can be a result of maritime accidents such as collisions; however, it can also be a result of faults during usual operational procedures, such as cargo loading and unloading, legal discharges, tank washing, or oil refueling (Ching & Yip, 2022). Based on the 10-year period of data available from 1988 to 1997, it is estimated that 1.25 million tonnes of oil, from ships and sea-based activities, reach the marine environment each year (GESAMP, 2007).

Oil pollution has a direct effect on marine life, such as plants and animals, as well as animals that depend on the marine ecosystem to survive. It also has the effect of disrupting ecosystems by reducing food sources for marine life, and contaminating areas, which makes it difficult for species to reproduce (World Economic Forum, 2022). In addition to the environmental impacts, there is also concern about the potential financial and social damage that an oil spill can cause to the communities in the region of the disaster (Machado et al., 2017).

The oil discharge can impact a large area and have an effect for years on the ecosystem as the oil, when in the marine environment, is exposed to different processes such as evaporation, emulsification, spreading, sedimentation, and natural dispersion (Reed et al., 1999). For this reason, it is important to mitigate the adverse effects of the pollution accident and effectively monitor maritime traffic (Mera et al., 2012).

SEWAGE POLLUTION

In 2005, the IMO, under the MEPC, approved Resolution A.982(24), in which the Baltic Sea, together with other regions, was designated as a Particularly Sensitive Sea Area (PSSA), that is, a region that requires particular safeguarding through measures taken by the IMO due to its importance for ecological, socio-economic, or scientific reasons, where these features are susceptible to being harmed by global shipping operations.

The Baltic Sea has an important role in the Northern European economy as it connects nine countries, including Denmark, Estonia, Finland, Germany, Lithuania, Latvia, Poland, Russia, and Sweden. The geographical characteristics of the Baltic Sea, as an enclosed sea with shallow areas and a lack of tides (Vaneeckhaute & Fazli, 2020), combined with the intensive ship traffic, make the region very susceptible to contamination by ship domestic sewage.

Sewage pollution from ships poses a substantial environmental challenge that can have harmful consequences for the marine ecosystem. The time taken to treat sewage onboard is relatively short, in contrast to a sewage treatment plant in a municipality (Huhta et al., 2007). And as per the water conservation procedures followed on ships, the ship size, and the large production, the sewage produced on board is typically two to three times more concentrated than the sewage produced on land (Vaneeckhaute & Fazli, 2020).

In light of the large levels of nitrogen and phosphorus that are present in ship residential sewage, discharging it into the environment without first having it treated can result in eutrophication, which can lead to the uncontrolled proliferation of bacteria, protozoa, and phytoplankton. This has the potential to disrupt the local environment and release toxins, both of which can affect humans as they accumulate along the food chain. (Chen et al., 2021).

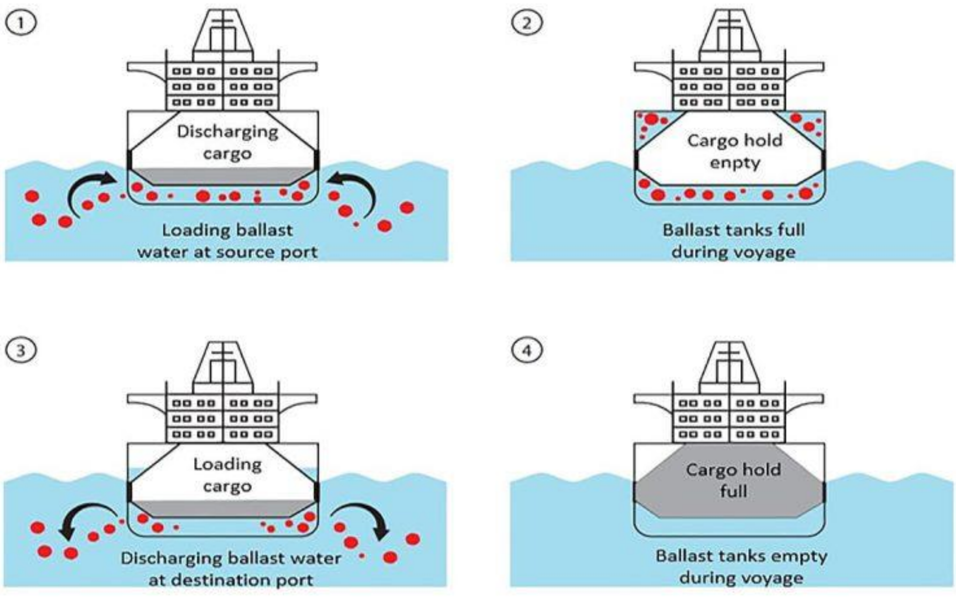
In Resolution MEPC.200(62), the IMO established the Baltic Sea as a special area for sewage discharge and added the requirements of a sewage treatment plant approved or holding tanks with satisfactory capacity for the retention of all sewage for later discharge in facilities on the port. The resolution is essential to guarantee that ships adhere to more rigorous environmental rules in the region and that the sewage pollution caused by ships is reduced to a minimum.

NON-INDIGENOUS SPECIES

Marine transportation is considered one of the main responsible for the introduction of non-indigenous species around the globe (Bailey et al., 2022). This occurs mainly due to the intake and discharge of ballast water. Ballast water, is a water, that can be either fresh or seawater, and it is allocated in ballast tanks in order to achieve the necessary operational conditions. It is a necessary requirement for ships to ensure stability and maneuverability throughout their journey (Apetroaei et al., 2018).

The water, along with sediments, animals, plants, bacteria, and viruses, can be transferred to the ballast tanks during cargo discharging and subsequently released when the ship has a new cargo movement in the next port (Figure 4) (Ibrahim & El-Naggar, 2012). It is estimated that ships' ballast water transports approximately 1019 bacteria globally on a daily basis (Brinkmeyer, 2016).

Figure 4 - Diagram with process of the ballast intake and discharge



Source: Danfoos (2022)

The ballast water exchange facilitates the introduction of a range of organisms into the local ecosystem, some of which may be non-indigenous. This transfer can result in economic, ecological, and health impacts in the region. The potential threats include competition with native species for resources and area, and the introduction of pathogens and toxic species that may pose risks to human health (Apetroaei et al., 2018).

A set of technologies and operational procedures can be applied to minimize the environmental impacts of the ballast water, such as adopting management procedures for exchanging 95% of the ballast water volume at least 200 nautical miles away from the nearest land (Vorkapić et al., 2016), and ballast water treatment, including mechanical methods such as filtration and chemical methods such as chlorination (Kurniawan et al., 2022).

GARBAGE POLLUTION

The increase in the consumption of goods has also increased waste generation in the past decade. When this waste, intentionally or unintentionally, ends up in the marine environment, it is called marine debris. Ships and platforms are a source of ocean-based marine debris that can be small solid materials such as microplastics and plastics, paper, metals, wood, textiles, hazardous waste, and batteries, to big sizes including machinery pieces and abandoned ships (Joshi et al., 2023).

There are several sources of waste generation onboard; as an example, the daily operations including maintenance, domestic and food waste, and cargo loading and unloading procedures. For a general cargo ship, it is estimated that 1 ton of waste is generated for every 100–150 tons of cargo transported, while 70kg of waste is generated for every 100 tons of bulk cargo transported (Zhang et al., 2021). The main concern is plastic, as it is estimated that the material composes more than 75% of all marine debris and may require decades to fully decompose (Saliba et al., 2022).

As on land, the best practice for waste management onboard is to reduce waste generation and to increase the use of onshore reception facilities (Zhang et al., 2021). Ships must follow restrictive regulations to dispose of waste to avoid garbage pollution, however, illegal disposal on the sea is common, mainly to reduce costs as the ships maintain the waste on board and, after a certain period, discharge it in terminals (Zuin et al., 2009), which generates expenses for removal for the ship owner or can even increase port time in case of delay in the unloading process.

There are several negative impacts of waste disposal on the environment and marine ecosystems. The entanglement and ingestion of waste by marine animals, and the release of toxins from the waste that can be later absorbed by marine life and humans affecting offspring (Gall & Thompson, 2015) and causing irreversible damage to the organism. There is also evidence that marine litter is associated with the disruption of the environment in coral habitats (De Carvalho-Souza et al., 2018).

To address this issue, the IMO developed regulations such as Resolution MEPC.220(63) that state a guideline for the development of a garbage management plan that provides procedures for minimizing, collecting, storing, processing, and disposing of garbage for ships. It was also implemented the requirement of the Garbage Record Book, where the ship's crew must record and sign details such as the ship's location, date and time, description of the garbage, and the estimated quantity of the garbage that was either discharged or incinerated in order to have stricter control of the regulations.

AIR POLLUTION AND GREENHOUSE GAS EMISSIONS

Air pollution has been acknowledged as the primary environmental hazard to human well-being, based on its significant contribution to causing cardiovascular and respiratory diseases, which is the leading cause of mortality worldwide (WHO, 2021). Addressing air pollution at its source is crucial, which involves taking action to control pollution from various sources such as transportation, agriculture, energy production, construction, and industry.

The shipping industry is a source of air pollution, particularly due to the emissions generated by their combustion process and an estimation of 60,000 premature deaths every year can be attributed to the discharge of particulate matter (PM) from shipping (Chatzinikolaou et al., 2015). Air quality is linked with climate change as the same factors that contribute to air pollution, such as burning fossil fuels, are also responsible for greenhouse gas emissions (WHO, 2019).

The greenhouse gases are, by definition, gases present in the atmosphere, from the either natural or anthropogenic origin, that trap infrared radiation and then re-emitted it back to the Earth's surface and atmosphere contributing to global warming. The main greenhouse gases in the Earth's atmosphere are Carbon dioxide (CO_2), Methane (CH4), Nitrous oxide (N2O) and Fluorinated gases, which includes include hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), and sulfur hexafluoride (SF6), according to the United States Environmental Protection Agency.

Most ships run by the combustion of fossil fuels that generate greenhouse gases, gases such as carbon dioxide (CO_2), methane (CH4), Sulphur dioxide (SO2), and carbon monoxide (CO) (Jun et al., 2000). Of these gases, CO_2 has the greatest impact on global warming (Winnes et al., 2015). To meet more sustainable transportation is important to take into consideration the Paris Agreement outline, adopted in December 2015, which aims to keep the global temperature rise below 2 degrees Celsius above pre-industrial levels and pursue efforts to reduce this value to 1.5 degrees Celsius.

Although shipping is recognized as a transportation less harmful to the environment when compared to road and air transportation, the sector represented 2.89% of global anthropogenic greenhouse emissions in 2018, and the numbers are still expected to grow 90–130% in 2050 compared to the value of 2008 (IMO, 2020). The sector is also responsible for the anthropogenic emission of 13% of Nitrogen Oxide (NOx) and 12% of Sulphur Oxide (SOx) (Mueller et al., 2022).

On 13 April 2018, the IMO, under the Marine Environment Protection Committee (MEPC), approved the MEPC.304(72) which is the initial IMO strategy for the reduction of GHG emissions from ships. It aims to reduce the amount of CO_2 released per unit of transportation, by at least 40% by 2030 and pursue efforts for a reduction of 70% by 2050, compared to levels in 2008. The resolution also aims to reduce total annual GHG emissions by at least 50% compared to 2008.

Ship owners and operators are exploring new solutions in order to meet the targets for the reduction of greenhouse gas emissions. Some of these new solutions include increasing the use of low-carbon fuels, such as hydrogen and biofuels, developing more efficient hull designs for use in the construction of new ships, and making adjustments to the operational procedures that are carried out on a daily basis, such as reducing speed and optimizing the route. Due to its impact on climate change, among all the environmental impacts caused by the maritime industry, this study will focus on CO_2 emissions.

3. MATERIALS AND METHODS

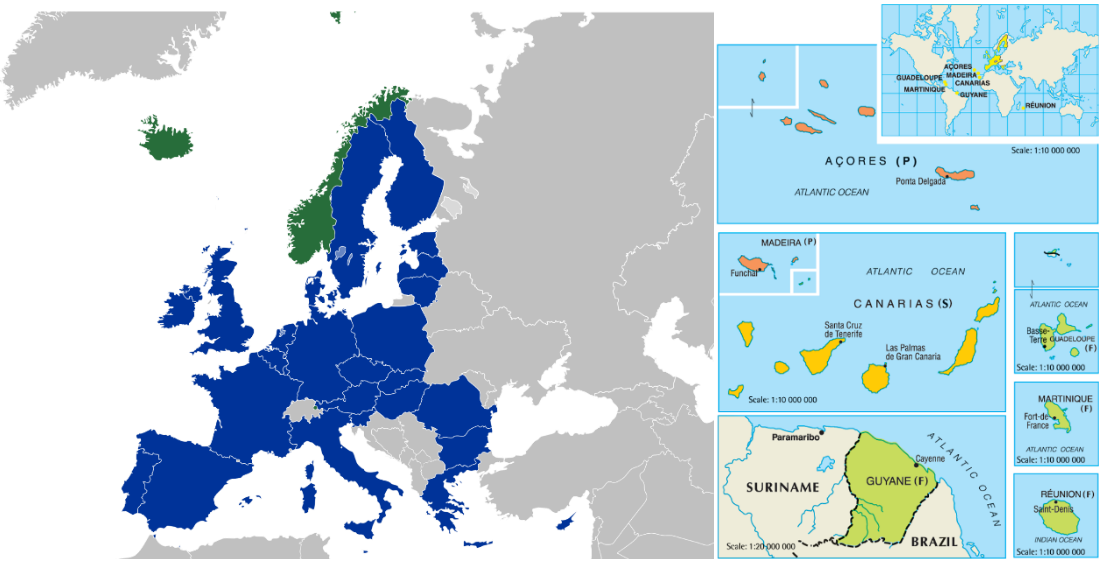
The secondary research approach that involved the synthesis of data and material collected from primary research sources was the type of research that was carried out. A review and analysis of previously published works of literature and studies, such as published books and articles, legal documents from government agencies, and records from educational institutions, were performed.

The data was gathered from the European Maritime Safety Agency (EMSA) CO_2 emission report developed in accordance with Regulation (EU) 2015/757 on monitoring, reporting, and verifying CO_2 emissions from maritime transport for the period between 2018 and 2021. All the data is in simplified form, so the numbers represent an approximation.

The period was chosen seeing that since January 1, 2018, shipping companies have been required to monitor and report, to an accredited verifier, which is a legal entity that has been approved by a national accreditation body to check and validate the papers sent by the company, data on each ship's CO_2 emissions, in addition to other relevant information that enables the determination of ships' efficiency.

The data consists of data collected from ships with a gross tonnage of more than 5,000 during voyages that involve ports of call within the jurisdiction of an EU Member State in addition to Norway, Iceland, and Liechtenstein, as well as the outermost regions of the EU, including the Azores, Canary Islands, Martinique, Mayotte, Guadeloupe, Saint Martin, French Guyana, Madeira, and Reunion (Figure 5).

Figure 5 - Area subjected to CO_2 emission report from the EMSA



Source: Verifavia Shipping (2017)

It's important to note that the UK withdrew from the EU on January 1, 2021, and therefore is not included in the data after this effective date. The data provided applies to various types of ships but does not apply to naval ships, governmental ships used for non-commercial purposes, ships used for fishing or processing fish, wooden ships of a primitive build, or ships that are not propelled by mechanical engines.

Before analysis, the data passed through the process of data wrangling, which is the process of gathering, cleaning, transforming, and organizing data into a structured and usable format for analysis and to answer an analytical question. The table below is the result of this step. Table 1 shows the total CO_2 emissions in millions of tonnes in the period from 2018 to 2021 for each ship type.

Another important note is that the values may vary from the official reports of each year since they represent the most recent figures available at the time of extraction (13/02/2023) and the number of emission reports is not a constant number, having a variation, increase, or decrease, from year to year according to the adoption of the report by each company.

Table 1 - Total CO_2 emissions in Millions [m tonnes]

Ship type	2018	2019	2020	2021
Bulk carrier	18.7	17.3	14.8	16.1
Chemical Tanker	9.5	9.7	9.2	8.8
Container ship	45.4	44.8	41.7	40.5
Container/ro-ro cargo ship	1.7	1.5	1.3	1.3
Gas carrier	2.6	3.0	2.7	2.4
General cargo ship	6.4	6.7	6.4	6.2
LNG carrier	6.1	8.0	8.1	6.3
Oil tanker	19.1	20.1	18.8	16.3
Passenger ship	6.6	7.0	1.2	2.5
Refrigerated cargo carrier	1.8	1.6	1.6	1.5
Ro-pax ship	14.8	14.9	12.2	12.4
Ro-ro ship	6.4	6.2	5.2	5.5
Vehicle carrier	5.1	4.8	4.3	4.0
Other ship types	1.3	1.4	1.2	0.9
Total CO_2 emissions per year	145.4	147.1	128.8	124.7

Source: EMSA (2023)

The secondary method was used to answer the research questions of this thesis such as:

- How is the CO_2 emission in the European Union?
- How do different types of ships impact CO_2 emissions?
- Do the regulations influence CO_2 emissions?
- How do different operational strategies impact CO_2 emissions from ships?

4. RESULTS AND DISCUSSION

4.1 CO_2 EMISSIONS

The CO_2 emissions from ships come from the use of fuel in main engines, auxiliary engines, generators, and boilers. The maritime industry uses two main approaches for measuring CO_2 emissions on ships. The first method involves determining the amount of fuel used and then calculating the CO_2 emissions. The second method involves the direct measurement of CO_2 emissions, which is still a developing technology and is not widely used.

The correlation between fuel consumption and CO_2 emissions can be expressed mathematically through a conversion factor, which represents the number of CO_2 emissions produced per unit of fuel burned. This factor represents the amount of CO_2 emissions produced for each unit of fuel burned, and it depends on the type of fuel (table 2) and the efficiency of the combustion process of each ship.

Table 2 – Conversion Factor between fuel consumption and CO_2 emissions

Type of Fuel	**Reference**	**Carbon content**	**Cf (t-CO2/tFuel)**
Diesel/Gas Oil	ISO 8217 Grades DMX through DMB	0.8744	3.206
Light Fuel Oil (LFO)	ISO 8217 Grades RMA through RMD	0.8594	3.151
Heavy Fuel Oil (HFO)	ISO 8217 Grades RME through RMK	0.8493	3.114
Liquefied Petroleum Gas (LPG)	Propane	0.8182	3.000
	Butane	0.8264	3.030
Liquefied Natural Gas (LNG)		0.7500	2.750
Methanol		0.3750	1.375
Ethanol		0.5217	1.913

Source: MEPC.308(73)

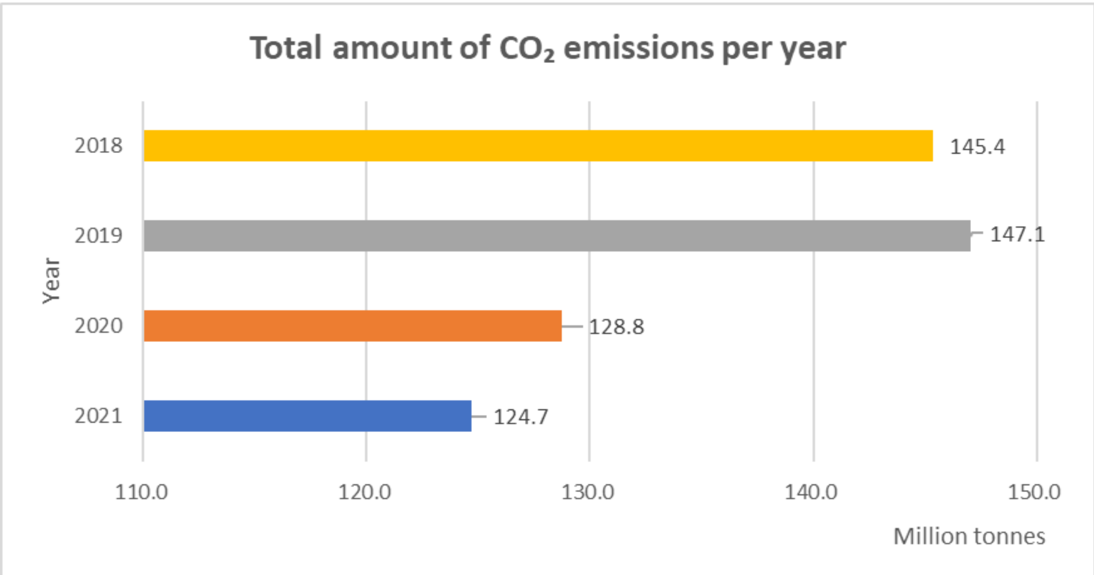
The most used fuel in global shipping is heavy fuel oil (HFO), which accounted for 79% of the total energy consumed for voyages in 2018, according to voyage-based allocation (IMO, 2018). In the transport sector, as a whole, biofuel-driven vehicles, such as methanol and ethanol, that have the lowest conversion factors of emissions, increased from 0.5% in 1990 to 4% in 2021. However, for international shipping, the percentage of use of biofuels was less than 0.5% in 2021 of the total energy demand (EIA, 2022).

After determining the amount and type of fuel used, it is possible to estimate the CO2 emissions by utilizing the conversion factor (Cf) in the following formula (a):

$$CO_2 \text{ emissions} = \text{Fuel consumption} \times Cf \quad (a)$$

In order to estimate the CO_2 emissions for the data that was provided by the EMSA report, the fuel consumption of each individual ship is taken into consideration, in addition to the specific emission factors that are defined for each kind of fuel. The bar chart (Figure 6) displays the total amount of CO_2 emissions (million tonnes) per year since the report's introduction in 2018.

Figure 6 - Total amount of CO_2 emissions per year



Source: Own Work (2023)

The graph indicates the significant role of the maritime transport sector in the European Union's carbon emissions. The graph illustrates that the total amount of CO_2 emissions in 2018 reached a value of 145.4 million tonnes of CO_2, which represents roughly 15% of the total CO_2 emissions produced by maritime transport around the world in that year and over 3% of the total EU CO_2 emissions (EMSA, 2021).

The graph shows that in the year 2019, there was a 1.17% rise in carbon dioxide emissions compared to the previous year, resulting in the release of a total of 147.7 million tonnes of CO_2. The increase in CO_2 emissions can be attributed to several factors. One reason may be that the same ships called at ports in the European Economic Area (EEA) more frequently during this time. Another factor could be the changes in trading demands, which led to longer distances traveled and more fuel consumption.

In 2020, there was a reduction of 12% in the overall amount of CO_2 emissions, which resulted in the total amount reaching 128.8 million tonnes. The pandemic caused by COVID-19 had an impact on a wide range of sectors, including the transportation industry. As a direct result of the pandemic, the industry was impacted by a disturbance in the supply chain, a contraction in demand with a seaborne trade decrease of 9.3% in the EU (EMSA,2021), and global economic instability.

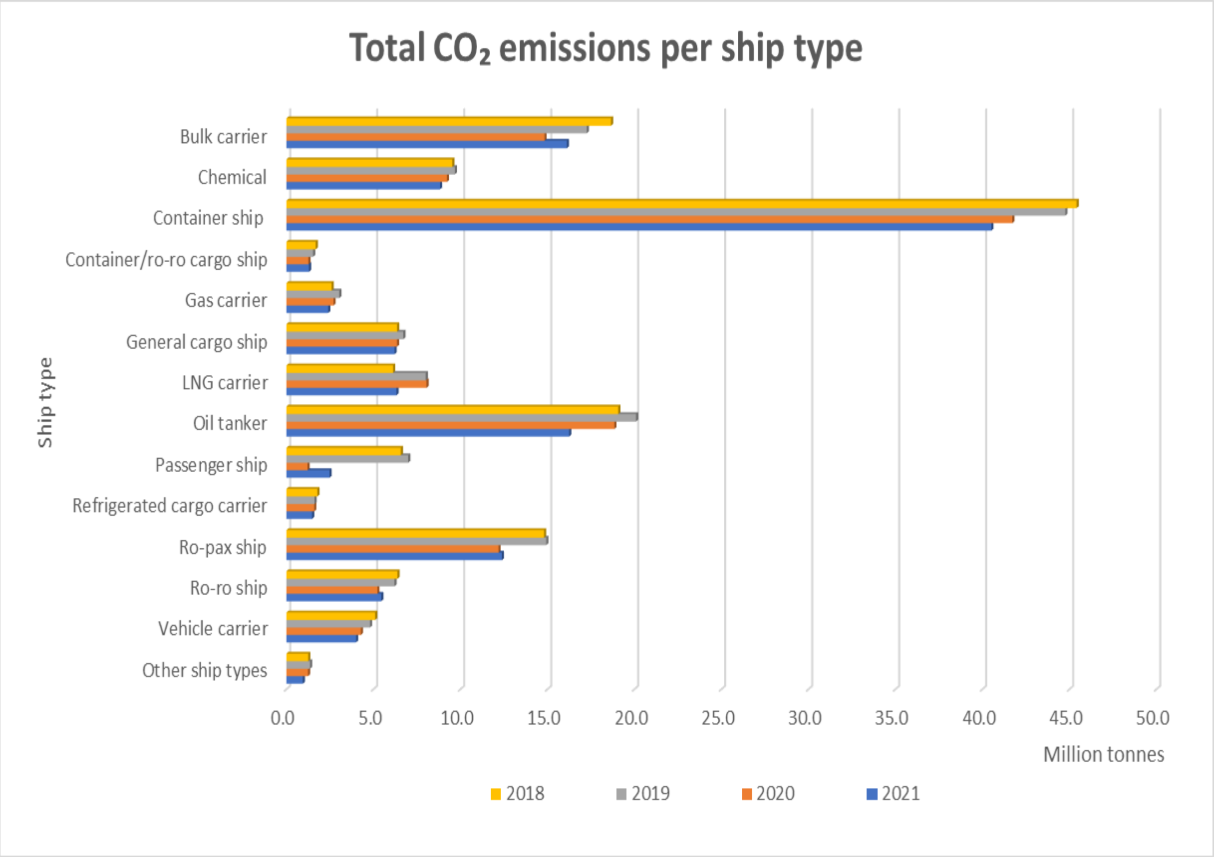
The graph on CO_2 emissions shows that the level of emissions in 2021 was the lowest it had been since the beginning of the reporting process. The data reveals that a total of 124.7 million tonnes of CO_2 were released into the atmosphere during that year. This reduction in emissions is a result of the ongoing impact of the COVID-19 pandemic, which has led to a decrease in economic activity as mentioned in the data from 2020.

However, it is important to note that the decrease in CO_2 emissions in 2021 is not solely due to the COVID-19 pandemic. The impact of the United Kingdom's withdrawal from the European Union also contributed to the reduction in emissions. The exit transitional period ended on January 1, 2021, and the effective exit of the country from the block started to count. The exit resulted in disruption to supply chains caused by the need for operators to adapt to new regulations and processes and also resulted in reduced CO_2 emissions as the emissions between ports of call in the UK are not included in the report anymore.

4.2 CO_2 EMISSIONS PER SHIP TYPE

The emissions of CO_2 produced by ships depend on various factors, such as size, age, and fuel type. The maritime industry features various types of vessels, including container ships, bulk carriers, and passenger ships, among others. Figure 7 displays the primary types of ships in operation within the EU area, as well as the total CO_2 emissions between 2018 and 2021. By analyzing this data, we can identify which ship types contribute the most to the industry's carbon footprint and implement measures to reduce emissions.

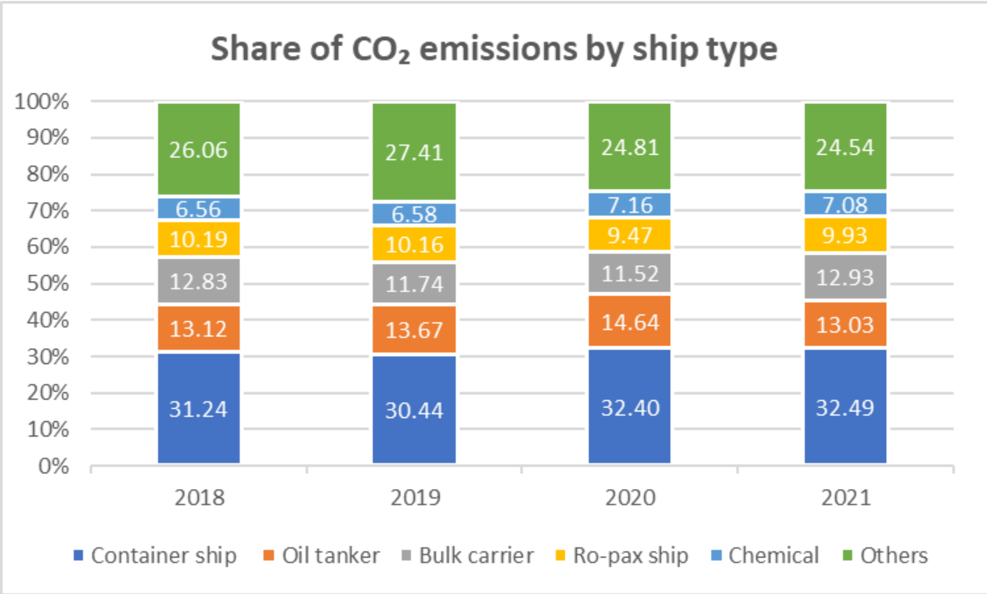
Figure 7 - Total amount of CO_2 emissions per ship type



Source: Own Work (2023)

In terms of the CO_2 emissions per ship type, the top five ship types that are dominating the emissions are container ships, bulk carriers, oil tankers, chemical tankers, and Ro-Pax ships, which together account for more than 70% of the emissions in the reporting years, as shown in the graph (Figure 8) that illustrates the share of the CO_2 emissions, in percentage, by the main 5 ship polluters.

Figure 8 - Share of CO_2 emissions by ship type



Source: Own Work (2023)

Container ships are responsible for the highest percentage of emissions in the European Union. The most significant portion of overall emissions was contributed by them. Beginning with a portion of 31.22% in 2018, having a decrease in 2019 to 30.45%, and growing again in 2020 with a share of 32.37% and an increase of 0.34% in this value is 2021, reaching the share of 32.48%.

Mainly associated with their massive size and long-distance traveled. The ability to carry thousands of containers, requires powerful engines to propel them, leading to increased fuel consumption and consequently CO_2 emissions. Additionally, container ships often use low-quality heavy fuel oil, which affects the released amount as shown in formula a. Moreover, the fact that this type of ship travels long distances between ports accounts for higher values in the final report.

The CO_2 emissions generated by oil tankers reached 19.1 million tonnes in 2018, increasing to 20.1 in 2019 and then decreasing to 18.8 million tonnes in 2020, and with a decrease of 13% in this value in 2021, reaching the emissions of 16.3 million tonnes. This decrease is believed to be a result of the decrease in oil demand due to the COVID-19 pandemic, as well as the implementation of more stringent environmental regulations.

Bulk carriers were responsible for the third highest contribution to CO_2 emissions in the maritime industry, accounting for almost 13% of the total reported emissions in both reporting years of 2018 and 2021, and approximately 12% in 2019 and 2020, contributing with a 16.1 million tonnes in 2021. Although there was a slight increase in their emissions from 2018 to 2019, their emissions have remained relatively stable over the last few years.

A considerable fluctuation was observed for LNG carriers with an increase of 31% in their CO_2 emissions from 2018 compared to 2019, remaining stable in 2020, and then having a decrease of 22% in 2021, reaching in this year the absolute terms of 6.3 million tonnes. These fluctuations in emissions can be attributed to various factors, such as changes in the demand for natural gas, the efficiency of the vessels, and the implementation of eco-friendly technologies.

From the reporting year of 2019 to 2020, passenger ships had the most abrupt decrease in CO_2 emissions due to the impact in the industry caused by the measures of the COVID-19 pandemic. A decrease of 82.85% in CO_2 emissions could be noticed, mainly due to the suspension or cancellation of trips due to reduced demand, health concerns in society, travel restrictions implied by governments, and the closure of borders.

Some passenger ship operators have successfully adapted their routes to serve domestic markets, offering shorter voyages to nearby destinations with less capacity, and enhancing their health and safety protocols. As a result of improvements in immunization rates and the relaxation of travel restrictions, the number of passenger ship voyages gradually rose in 2021, resulting in an increase of 108% in CO_2 emissions in 2021 compared to the previous year.

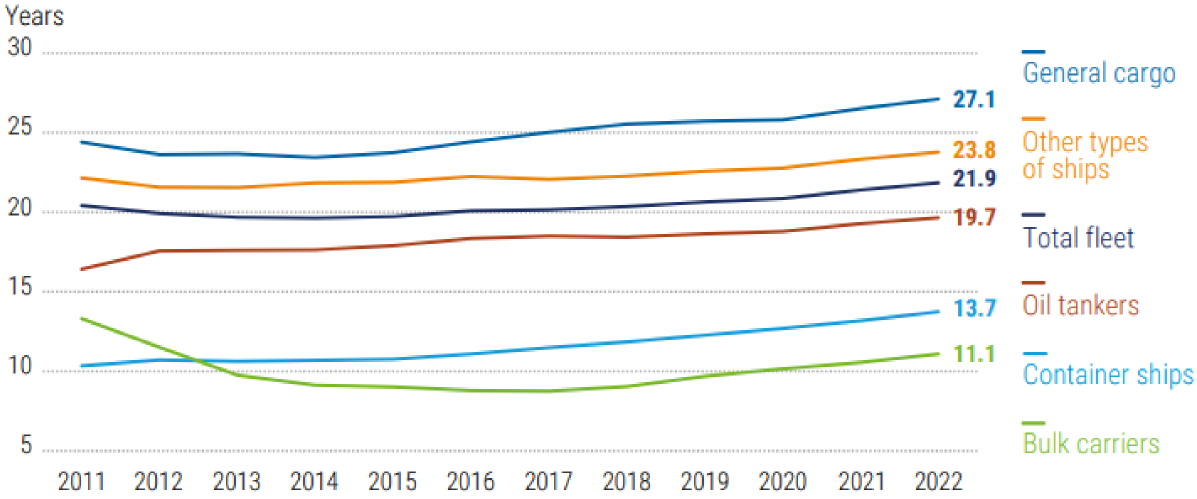
Roll-on/roll-off (Ro-ro) and Roll-on/roll-off passenger (Ro-pax) ships together reported 21.2 million tonnes of CO2 emissions in the reporting years of 2018 and 2019 and had a reduction to 17.4 and 17.8 million tonnes in the subsequent reporting years of 2020 and 2021. The pandemic measures taken during the COVID-19 outbreak also had an effect on reducing the number of CO2 emissions produced by Ro-Pax ships because of their ability to transport vehicles in addition to providing passenger accommodations.

4.3 INTERNATIONAL REGULATIONS FOR CO_2 EMISSIONS

On overall, the regulations of maritime transport are carried out by the International Maritime Organization (IMO) which is "the United Nations specialized agency with responsibilities for the safety and security of shipping and the prevention of marine and atmospheric pollution by ships" according to IMO's own definition. The organization's main task is to develop a regulatory structure for the shipping industry, as well as the assurance of fair and equitable conditions for international maritime trade, while supporting the UN's sustainable development goals.

From 2021 to 2022, an increase in the global commercial fleet of 2.95% in terms of deadweight tonnage (dwt) could be observed. Although new ships adopt new technologies to meet environmental regulations, there was an increase in the global fleet average age of 7% from 2011 to 2022 (Figure 9), with an average age going from 20.4 years to 21.9 years. This aging is mainly associated with the introduction of new technologies on the market and the constant changes in resolutions, that have postponed new investments and prolonged the operation lifetime of ships (UNCTAD, 2022).

Figure 9 - Average age of merchant fleet, 2011–2022



Source: UNCTAD calculations, based on data from Clarksons Research (2022)

The rising average age of ships is a cause for concern in terms of environmental protection. As ships get older, their efficiency tends to decrease, which can lead to increased emissions and a higher likelihood of breakdowns that may cause environmental damage. This is especially true when outdated machinery is not updated. The UNCTAD has emphasized the importance of addressing this issue, as it has the potential to impact both the safety of seafarers and the health of our oceans. Updating older ships with new technologies and improving maintenance can help mitigate the negative environmental impacts of aging vessels.

Over the past few years, the maritime industry has undergone a transformation in regulations associated with environmental protection. Governments and non-governmental organizations have pressed for the creation and updating of regulations and policies both at the international level, with the IMO regulations, and at national and regional levels. The implementation of these regulations is vital to maintaining the industry's sustainability and reducing its environmental impact. It is also essential to address the problem of aging vessels, and in some cases, they may need to be replaced or upgraded to meet new environmental standards.

The International Convention for Prevention of Marine Pollution from Ships states as the main convention for the prevention of marine environmental pollution. MARPOL is designed to minimize pollution of the seas by introducing requirements for specific operational technologies and several modified design prerequisites, with the main goal of preserving the marine environment by eliminating pollution by oil and other harmful substances and minimizing the consequences of accidental discharges of harmful substances to the marine environment.

It consists of six annexes with the purpose of controlling and eliminating pollution caused by ships. The annex dealing with air pollution is the annex VI which aims the regulation for prevention of air pollution from ships and it is applied to all ships with 400 gross tonnage or more. The annex gives details about the equipment used in the ship to avoid air pollution and enforce the issue of certificates of compliance.

In this regulation is stated the limits of emission of NOx and sulfur content of any fuel oil used on board ships shall not exceed 0.5% m/m after 1st January 2020, and for control areas such as the Baltic Sea, they shall not exceed 0.1% m/m after the same date. It is also stated that deliberate emissions of ozone-depleting substances, that are substances that decline the ozone layer, like hydrochlorofluorocarbon, are prohibited for all ships and banned in newly built ships since 2020. In addition, the Annex introduced the Energy Efficiency Design Index (EEDI) and the Ship Energy Efficiency Management Plan (SEEMP), both of which were designed to encourage increased energy efficiency in ships.

The EEDI applies to newly built ships and stipulates a minimum energy efficiency level for their equipment and engines. This index takes into account the type, and dimensions of the ship and provides a precise value for each individual ship design, which should be as low as possible for an energy-efficient ship design. This index has the proposal to adopt a tighter requirement every 5 years to encourage the improvement of technologies in the industry that is essential to improve the emissions rate of the sector. The SEEMP strategies are going to be better explained in the next chapter.

Two new certifications put additional pressure on ship operators to improve in the efficiency of the ships in order to reduce CO_2 emissions. The Energy Efficiency Existing Ship Index (EEXI) and the Carbon Intensity Indicator (CII) that were introduced by IMO as an amendment to MARPOL Annex VI came into force on January 1st, 2023.

The EEXI is a one-time certificate for ships from 400 gross tonnage and above and has the aim of measuring energy efficiency. Ship operators will be required to evaluate their vessels' levels of energy consumption and CO_2 emissions, guaranteeing that the ship satisfies a minimal requirement for energy efficiency and ensuring that the EEXI obtained is less than the required one.

The CII is an annual indicator for ships above 5,000 gross tonnage that are trading internationally, and it is calculated as CO_2 emitted per cargo-carrying capacity and nautical mile. The carbon intensity of a particular ship will be assessed based on the Carbon Intensity Indicator (CII) and graded on a scale of A, B, C, D, or E, where A represents the highest rating.

For those with a one-year rating of E or 3 consecutive years with a rating D, it will be necessary to obtain a corrective action plan from the ship owners showing how a rating of C or above will be achieved. This rating can be improved using the strategies in the SEEMP or by even updating the propulsion system to a less harmful one. A good approach is for governments to give incentives, mainly financial ones, to those ships with ratings A and B, this way encouraging other companies to take action to reduce their emissions.

The IMO also established in 2018 the IMO Data Collection System, which functions similarly to the EU EMSA Regulation in that it provides a clearer report of the emissions and has the potential to result in enhanced awareness of the emissions among stakeholders, including governmental institutions. All these regulations and resolutions assist businesses in determining areas in which they can save money, lower their carbon footprint, increase their energy efficiency, and comply with regulatory standards, thereby avoiding the fines that are associated with non-compliance.

4.4 STRATEGIES TO REDUCE CO_2 EMISSIONS

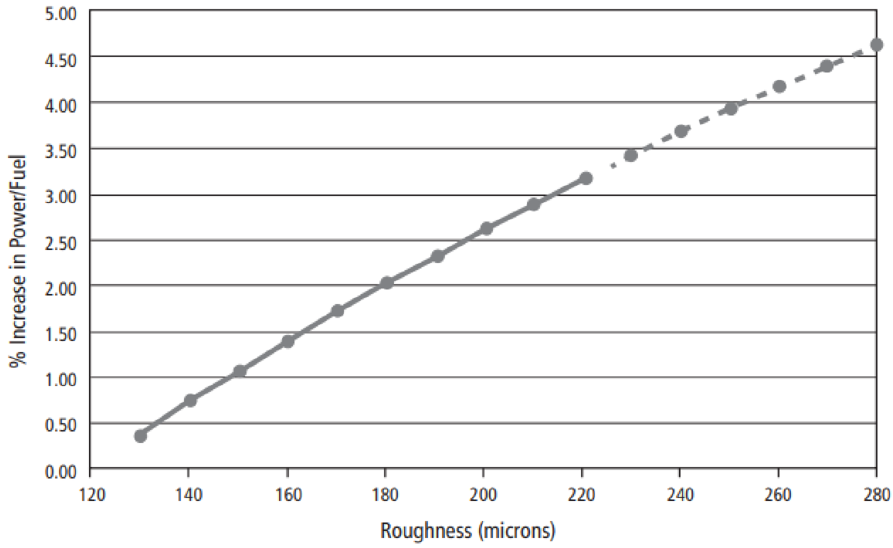
The amount of fuel that a ship uses in one nautical mile is subject to significant variation on account of the ship's particular characteristics as well as the environmental conditions in which it sails. With the increase in the fleet’s age and ship owners being reluctant to make fleet upgrades, operational strategies are becoming more important than ever. There are many operational solutions that can be utilized to lower the amount of carbon emissions produced by enhancing the efficiency with which oil is consumed. By adopting these measures, ship operators can reduce their carbon footprint and save significant amounts of money on fuel costs.

This section of the study is organized in accordance with the Ship Energy Efficiency Management Plan (SEEMP) that was presented by the IMO in MEPC.246(78), and it is accompanied by a technical review of the study that was conducted by the ABS in 2013 titled Ship Energy Efficiency Measures Advisory. The goal of the SEEMP is to assist ship operators in identifying, evaluating, and putting into action operational solutions that will improve energy efficiency and minimize emissions of greenhouse gases.

Hull Maintenance

The degree of roughness of the ship’s hull surface that comes into contact with the water flow significantly affects the magnitude of the frictional resistance and, consequently, the engine's power and fuel consumption, as shown in Figure 10. The maintenance of the ship's hulls has an important influence on its fuel efficiency and CO_2 emissions since it helps to minimize the amount of frictional resistance produced by the roughness in the structure. Both physical sources, such as mechanical damage and corrosion, and biological sources, such as animals and algae, are capable of contributing to the surface's roughness.

Figure 10 - Increase in Fuel Consumption for a Fast Containership with Increasing Roughness



Source : Ship Energy Efficiency Measures Advisory (ABS, 2013)

Measures such as hull cleaning, which is the process of removing marine organisms or debris that accumulate over time in the underwater portion of the ship's hull, can reduce propulsion fuel consumption by up to 7 to 9% in the case of light slimes, up to 15 to 18% for heavy slimes, and up to 20 to 30% in cases of cleaning heavy macroincrustations (ABS, 2013).

The timely full removal and replacement of the paint in the submerged section is also advised, as despite implementing effective maintenance procedures, the average roughness of a hull can still increase by 10 to 25 m per year, as stated in the same study. These measures have a positive impact on reducing resistance while navigating and, consequently, decreasing oil consumption and CO_2 emissions. In addition, the use of new technology in coating systems can lead to the optimization of hull resistance.

The disadvantage of this strategy is that this process costs money and time for the ship operators, as it is normally necessary to allocate the ship to a dry dock for cleaning, requiring specialized personnel and equipment and reducing the operational time of the ship. Another disadvantage is the use of chemicals for the removal of the incrustation, which can lead to water pollution and be harmful to the marine environment.

Route and operations optimization

The planning and management of routes are essential to ensuring safe and efficient operations and reducing fuel consumption and CO_2 emissions. A critical aspect is to analyze and plan the route in advance, taking into consideration the most efficient distance and time route, operations deadlines, and the weather forecast, including wind speed, currents, and wave height, with the assistance of a marine weather routing system providing accurate weather information. The most significant benefits of this operational method are gained by ships that travel longer distances through harsh weather conditions.

Moreover, effective communication with port facilities is a key component of this strategy to reduce operating wait times. Additionally, this strategy should have the support of port authorities in order to reduce delays and increase the efficacy of port-ship operations. Planning and management necessitate the analysis of multiple factors, evaluating the possibility of any hazards along the route, and taking measures to protect against those dangers while keeping cargo and crew safety a priority.

Energy Management

Each piece of machinery and equipment that is present on the vessel has its own unique energy requirements. One such technique for lowering CO_2 output is to cut down on the amount of power that is required on board. Installation, review, and replacement of onboard electrical equipment and devices with ones that are more energy efficient or fit for the particular load or service situation, such as light bulbs that use less energy, are all part of this process.

In order to achieve maximum energy efficiency, maintenance is another essential component that must be considered. It is possible to avoid wasting energy, cut down on the amount of time the equipment is out of commission, and increase its overall lifespan by performing maintenance in the right manner and at the right intervals.

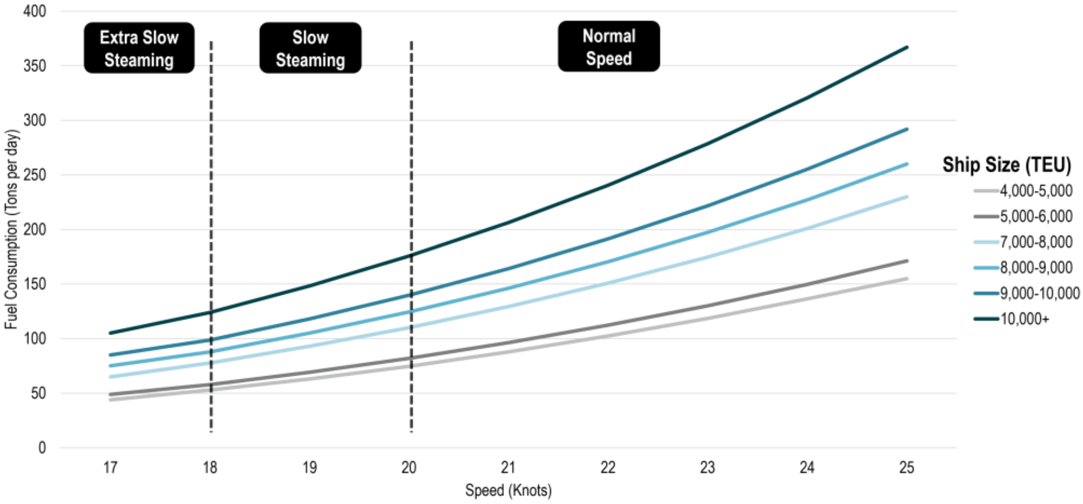
Speed optimization

In the marine industry, speed optimization is a method that is frequently used to decrease operating costs and minimize the carbon footprint. This approach may be used by any type of ship, regardless of the type of cargo or the size of the ship. However, the greatest benefits are for ships traveling at higher speeds.

There is not a linear relationship between the quantity of fuel consumed and the speed of the ship. The relationship between propulsion power and speed can be described as an exponential function with an order of magnitude of three or four. Being dependent on the characteristics of the ship, such as its size and hull design (Schiller, 2016; Gusti & Semin, 2018; Serra & Fancello, 2020).

As can be seen in figure 11 (Rodrige, 2020), the fuel consumption of containerships was examined, taking into consideration the size and speed of the ships. This resulted in a significant drop in the amount of fuel that was used when even a modest reduction in speed was made. If we take container ships that have more than 4,500 TEU as an example, decreasing their speed by one knot results in a 12 to 15% decrease in their propulsion fuel usage, according to an ABS study.

Figure 11 - Fuel Consumption by Containership Size and Speed



Source: Rodrigue (2020) based on Notteboom and Cariou (2009)

In the shipping industry, a technique known as "slow steaming" refers to the practice of reducing a ship's speed below its full capacity, often by 10–20 percent, in order to save fuel and minimize emissions. The practice of slow steaming has gained widespread adoption among ship owners and operators, mainly due to its capacity to assist companies in reducing fuel costs. Other potential benefits of slow steaming include reduced levels of environmental noise pollution.

Unfortunately, this method can also result in certain downsides, such as a shorter lifespan for the engine as a result of less-than-optimal utilization of the engine. In addition, if it is not adequately managed, it may result in the necessity of increasing the number of vessels in the fleet. This is because it extends the amount of time it takes to travel and decreases the amount of cargo that can be transported. It is essential for shipping companies to give serious consideration to the potential negatives of this strategy prior to putting it into action.

Often, some of the operational strategies exposed in this section cannot be implemented due to various management factors such as weather conditions, time expected for operation, reduction of the operation time, and charter contract speeds. These factors can often put pressure on ship owners to meet certain speeds, reduce some maintenance measures, or risk being hit with fines or other penalties for not fulfilling the contract requirements, arriving late for operation, or failing to achieve the contract speed.

To address this issue, it's important for ship owners and operators to take a proactive approach and consider slow-steaming speeds when drafting their charter contracts and to work together to find solutions that balance environmental sustainability and financial viability. This can help to ensure that operational strategies are feasible and can be put into practice without putting pressure on the ship operating company to always maintain high speeds.

5. CONCLUSION

Maritime transport plays a crucial role in international transportation, as it is responsible for the transportation of over three-fourths of all goods worldwide. Despite its significance, this mode of transportation has significant drawbacks, particularly its negative impact on the environment. The emissions and pollutants from ships can cause severe ecological damage, such as oil, air, and noise pollution.

The main concern is with air pollution, since it can affect human health and also has a great influence on climate change. The primary contributor to CO_2 emissions, in addition to other types of polluting gases and particles, is the burning of fuel in ships' primary propulsion or auxiliary machinery. This study showed that there was a significant decrease in the number of CO_2 emissions between 2018 and 2021 in the European Economic Area. Reaching its lowest value in the year of 2021 with a total amount of 124.7 million tonnes of CO_2. Despite a general decrease over the past few years, maritime transportation still makes a significant contribution to CO_2 emissions in the European Union, which is an important concern for the relevant authorities.

The COVID-19 outbreak and the United Kingdom's decision to leave the European Union each had an effect on the region's emissions. This is evidenced by the significant reduction of CO_2 emissions in the years 2020 and 2021. In the instance of COVID-19, this is a consequence of the decrease in ship activity in the period of 2020. However, there is a risk that the emission numbers will grow and revert to levels that existed prior to the pandemic once the economy stabilizes and starts improving again. It is essential to take preventative steps, as shown in the strategies, in order to avoid this happening.

For the case of the reduction in 2021, the same year of the UK withdrawal does not necessarily mean that there is a more efficient use of energy or fewer emissions, but it is mostly indicated that the numbers are lower due to a decrease in the number of reports since some of the ships with voyages between UK ports or with voyages outside the EEA and the UK are not accounted anymore. It would be vital to have continual tracking of the emissions, even without accounting for the EEA emissions, since the emissions in the UK inevitably damage the health and environment of the other EEA nations due to its proximity to those countries.

On the other hand, there is an expectation that there will be a reduction of CO_2 emissions in maritime transport data from 2023 onward as new requirements such as the EEXI and CII certifications are implemented. During this phase of this process, shipping companies will work to improve their energy efficiency in order to avoid being negatively rated and, in an optimistic scenario, to benefit from high ratings.

Transport by container plays an important role in the supply chain sector as it enables the easy transfer of goods to other modes of transport. The containers can be placed on ships, trucks, trains, and even airplanes, depending on the size. However, the fact that it is responsible for a significant portion of the EEA's total CO_2 emissions—more than 30% each year—, shows that it is important to address this issue by adopting operational strategies, such as better route planning, is essential to tackle more efficient oil consumption and consequently the CO_2 reduction. In addition, the expressive reduction of more than 82% in emissions from passenger ships that occurred throughout the course of the COVID-19 outbreak underlines the relevance of rethinking a more environmentally friendly approach to travel and the necessity of selecting a journey that is more local.

It is of the greatest importance to emphasize to ship operators the importance of informing the data in order for governments and the IMO to have a clear insight on the present situation in order to revise the regulations. The decrease in emissions is a favorable advancement toward achieving the global climate objectives, and it emphasizes the possibility for further reductions in emissions by implementing changes in policy and technology. The regulations have a prominent place in the reduction of CO_2 emissions. The increase in regulations for CO_2 and GHG emissions in the past few years, such as the inclusion of the Carbon Intensity Indicator (CII) certificate, has put the maritime industry on a good path.

It has been argued that in order to improve the industry's overall environmental sustainability, the maritime sector needed stricter regulations. A constant improvement regarding environmental regulations, policies, and short-term and long-term strategies would allow faster achievement of the target of reducing CO_2 emissions by at least 40% by 2030, as proposed by the Maritime Organization faster. However, it is important to note that the constant modification of regulations can lead to a state of uncertainty for ship owners. This is well illustrated by the fact that the average age of the fleet has been steadily increasing over the course of the past few years, reaching an average of 21.9 years.

Any negative effects on the environment that are a direct result of the operation of the ship are the responsibility of the ship's owners and operators. Given the aging of the fleet, the implementation of operational strategies is an effective method for decreasing CO_2 emissions on ships that are already operational. When the right approach is taken in the planning, implementation, monitoring of operational strategies, and corrective measures, there is a significant potential for a reduction in CO_2 emissions. Strategies such as effective hull maintenance and speed optimization can be adopted by any type of ship and bring a significant reduction in fuel consumption reaching more than 10% in specific cases, also reducing CO_2 emissions.

However, there are still a few obstacles to be conquered in order to achieve success in minimizing the negative environmental impacts created by the maritime industry. One of the most significant problems facing the sector is the conflict of interest between the promotion of environmental sustainability and the pursuit of financial gain. Although there are many procedures that may be implemented to decrease CO_2 emissions and minimize the environmental impact of shipping, contractual incentives typically speak louder, leading to environmental inefficiencies.

Through the examination of primary sources as well as secondary literature, this study demonstrates, in summary, that the maritime industry plays a key role in the overall functioning of the global economy. Nevertheless, the sector must make significant efforts to find a balance between its economic goals and the impacts it has on the environment. In order to accomplish this goal, collaboration among different stakeholders is absolutely necessary.

6. SUMMARY

In 2021, more than 80% of all cargo in the world's trade will be transported by maritime transportation, according to the UNCTAD. However, the exponential growth of consumption demands has increased concern about the environmental impacts that this means of transportation can cause. To address these concerns, this study's objective is to provide a comprehensive overview of the environmental effects of maritime transportation.

The objective is also to analyze the levels of CO_2 emissions in the European Union from 2018 to 2021 and provide an overview of pertinent air pollution resolutions. Additionally, this study presents prospective strategies for reducing carbon emissions and mitigating the shipping industry's negative environmental impacts. For that, data on CO_2 emissions in the EEA and the literature review method were used. First, the CO_2 emissions data from 2018 to 2021, provided by the European Maritime Safety Agency (EMSA) in accordance with Regulation (EU) 2015/757, was analyzed. For the secondary research method, a systematic method review was used.

The findings reveal that CO_2 emissions in the EU are still high—more than 120 million tonnes of CO_2 per year—even after the tightening of new regulations. The research also highlights the importance of operational strategies to increase the energy efficiency of ships and consequently reduce CO_2 emissions. Also, it is important for stakeholders to find a balance between environmental protection and financial gain. Furthermore, the conclusion of this investigation has the potential to provide shipping companies with helpful insights that may be applied toward the reduction of CO_2emissions.

Keywords: Maritime Transportation, CO2 Emissions, Environmental Impact, European Union, Environmental Regulations

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9. APPENDIX

APPENDIX I – STUDENT AND SUPERVISOR’S DECLARATION

STUDENT DECLARATION

Signed below, ____Rayza Jansen dos Santos____, student of the Szent István Campus of the Hungarian University of Agriculture and Life Science, at the BSc Course of __Environmental Engineering__ declare that the present Thesis is my own work and I have used the cited and quoted literature in accordance with the relevant legal and ethical rules. I understand that the one-page-summary of my thesis will be uploaded on the website of the Campus/Institute/Course and my Thesis will be available at the Host Department/Institute and in the repository of the University in accordance with the relevant legal and ethical rules.

Confidential data are presented in the thesis: yes no*

Date: 2023 May 1st

Rayza Jansen dos Santos

Student

SUPERVISOR’S DECLARATION

As primary supervisor of the author of this thesis, I hereby declare that review of the thesis was done thoroughly; student was informed and guided on the method of citing literature sources in the dissertation, attention was drawn on the importance of using literature data in accordance with the relevant legal and ethical rules.

Confidential data are presented in the thesis: yes no *

Approval of thesis for oral defense on Final Examination: approved not approved *

Date: 2023 May 1st

Dr. Mészáros K.

Signature

APPENDIX II – STATEMENT ON CONSULTATION PRACTICES

STATEMENT ON CONSULTATION PRACTICES

As a supervisor of ________Rayza Jansen dos Santos______F4692C, I here declare that the final essay/thesis/master's thesis has been reviewed by me, the student was informed about the requirements of literary sources management and its legal and ethical rules.

I recommend/don't recommend the final essay/thesis/master's thesis/portfolio to be defended in a final exam.

The document contains state secrets or professional secrets: yes no*

Place and date: _________2023_______ year ____May___________ month____1st___ day

Dr. Mészáros K.

Internal supervisor