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Specialization: Quality in Shipping

Decarbonization of Shipping

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Declaration

I hereby declare that the work in this thesis titled " Decarbonization of Shipping" has been carried out by me and the dissertation was not formed to obtain any other degree or professional certification. In addition, I declare that I have acknowledged the work of others by providing specific references to that work.

This master's dissertation was approved by the three-member advisory committee appointed by the department of maritime studies of the University of Piraeus in accordance with the regulations of the postgraduate studies program. The members of the committee were

- Anastasios Tselepides (Supervisor)
- Ernestos – Spyridon Tzannatos
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Abstract

Shipping is considered to be the most important pillar of the global economy because it is not only the only way to transport raw materials, food, and products to every corner of the globe, but it also benefits everyone’s economic development. The shipping industry's environmental impacts include greenhouse gas (GHG) emissions, noise pollution, and oil pollution. Approximately 90% of global trade is carried out by ship. According to an IMO report (2009), international shipping is responsible for 2.7% of global carbon dioxide (CO2) emissions. The figure below details the CO2 emission rates per sector as processed and calculated in the 2009 IMO report.

According to what was previously stated about shipping decarbonization, it should be also stated that shipping transport is by far the most energy efficient mode of transport in terms of energy/tonne kilometer. Ships currently consume only 3% of the world's final energy demand, including 7% of the world's oil, primarily for international cargo shipping, also known as ocean liners. The IMO sulfur cap regulation went into effect in 2020, requiring the use of fuel with reduced sulfur to 0.5% or the use of a fuel catalyst for ships that use the old type of oil as fuel. As a result, the type of fuel used by the fleet has changed dramatically. - However, a significant amount of heavy fuel oil is still used on ships equipped with scrubbers.

Furthermore, substantial additional investment is required to provide the necessary recharging and refueling infrastructure, particularly for zero-emission vessels and port infrastructure. These resources are not currently planned for by Member States, as reported in national implementation reports, and additional funding may be required to meet the climate target. According to available data, the majority of Member States have made limited investments in alternative fuel infrastructure for ship refueling with Liquefied Natural Gas and energy supply from shore to ports. However, as the target dates for implementation in 2025 or 2030 approach, the directive is likely to have a significant impact, particularly in these areas.

1st Chapter - Introduction

Shipping is considered to be the most important pillar of the global economy because it is not only the sole way to move raw resources, food, and products to every corner of the globe, but it also improves people's economic progress. Shipping is a component of the Greek industry and a topic of interest as well as discussion among the people. To formulate its definition, someone can say *that the transport sector, which deals with the transport of goods and passengers by sea, constitutes the Shipping Industry* (Sabrakos, Giannopoulos 2017).

The shipping industry helps to reduce unemployment by providing jobs to the countries' labor force, but it also helps to increase Gross Domestic Product by collecting foreign currency fares for the transport of cargo from third countries and converting them into naval currency. It also generates other economic activities that are directly or indirectly related to shipping, such as chartering, brokerage, shipbuilding, insurance, technical inspection companies, marine equipment production, and so on. Shipping is distinguished by the fact that it is an economic unit that does not produce goods but rather transports economic units from production to consumption.

However, due to the large percentage of the world's trade it serves, trade shipping becomes vulnerable to the various economic events that occur even in the most isolated areas. As a result, the corresponding influence of this change in fare prices is observed with each fluctuation in the rate of economic growth.

Region or country	Average 2001–2008	2018	2019	2020*
World	3.6	3.1	2.5	–4.3
Developed countries	2.3	2.3	1.8	–5.8
of which:				
European Union (27)	2.1	2.1	1.5	–7.3
Japan	1.2	0.3	0.6	–4.5
United States	2.6	2.9	2.3	–5.4
Developing countries	6.6	4.3	3.5	–2.1
of which:				
Africa	5.8	3.1	3.1	–3.0
East Asia	9.2	5.9	5.4	1.0
of which:				
China	10.9	6.6	6.1	1.3
South Asia	6.7	5.1	2.8	–4.8
of which:				
India	7.6	6.8	4.2	–5.9
South-East Asia	5.7	5.1	4.4	–2.2
Western Asia	5.5	2.0	0.9	–4.5
Latin American and the Caribbean	3.9	0.6	–0.3	–7.6
of which:				
Brazil	3.7	1.3	1.1	–5.7
Caribbean	5.0	3.5	1.9	–6.4
Transition economies	7.2	2.8	2.2	–4.3
of which:				
Russian Federation	6.8	2.3	1.3	–4.2

Table No.1 - Global Economic Growth, 2018-2020 (annual percentage change)

(UNCTAD 2019)

The global economy's growth is measured by GDP, which, as shown in Table o.1, fell to 3.1% in 2018 from 3.6% on average over the previous seven years, i.e. below the average recorded between 2001 and 2008. However, 2.9% growth in the United States in 2018 helped offset the weakness of the rest of the world, including the European Union. However, the decline continued, with the percentage falling to 2.3% in 2019 (UNCTAD, 2019).

The table also shows that the division of countries into developed and developing countries is necessary due to their different contributions to the course of global economic history. Countries in the first category include the United States, Japan, and the European Union. China, Russia, Brazil, India, and Africa are among the second-tier economies hoping to dethrone some of the first-tier economies (developed countries). According to UNCTAD, the movement of maritime trade in 2018 is shown in table No.2. The total number of goods transported by sea reached 11 billion tons, up from 10.7 billion in 2017, representing a small but significant increase. 2019 (UNCTAD). According to UNCTAD, the transport of maritime trade in 2019 (Table No.3) is shown in the table below. The total number of goods transported by sea reached 11.07 billion tons in 2017, while it was 11 billion tons in 2018, indicating a slight increase.

Country group	Year	Goods loaded				Goods unloaded			
		Total	Crude oil	Other tanker trade[a]	Dry cargo	Total	Crude oil	Other tanker trade[a]	Dry cargo
		Millions of tons							
World	2017	10 716.2	1 874.6	1 271.6	7 570.1	10 702.3	2 033.7	1 289.4	7 379.2
	2018	11 005	1 886.2	1 308.1	7 810.7	11 002.2	2 048.5	1 321.8	7 631.9
Developed economies	2017	3 709	152.7	491.2	3 065.1	3 795	979.1	494.7	2 321.2
	2018	3 821.7	157.7	511.2	3 152.7	3 822.9	946.5	495.8	2 380.5
Transition economies	2017	694.4	206.8	41.6	445.9	81.4	0.3	4.6	76.4
	2018	713.3	203.8	39.6	469.9	86.5	0.3	4.8	81.3
Developing economies	2017	6 312.8	1 515	738.8	4 059	6 825.9	1 054.3	790	4 981.6
	2018	6 469.9	1 524.7	757.3	4 188	7 092.8	1 101.6	821.2	5 170
Africa	2017	740.9	291.3	70.4	379.1	496.8	40.5	93.8	362.6
	2018	767.2	289.3	73.8	404	516.3	42.5	93.9	380
America	2017	1 371.8	225.2	71.9	1 074.7	617.2	47.5	141.4	428.2
	2018	1 403.7	219.3	78.3	1 106.1	652.5	51.8	149	451.8
Asia	2017	4 192	996.9	595.6	2 599.5	5 696.9	965.4	549.4	4 182.1
	2018	4 290.7	1 014.4	604.1	2 672.1	5 908.3	1 006.5	572.5	4 329.3
Oceania	2017	8.1	1.6	0.8	5.7	14.9	0.8	5.4	8.7
	2018	8.4	1.6	1.0	5.8	15.6	0.8	5.8	9

Table No.2 - International Maritime Trade, 2017-2018 (cargo type, country breakdown and region)

Designation	Year	Goods loaded: Total	Goods loaded: Crude oil	Goods loaded: Other tanker trade*	Goods loaded: Dry cargo	Goods unloaded: Total	Goods unloaded: Crude oil	Goods unloaded: Other tanker trade*	Goods unloaded: Dry cargo
		Millions of tons							
World	2018	11 019.0	1 881.0	1 319.7	7 818.3	11 016.8	2 048.8	1 338.6	7 629.4
	2019	11 075.9	1 860.2	1 308.4	7 907.3	11 083.0	2 033.4	1329.3	7 720.3
Developed economies	2018	3 862.8	206.2	507.5	3 149.1	3 844	931.9	494.8	2 417.8
	2019	3 935.2	242.9	506.9	3 185.4	3 780	913.6	472.6	2 394.0
Transition economies	2018	713.0	203.8	37.6	471.6	99.4	0.3	4.8	94.3
	2019	715.8	193.9	41.1	480.8	102.0	0.8	5.4	95.8
Developing economies	2018	6 443.4	1 471.1	774.6	4 197.6	7 072.9	1 116.6	839.0	5 117.3
	2019	6 424.8	1 423.3	760.3	4 241.2	7 200.7	1 118.9	851.3	5 230.5
Africa	2018	763.0	297.4	70.4	395.2	501.8	39.0	99.9	362.8
	2019	762.1	293.5	69.9	398.7	504.5	39.2	99.3	365.9
America	2018	1 385.4	200.6	88.7	1 096.1	638.1	47.1	149.3	441.8
	2019	1 386.3	204.2	82.3	1 099.8	621.7	47.8	138.8	435.1
Asia	2018	4 280.4	971.3	607.8	2 701.3	5 918.9	1 029.7	584.7	4 304.5
	2019	4 261.8	923.9	600.5	2 737.5	6 059.1	1 031.1	607.7	4 420.3
Oceania	2018	14.5	1.7	7.8	5.1	14.1	0.8	5.0	8.2
	2019	14.6	1.8	7.7	5.1	15.4	0.7	5.5	9.1

Table No.3 International Maritime Trade, 2018-2019 (cargo type, country breakdown and region)

Finally, at the start of 2019, the global merchant fleet consisted of 95,402 vessels with a total tonnage of 1.97 billion deadweight tons (dwt). Bulk carriers and oil tankers account for 42.6% and 28.7% of all vessels in the global fleet, respectively. In comparison to the beginning of 2018, transportation capacity increased by 2.6%. (See Table No. 4). It is worth noting at this point that the global economy has a significant impact on the development of shipping, but it is not the only one. Other factors that influence the course of shipping include the freight market (which is formed by the supply and demand for ship capacity for the transport of goods) and the drop in ship value. (UNCTAD, 2019)

Principal types	2018	2019	Percentage change 2019/2018
Oil tankers	562 035 *29.2*	567 533 *28.7*	0.98
Bulk carriers	818 921 *42.5*	842 438 *42.6*	2.87
General cargo ships	73 951 *3.8*	74 000 *3.7*	0.07
Container ships	253 275 *13.1*	265 668 *13.4*	4.89
Other types	218 002 *11.3*	226 854 *11.5*	4.06
Gas carriers	64 407 *3.3*	69 078 *3.5*	7.25
Chemical tankers	44 457 *2.3*	46 297 *2.3*	4.14
Offshore vessels	78 269 *4.1*	80 453 *4.1*	2.79
Ferries and passenger ships	6 922 *0.4*	7 097 *0.4*	2.53
Other/ not available	23 946 *1.2*	23 929 *1.2*	-0.07
World total	**1 926 183**	**1 976 491**	**2.61**

Table No.4 - Global own-type vessel fleet, 2018-2019 (thousands of dead-weight tons2 and percentage)

With the exception of a small increase in 2017, the growth rate has been decreasing continuously since 2011, remaining below the general trend over the last decade.

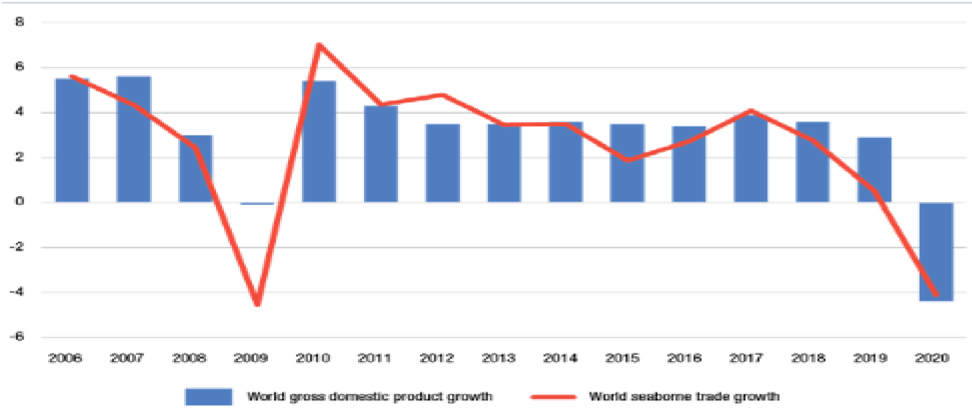


Table No.5 - Growth of international maritime trade and global production, 2006-2020 (Annual percentage change)

As shown in the table, the expansion of maritime trade has slowed in tandem with the slowing of global GDP growth. In addition, global GDP and maritime trade are expected to contract by 4.1% in 2020, according to the data. The pandemic's onset in early 2020 and its impact on global economies, travel, transportation, and consumer standards, as well as manufacturing activity and supply chains, resulting in a global recession in 2020 (UNCTAD, 2020).

Year	Tanker trade[a]	Main bulk[b]	Other dry cargo[c]	Total (all 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	3 169	3 225	4 682	11 076

Table No.6 - Development of international maritime trade, selected years (million tons of cargo)

As a result, the European Union is moving faster than the IMO in terms of environmental legislation, with shipping expected to be significantly affected beginning in 2024. The EU's pressure is beneficial in that it pushes the IMO - whose role remains and must remain a leading one - to introduce new frameworks and revise the goals it has set. Indeed, the IMO will set more stringent targets in 2023 (UNCTAD, 2019).

However, the EU is not the only pressure point. After all, shipping financing varies greatly and is heavily influenced by environmental footprint criteria, specifically energy and operational efficiency. Not only are the charterers moving in the same direction, but so are the insurance companies. Continuous initiatives are being driven by multifaceted pressures, accelerating technological advancements with a focus on decarbonization. In any case, it is unclear which fuel will be the dominant fuel in the future. After all, this is determined by a variety of factors, including the energy transition horizon and the cost of each fuel. Uncertainty, on the other hand, does not deter investment (UNCTAD, 2019).

21% (1,046) of the ships under construction will be able to use alternative fuels. The majority of these (534) will be LNG-fired, confirming LNG's critical role as a medium-term transition fuel. Along with LNG, liquefied petroleum gas (57 ships) and methanol (35 ships) are gaining popularity. Furthermore, 417 ships will be outfitted with hybrid battery systems for commercial use, primarily in short-distance shipping. It is worth noting that larger ships are more interested in LNG and methanol. In terms of tonnage, 25% of the ships ordered in 2022 will use LNG. Almost all ordered containerships will run on LNG or methanol (UNCTAD, 2019).

Simultaneously, it is estimated that in the coming decades, there will be approximately four different fuels, with the main candidates being fuel oil, LNG, methanol, and ammonia. The existence of regulatory frameworks for methanol and LNG encourages their adoption, whereas the "radio silence" at the regulatory level regarding ammonia and hydrogen - as well as the lack of required technologies - creates barriers to relevant investments (UNCTAD, 2019).

2nd Chapter – Shipping Emission and Decarbonization in Shipping

2.1 Drives for Reducing Pollution Emissions from Ships

It is true that shipping is a major source of air pollutants, which have a negative impact on climate change, affecting both human health and the sustainability of ecosystems. Carbon dioxide, nitrogen oxides, and sulfur dioxide all have significant effects on both climate change and public health. Exhaust gases from ship engines contain a high concentration of nitrogen, oxygen, water vapor, and carbon dioxide. They also contain trace amounts of nitrogen oxides, sulfur oxides, carbon monoxide, and suspended particles.

The perfect combustion of carbon fuel produces carbon dioxide. Internal combustion engines do not always burn perfectly, resulting in the production and emission of a variety of particles, including unburned hydrocarbons. Because of the dangers of the greenhouse effect, it is imperative that its production be reduced on a global scale. This can be accomplished by using fuels with fewer or no carbon atoms, such as hydrogen, or by increasing the efficiency of heat engines.

When sulfur dioxide is burned, it reacts with water vapor in the atmosphere to produce sulfuric acid particles, which are then released into the atmosphere. Because of the high temperatures, the nitrogen in the ship's internal combustion engines reacts with the oxygen in the air and is oxidized to nitrogen oxides. Suspended particles are made up of both organic and inorganic materials. These include coal, soot, ash, and incompletely burned fuel particles (Klianis, Nikolos, Sideris, 2003).

The entire maritime community strives for more sustainable growth, ecology, and environmental protection. It is true that the recent economic crisis has highlighted the vulnerable side of global society. Recent events have shown signs of recovery, which can be attributed to well-organized global strategies and policies. It is widely acknowledged that the shipping industry, including trade, generates wealth that is critical for the majority of the world's population.

The shipping industry continues to emphasize energy-efficient, environmentally friendly technologies, both in terms of energy production and ship operational structure. The International Maritime Organization (IMO) also plays an important role in adopting the necessary and appropriate regulations and regulatory provisions for each ship. The aforementioned provisions significantly ensure environmentally sustainable shipping, with their foundations in predetermined strategies, policies, and solutions, while also allowing for new innovative technologies (e.g., green ships, options to reduce pollutant emissions).

The shipping industry's environmental impacts include greenhouse gas (GHG) emissions, noise pollution, and oil pollution. Approximately 90% of global trade is carried out by ship. According to an IMO report (2009), international shipping is responsible for 2.7% of global carbon dioxide (CO2) emissions. The figure below details the CO2 emission rates per sector as processed and calculated in the 2009 IMO report.

The emission of pollutants into the atmosphere during maritime transport is exacerbating the EU's gas quality problems. The main consequences begin with human health and spread beyond coastal areas. According to the EU's 2005 Thematic Strategy on Air Pollution, sulfur emissions from ships are expected to exceed emissions from all land-based sources by 2020. As a result, an action plan with the primary goals of protecting human health on the one hand and environmental protection on the other.

Because of the multifaceted nature of the shipping industry, the Commission proceeded to implement the necessary action measures within the framework of the IMO (International Maritime Organization) to reduce pollutant emissions from ships. As a result, the co-legislators have repeatedly emphasized the importance of taking the necessary steps, approving the most recent amendment to Directive 19999/32/EC on the sulfur content of certain liquid fuels, which regulates the degree of quality of fuels used by ships in EU maritime areas and ports (COM., 2011/441).

2.2 Where do we Stand Today

The development and implementation of efficient, environmentally friendly solutions is a critical step for the shipping industry. The technologically developed standards address carbon dioxide emissions, as well as nitrogen and sulfur oxides. The IMO strategy establishes some lofty goals, such as phasing out greenhouse gas emissions. Its immediate plans include cutting greenhouse gas emissions by up to 50% by 2050 in comparison to 2008 (ICS, 2019).

As a result, the methods for reducing carbon dioxide emissions are divided into three major shipping axes. First, they include the ship's technological component in the sense that they accept changes to the hull, propeller, and engine. The hull modifications are intended to reduce the resistance created by the ship's movement. The forces generated are based on the friction between the hull and the water, the waves generated, and the eddies at the ship's stern. When the hull of a ship is improved (especially in small ships), the water resistance decreases and thus the fuel consumption decreases. This reduction is estimated to be around 9% (Karageorgos, 2015).

Furthermore, lubricating the ship with air is an equally effective solution, as the use of air bubbles reduces the resistance of the ship's hull and the sea water. It is worth noting that this system is suitable for use on new ships with a minimum length of 225 meters. This method is expected to reduce carbon emissions by 10-15% (Karageorgos, 2015).

Improvements to the ship's propeller to create and achieve hydrodynamic design are another way to reduce carbon emissions. The degree of efficiency of the propeller is achieved by increasing the diameter of the blades while decreasing the revolutions per minute. In terms of functionality, lowering the ship's speed, lowering its resistance, and generally improving the voyage reduces carbon dioxide emissions. It has been discovered that sailing at slower speeds consumes less fuel. More specifically, it is reported that every 10% reduction in speed reduces fuel consumption by 19% per tonne-kilometer. Another method is to optimize the ship's behavior by distributing load and ballast properly. In this case, the reduction is expected to be between 0.5% and 2%. To reduce SO2 emissions, low sulfur fuel must be used. Alternative methods for reducing emissions include appropriate technology (the use of scrubbers), alternative fuels, and land-based energy.

2.3 Decarbonizing Shipping – the Global Challenge

Every day, people are affected by climate change and global warming through extreme weather, rising sea levels, and altered seasonal patterns. Human health is being harmed by deteriorating food security, rising demand for safe drinking water, and large population movements in search of safety. The combustion of fossil fuels emits carbon dioxide, a "greenhouse gas," at an all-time high, hastening climate change. Everyone came together in 2016 to take action. 196 countries signed the Paris Agreement at the United Nations Framework Convention on Climate Change. It committed nearly every country, including the top carbon emitters, to keeping global warming well below 2 degrees Celsius above pre-industrial levels this century. It also committed signatories to continue efforts to limit temperature increases to 1.5 degrees Celsius. The agreement supports the transition of economies away from the use of fossil-based fuels and toward alternative energy sources and technologies (IMO, 2022).

The shipping industry is vital to the global economy. According to the United Nations Conference on Trade and Development (UNCTAD), it transports nearly 80% of global commerce volume, making it by far the most efficient mode of freight transportation. However, as the industry grows, so does the amount of carbon emissions produced by shipping. To usher in a new era, a set of doable, practical steps that could end the impasse and accelerate decarbonization can be taken today. Cooperation across the shipping ecosystem, within the shipping industry, and with other industries is required to achieve this (IMO, 2022).

Shipping is responsible for 2.9% of global man-made carbon dioxide emissions, according to a 2020 report by the International Maritime Organization (IMO). It was discovered that shipping emissions increased by 10% between 2012 and 2018. The International Maritime Organization (IMO) had already set a lofty goal of reducing greenhouse gas emissions from shipping by 100% by 2050. According to Lloyd's Register research, a 50% reduction in absolute emissions equates to an 85% reduction in operating CO_2 intensity. To account for the increased number of ships and activity in the coming years, ships will need to reduce their carbon dioxide emissions by 85% per nautical mile. The maritime industry is facing a difficult situation (IMO, 2022).

2.4 2018 International Maritime Organization

In an effort to reduce emissions from international shipping, the International Maritime Organization (IMO) released its Initial Greenhouse Gas Strategy in 2018. The strategy aims to reduce absolute GHG emissions by at least half of what they were in 2008 by 2050, and then completely eliminate them. It also aims to reduce the carbon intensity of international shipping by at least 40% by 2030 and 70% by 2050 compared to 2008. To achieve these goals, the IMO has established short-term (approved in 2020), medium-term (between 2023 and 2030), and long-term (after 2030) measures (IMO, 2022).

2.5 2020 International Maritime Organization

IMO member countries approved a set of short-term measures in 2020 in order to meet the target of reducing carbon intensity by 40% by 2030. The adopted measures include mandatory goal-based operational and technical requirements. The technical specifications are based on the new Energy Efficiency Existing Ship Index. Starting in 2023, specific energy efficiency targets based on ship type and size will be applied to the existing vessel fleet. This metric is based on the same logic as the Energy Efficiency Design Index, but it applies efficiency improvement targets to the entire fleet rather than just new build ships.

Meanwhile, operational requirements are based on a Carbon Intensity Indicator (CII), which calculates the amount of CO2 emitted per ton of cargo and nautical mile. Each vessel will be assessed against a baseline CII, which will become more stringent over time. Some countries and shipping companies have publicly stated that the approved short-term measures are insufficiently ambitious. While some countries are now demanding that negotiations on medium- and long-term market-based measures begin immediately, others are opposing this proposal. While not challenging the IMO's jurisdiction or authority, some regions have begun to develop their own shipping emission regulations (IMO, 2022).

2.6 Shipping Emissions by 2035 (IMO)

The IMO's newly approved technical and operational measures are insufficient to reduce GHG emissions from international shipping in the long run. The short-term measures call for an average annual efficiency improvement of nearly 2% in the global vessel fleet (as measured by emissions per tonne-kilometer) between 2020 and 2030. This is only marginally better than the historical average annual improvement rate of 1.6% from 2000 to 2017. To put international shipping on the Net Zero Emissions path by 2030, average annual improvements of more than 4% are required (IMO, 2022).

2.7 Shipping Emissions by 2050 (IMO)

According to the IMO, maritime trade could increase by 40% to 115% by 2050 compared to 2020 levels. Fossil fuels meet approximately 99% of the international shipping sector's energy demand, with fuel oil and marine gas oil accounting for up to 95% of total demand (IMO, 2020a). According to the IMO, if effective mitigation policies are not implemented, GHG emissions associated with the shipping sector could increase by 50 percent to 250 percent by 2050. As previously stated, the IMO's broad range reflects the sector's uncertainty over the next 30 years, but even the lower band increase would undermine efforts to limit global warming. To reduce the level of risk, it is critical to plan ahead of time and analyze pathways to decarbonize the international shipping sector by 2050 (IMO, 2022).

3rd Chapter – Measures to Reach Decarbonization and the Meaning and Characteristics of Green Shipping in Maritime Industry

3.1 Technological Measures to Research Decarbonization

3.1.1 The Use of Scrubbers

The Scrubber system is an air pollution control device. Its application is to remove particles and gases from industrial exhaust gases. Scrubber, which means cleaner in Greek, refers to a device that controls pollution in the shipping industry. The extent to which ship engines determine gaseous pollutants is an issue that requires more attention because it affects both the technical maritime aspect and the social aspect in terms of impacts. Walker (2019) categorizes NOX pollution reduction technologies as follows:

- Primary methods (from within the cylinder)
- Secondary methods (treatment of exhaust gases)

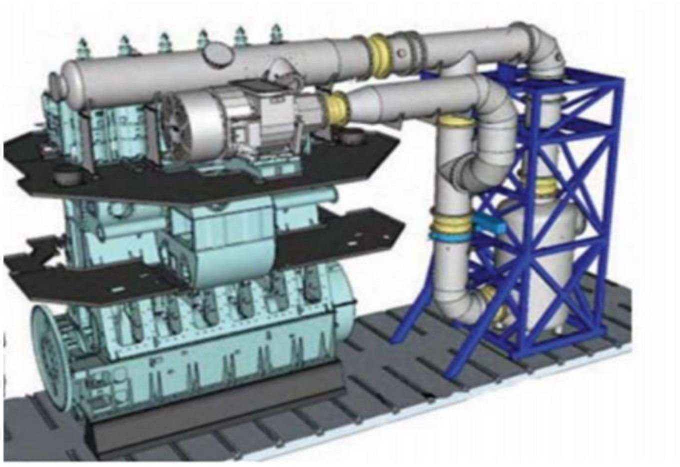
Lowering the average combustion temperature slows NOX generation in the primary process sector. The fuel injection delay is required to limit the maximum combustion temperature not only in magnitude but also in duration. The infusion rate must be increased to compensate for the increase in consumption. As a result, the duration of combustion is reduced. The primary reason for increased compression is to prevent ignition quality degradation. Furthermore, the thermal stress of valves due to potential flue gas temperature rise must be considered. Cooling the charge lowers the maximum temperature of the flame as well as the temperature of the cylinder ends. As a result, the gases in these areas are not hot enough to contribute significantly to NOx production.

Picture No.1: Scrubber system in a 2-X engine (Source – Kirtatos, 2010)

EGR (exhaust gas recirculation) works in a variety of ways. Because exhaust gases have a greater heat capacity than charge air, they trap heat and lower the average combustion temperature. At the same time, they contain less oxygen and have a slower burning rate. To avoid impairing the volumetric efficiency of the engine, the exhaust gas must be cooled in this type of exhaust gas circulation. Furthermore, to reduce compressor pollution, the recirculated exhaust gases must be cleaned either dry through a filter or wet through a filter (Karageorgos, 2015).

Picture No.2 - Exhaust gas feedback system - EGR in 2-X engine - (Source: Kyrtatos, 2010)

The corresponding attention that must be given in the course of this process to addressing the problem of corrosion from sulfuric acid produced in the cooled exhaust gas of the EGR loop from sulfur in the fuel, as well as the issue of dealing with acidic wash water, should not be overlooked. Of interest is pseudo-recycling, which consists in removing exhaust gases from the cylinder during a closed cycle through a special valve. It is worth noting that nitrogen oxides produced in the cylinder can be reduced by using ammonia.



Picture No.3 - Experimental scrubber unit on a 2-X engine – (Source: Kyrtatos, 2010)

Secondary methods used by thermal power plants to reduce NOX include catalytic reduction of exhaust gases. Scrubber applications of this type have been installed on a total of 500 ships. The catalyst system is quite large and quite costly. However, the most significant advantage is that it can reduce NOx emissions by up to 98%. Engine monitoring and control systems for marine engines are now widely used. The dominant issue is their respective management, as well as their necessary maintenance based on predetermined standards (Kyrtatos, 2010).

3.1.2 The Renewable Energy Sources

Alternative fuels have previously been used in the transportation sector. The process of converting coal, biomass, and natural gas into liquefied fuels began in the 1920s. The Germans Fisher & Tropsch invented the current process, which became known as Fisher - Tropsch. Its use was especially important during World War II for the production of liquid fuels from coal, as well as in South Africa during the 1970s and 1980s oil embargo (Walker, 2019).

Of course, green renewable energies are still in their infancy in today's world. The use of biofuels, fuel cells, wind and solar energy will then be investigated. Finally, it is worth noting that all washing machines are classified into two types:

Liquid cleaners, which are classified into the following categories:

Sulfur oxide cleaners - This system is in charge of cleaning the exhaust gases produced by the main engine. It is installed at the engine's exhaust outlet. The amount of water used during the wash is followed by the removal of the water.

Nitrogen oxide neutralization systems - Exhaust gas recirculation, as previously stated, aims to reduce nitrogen oxides from the engine. More specifically, the cleaning system redistributes all exhaust gases by mixing in clean combustion air, lowering the oxygen content and increasing the heat capacity of the combustion gas.

Idle gas scrubbers - The inert exhaust gas is designed to remove sulfur oxides and suspended particles (PM). It essentially replaces natural gas or liquid in its tanks and pipelines with natural gas.

Dry type washers - These cleaning systems are used to completely remove sulfur from exhaust gases. The primary ingredient is limestone, which is used as a cleaning agent (Kyrtatos, 2010).

3.1.3 The Use of Biofuels

The shipping industry's primary goal in using biofuels is to reduce environmental impact while improving efficiency and effectiveness in its transportation sector. Biofuels are an important solution that will have a significant impact on reducing carbon dioxide emissions during ship propulsion. In more detail, they are a method that yields less energy and in a different way depending on the type of biofuel ().

Solid biomass is the most common and widely used type of biofuel in the energy industry. Companies in the shipping industry use a significant amount of liquid biomass. Biofuels contribute significantly to the reduction of greenhouse gas emissions, lowering the risk of marine pollution in the event of a spill. Biofuels are also characterized as versatile because they can be blended with conventional fossil fuels in internal combustion engines. In addition, biogas production can be used to replace liquefied natural gas. Biofuels ensure that the required volume of production is met. Those derived from algae appear to be more effective, and their application process consumes a significant amount of carbon dioxide. Their experiments began on large vessels, and the results were promising. However, they are expected to play an important role by 2030 if a satisfactory level of sustainability can be developed at an affordable price (Dulebenets, 2018).

3.1.4 The Use of Nuclear Energy

Along with the use of biofuels, an attempt is being made to discuss the potential use of nuclear energy during ship propulsion. Of course, the use of such an application may result in additional issues relating to the legal issues of the ports that host such ships. Nuclear power is a contentious technological method that, depending on technological advancements and social acceptance, may be used by shipping. The International Atomic Energy Agency defines nuclear material. Although it is regarded as an imprecise alternative for sustainable development due to restrictive conditions, its use has the advantage of contributing to the reduction of greenhouse gas emissions. Large ships can be propelled by nuclear power (Karageorgos, 2015).

3.1.5 The Use of Fuels Cells

The novel application of fuel cells is still in its early stages. The use of fuel cells has the potential to reduce fuel consumption while also slowing emissions of gaseous pollutants. Furthermore, it has the potential to reduce noise from sound as well as ship maintenance costs. Their technology has a low carbon footprint while lowering investment costs and increasing capital efficiency. Fuel cells are made up of two parts:

- The first part contains fuel
- The second part contains gas

The efficiency of fuel cells stems from their ability to convert the chemical energy of fuel into electricity.

3.1.6 The Production and Use of the Electrical Energy

Recent advances in ship electrification hold great promise for more efficient energy use. Renewable energy can be used to generate electricity to power ships. Electricity in ships has the potential to improve energy management and fuel efficiency. Conventional power plants can be used if renewable energy from the sun or wind is not available to generate electricity on land. Emissions of greenhouse gases and other pollutants will still occur in this case, but they can be reduced through exhaust gas cleaning systems. When using electricity to propel ships, energy storage mechanisms are essential. Engine propulsion systems for smaller ships are already in development, while engine manufacturers are focusing on the hybrid battery format for larger ships. After 2020, there will be a significant increase in hybrid ships (Fakiolas, 2021).

3.1.7 The Wind Energy

Wind energy is one of the most important renewable energy sources because it has no environmental impact and emits no greenhouse gases. The most common type is sailing boats, which travel solely with the assistance of the wind (Fakiolas, 2021).

3.1.8 The Solar Energy

The use of solar energy reduces energy consumption, significantly improving the competitiveness of a conventional ship. Solar devices are placed on the decks of ships to collect sunlight during the application of solar energy. Solar energy applications are typically performed on pleasure boats, significantly reducing fuel consumption. Due to the complexity of technology, the implementation of any alternative and renewable energy source is slow. Because of the uncertainty surrounding the development of appropriate infrastructure, new energy carriers have been launched and are being used initially on short-haul ships. Each new fuel can be used in larger ships as technology matures and infrastructure begins and develops. Renewable energy sources will continue to expand in marine applications. However, as the effects of climate change worsen, more reductions in greenhouse gas emissions will be required, making the implementation of such technologies even more urgent (Walker, 2019).

3.2 Operational Measures to Reach Decarbonization

3.2.1 Definition and Utility of Green Shipping

Before discussing green shipping, it is useful to define the terms pollution and environmental pollution as they are defined. The Greek Law 1650/1986 on Environmental Protection defines specific types of environmental damage as follows (Law 1650/1986):

1. Pollution is the presence in the environment of pollutants, i.e. any type of substance, noise, radiation or other forms of energy, in quantity, concentration or duration that can cause negative effects on health, living organisms and ecosystems or material damage, and in general to conquer the environment unsuitable for its desired uses.

2. Environmental pollution is a special type of pollution characterized by the existence of high concentrations of pathogenic microorganisms or sediments in the environment. Pollution refers to any harmful effect on the environment and therefore can be considered as an infringement of the right to the environment, i.e. a destructive intervention that affects the global ecosystem. Harming the environment essentially means altering the natural elements, namely air, land and sea, through human activity.

Environmental pollution can be classified as atmospheric, thermal, sound, nuclear, visual, solid waste, or water pollution (Alexopoulou, Fournaraki 2015). Because of its effects on basic biological factors that govern life on our planet, sea pollution has become one of the most dangerous forms of environmental pollution in our time. Sea pollution occurs in a variety of ways and from a variety of sources, and it is either unintentional or the result of human error.

Although the importance of shipping in people's lives was discussed at the outset, it is an important source of air pollutants that have negative effects not only on the ecosystem but also on citizens' lives in the long run. Carbon dioxide (CO_2) is thought to contribute significantly to climate change, whereas particulate matter (PM), oxides of nitrogen (NO_x), and sulfur oxide (SO_x) have serious implications for public health. The release of sulfur into the atmosphere, for example, in the form of SO_x, is responsible for the effects of acid rain and the secondary formation of particulate matter. It is also harmful to the respiratory system, particularly in asthmatics.

The prevention of ship-generated air pollution is included in Annex VI of the MARPOL4 Convention, which was adopted in 1997 and covers the successive reduction of pollutant emissions with continuous renewals. A recent renewal of Convention VI documents the decision to reduce the sulfur content by weight of marine fuels from 3.5% to 0.5%, which has been in effect since January 1, 2020 (Walker, 2019).

This will significantly reduce the amount of sulfur oxides emitted by ships, resulting in significant health and environmental benefits, particularly for populations living near ports and coasts. According to a related study on the effects of SO x emissions from ships on human health (IMO's 6MEPC 2016), if the SOx limit for ships is not reduced by 2020, air pollution from ships will contribute to more than 570,000 premature deaths worldwide between 2020 and 2025.

This reduction is expected to result in significant reductions in strokes, bronchial asthma, cardiovascular disease, lung cancer, and lung disease. Reduced sulfur emissions also help to prevent acid rain, which means less damage to crops, forests, and aquatic life, as well as addressing ocean acidification. Furthermore, as of March 1, a transport ban is in effect, which prohibits the transport of non-compliant fuel oil for burning or operation on board unless the ship has a scrubber installed. (This does not apply to cargo oil). However, as of January 1, 2015, the maximum allowed content in SOx Emission Control Areas (SECA) is 0.1%. These areas are the Baltic Sea, the North Sea, the North American region, and the Caribbean region of the United States (IMO 2020).

The implementation of the new regulations affects not only the oil processing industry, but also shipowners, because lighter fuels with lower sulfur content incur additional costs when compared to residual fuels. As a result of this additional financial burden, ship owners are looking for ways to save money or even make more money. As a result of their search for new processes that will benefit their bottom line, ship owners are increasingly turning to environmentally friendly solutions. However, the benefits of this shift include not only financial and environmental benefits for shipowners, but also the creation of new jobs as the industry expands globally.

3.2.2 Methods and Difficulties of Green Shipping Application in Maritime Industry

For the reasons stated above, it is clear that green shipping must be implemented. The alternatives are to use compatible fuels, biofuels, or detergents. Some methods for its application are already known in the field, and are detailed below. For marine engines, the following novel categories have been proposed:

1. Use of two types of fuel

2. Fueling an engine with LNG fuel

3. Mixing water and fuel

4. Specially designed filters for filtering exhaust gases (Scrubbers)

5. Electrification of ships from land

6. Electric Propulsion

Regarding the proposals for renewable energy sources, they are the following:

7. Biofuels

8. Fuel cell

9. Wind energy

10. Solar energy

Some of the above are in the planning stages, but it is only a matter of time before they are put into action. Finally, in order to reduce fuel consumption and, thus, costs, the IMO (International Maritime Organization) has proposed the following category breakdown for marine engines:

1. <u>Use of two types of fuel</u>

This category includes commercially available technologies that replace traditional forms of propulsion (ship movement). Its use results in a reduction in nitrogen oxides (NOx), allowing it to meet IMO (Regulation 13) requirements. LNG is commonly used in dual fuel engines in conjunction with Marine Diesel Oil (MDO), biofuels, or Heavy Fuel Oil (HFO). The ability to switch the use of fuel during operation without affecting performance is a key advantage and characteristic of these engines (Mohsenietal, 2019).

2. <u>Fueling an engine with LNG fuel</u>

LNG is the purest form of natural gas, containing 98% methane, and is often used interchangeably with methane. It is a safe, practical, and sustainable fuel for the shipping industry, derived from cooling natural gas to a temperature of -162°C at atmospheric pressure. LNG demand is expected to rise in the coming years as it supports the full implementation of MARPOL ANNEX VI to prevent ship-borne air pollution. Furthermore, it is a cost-effective option not only for environmental reasons but also for fuel savings. According to the Naftemporiki newspaper, using LNG instead of diesel reduces carbon dioxide (CO_2) emissions by 25-30%, nitrogen oxides (NOx) emissions by 80%, and sulfur oxides (SOx) and particulates by 99% (EL.I.N.T Hellenic Institute of Maritime Technology).

However, concerns about the complexity of converting old ships, the high cost of building new ones, and market availability due to previously insufficient infrastructure persist. As a result, in order to achieve the goal of uninterrupted maritime transport at the lowest possible environmental cost, gradual steps are being taken with the goal of creating a sustainable supply chain, addressing pricing policy issues, and assisting ship owners in the process of converting ships into moving ships with LNG.

Finally, according to a SEA/LNG report, 93 ports around the world have already developed infrastructure for refueling ships, with 54 receiving significant investment. According to available data, there are 175 LNG-powered vessels in service, with another 203 on order. In June 2019, the corresponding figures were 163 and 155. At the same time, there were 6 LNG Bunkering vessels worldwide at the start of 2019, which has now increased to 12, with another 27 ordered or under construction (Bardounias, 2020).

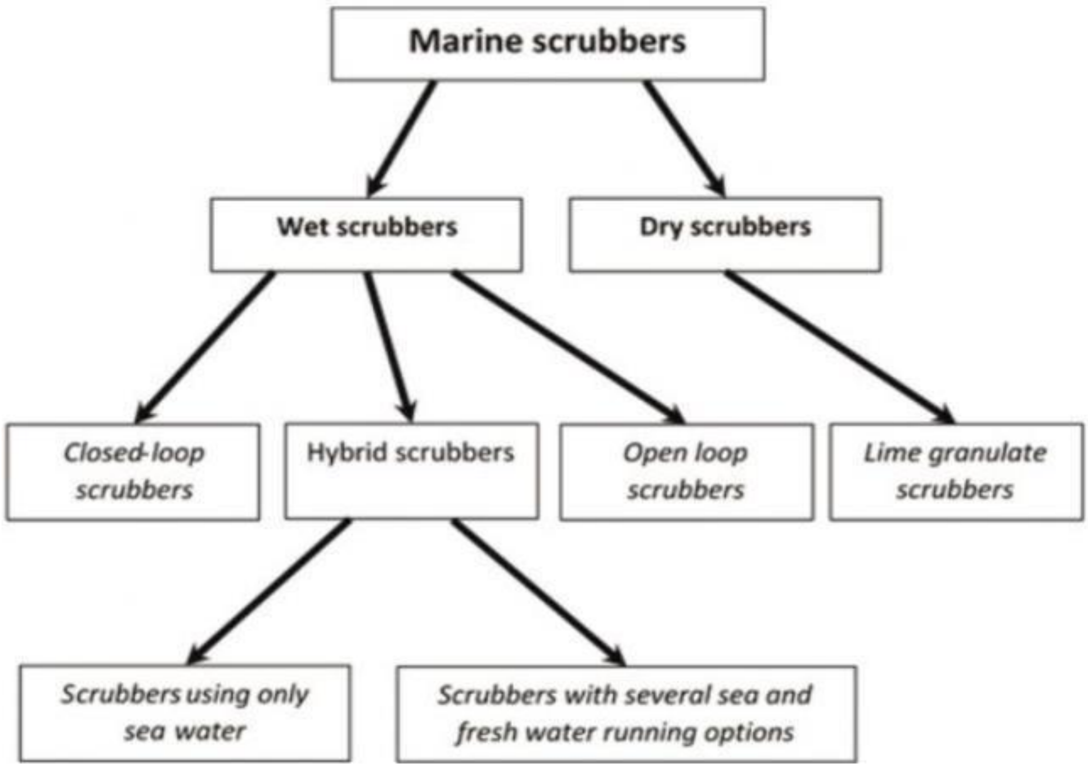
3. <u>Mixing water and fuel</u>

The formation of nitrogen dioxide occurs at the extremely high temperatures produced during combustion. Adding water to the fuel is one way to limit their formation. Water evaporates during the combustion process, limiting the formation of nitrogen dioxide. A reduction of up to 30-35% has been observed, while carbon dioxide levels have increased by 1-2%. When combined with superchargers, the use of water in fuel has the added benefit of lowering consumption. However, changes to both engines and auxiliary systems are required to make this process feasible and efficient (European Marine Equipment Council 2010).

4. <u>Specially designed filters for filtering exhaust gases (Scrubbers)</u>

Shipping companies, as mentioned earlier in the chapter, will be required to comply with the new regulation (IMO 2020) and implement the recommended changes. One of the changes that companies are required to implement is the installation of scrubbers on ships, i.e. the installation of an exhaust gas cleaning system. Scrubbers are an alternative to using high sulfur fuels. Scrubbers, in essence, control and prevent air pollution by preventing the release of harmful pollutant particles into it via exhaust gases. Scrubber installation on any ship does not require engine changes, but the process is complicated and requires repairs.

Despite the high initial investment, the cost is amortized due to the use of low-cost fuels. Scrubbers are classified as wet or dry based on their function. Quicklime is used as an alkaline scrubbing material in dry scrubbers to remove sulfur dioxide from flue gas. Liquids, on the other hand, use sprayed water for the same reason. Closed and open loop liquid scrubbers, as well as hybrids, are the different types of liquid scrubbers. Fresh or sea water can be used as cleaning liquid in closed cleaning loops, while sewage is stored in special tanks inside the ship and discharged at ports. Open loop scrubbers consume seawater during the scrubbing process and discharge waste water into the sea. Depending on the sailing sector, hybrids provide the option of open or closed sails (Priebe 2020).



(Sethi 2020).

Diagram No.1- Classification of marine scrubbers.

In more details, are mentioned the following:

<u>Liquid scrubber</u>: When used, exhaust gases are routed through an area that is sprayed with water, causing polluting gases and particles to dissolve or be channeled into it. In

addition to water, other chemicals can be added that are specifically designed to react to specific atmospheric pollutants - acid gases. Sodium hydroxide (NaOH) and limestone ($CaCO_3$) are the most commonly used additives. This process introduces a significant amount of steam into the exhaust gases, causing them to be released and emit white smoke into the atmosphere. A typical scrubber is made up of ducts and a fan system that pushes gas through its chambers. There is also a spent liquid pump and collection area, as well as some method for removing the spent liquid from the purified gas. Because of its chemical composition, this liquid cannot be simply discarded or reused. After passing through a separator to remove any sludge, it is discharged into the open sea, and the cleaned gases exit the system. According to MARPOL regulations, used wash water must be monitored before discharge to ensure that the PH value is not too low. There are advantages and disadvantages to using a liquid cleaner. Of course, one of the benefits is that the purpose of their use prevents the emission of pollutants into the atmosphere to a large extent. Furthermore, the cleaner is resistant to a wide range of temperatures, allowing it to work in any environment. The need for frequent maintenance, however, is a disadvantage because it can suffer from severe corrosion. However, with proper preservation and ventilation, it can be used for years before it needs to be replaced (Afework et al. 2018).

Dry cleaner: One reason for the development of dry cleaning was that the sprayed water added significant weight and bulk to the waste, making storage and disposal difficult. A mixture of dry reagents is sprayed at high speeds into an exhaust gas stream during operation. Depending on the material being removed, these chemicals react differently. Some of them use a chemical reaction to neutralize harmful pollutants in the stream, while others cause a material to react and change into a different substance. This substance is then removed from the gas stream or captured in a particle "canvas" separator. In the case of dry cleaning, an advantage is the removal of hazardous substances from exhaust gases, which prevents a large number of polluting substances from escaping into the air. Another advantage is that they produce less waste than liquids, which is why they are more commonly used. Finally, using dry cleaners is less expensive because there is no cost to remove, transport, and store wet cleaner waste water. The residual dust, which must be disposed of because it is a hazardous material, is a disadvantage. Because of their chemical composition, these wastes must be treated by specialists. Another disadvantage is the high cost of cleaning (Afework et al. 2018).

Open-loop scrubber: Uses seawater as a cleaning and neutralizing agent, while no other materials are required for gas desulfurization. The system is highly efficient, but the amount of seawater required necessitates a large pumping capacity. When the seawater used for cleaning is alkaline enough, the system works well. However, seawater at high ambient temperatures, fresh water, or even brackish water (the result of mixing fresh water and seawater) are ineffective and cannot be used. As a result, the open cleaning system is not recommended for use in areas with low salinity levels, such as the Baltic. This system has the advantage of not requiring waste storage, as well as requiring much less maintenance aside from pollution prevention and operation controls. The issue with open-type scrubbers is that, according to scientific studies, the wastewater may pollute the environment by raising the pH of the water. Furthermore, a large volume of seawater is required for effective cleaning, so the system consumes a lot of power. Finally, in ECA zones and ports, higher-cost fuels must be consumed (Sethi 2020). However, many ports around the world have banned the use of open-loop scrubbers, with Malaysia and Panama being the most recent.

Closed loop washer: Uses fresh, chemically treated water instead of seawater as a cleaning agent. Sulfur oxides (SOX) from the exhaust gas stream are converted to the non-hazardous sodium sulfate. The water used for washing passes through a tank where it is cleaned before being recycled. Ships can carry fresh water in tanks or generate it on board using fresh water generators. A closed-loop system uses nearly half as much water as an open-loop system, but requires more tanks, such as a process or isolation tank, a containment tank through which discharge into the sea is prohibited, and a storage tank capable of regulating the temperature of sodium hydroxide, which is usually used as a 50% aqueous solution.

5. Electrification of ships from land

Aside from the use of green fuels, renewable sources, and scrubbers, the use of electricity for ship movement has already been explored. The electrification of ships from land, also known as Cold Ironing around the world, is the process of providing electrical power to a ship at anchor while the main and auxiliary engines are turned off. During Cold Ironing, the ship's engines are turned off while it connects to a shore power source. Using this method, emergency equipment, cooling, heating, lighting, and other equipment receive continuous power while the ship is loading or unloading cargo without disrupting on-board services.

In fact, Cold Ironing is a shipping industry term that first appeared when all ships used carbon engines. When a ship was docked, there was no need to keep feeding the fire, so the iron gradually cooled, hence the term Cold Ironing (Kohli 2009). The electrification method reduces harmful emissions from diesel engines by connecting the ship to a more environmentally friendly source of electricity. Shore power can come from a power company's grid, but it could also come from an external, remote grid generator. These generators can run on diesel or renewable energy sources like wind, water, or solar energy.

Cold ironing primarily benefits society and the environment. Air quality is significantly improved as a result of reduced CO_2 emissions. Cold Ironing, in addition to limited editions,

1. Lowers noise pollution
2. Provides ship owners and customers with a green profile
3. Lowers life cycle costs by reducing fuel consumption and maintenance costs.

Despite the undeniable environmental benefits, cold ironing is a difficult process. As a result, the requirements it necessitates are quite "challenging" and may pose obstacles to the implementation of such a process. As an example:

• Port electrical infrastructure must be suitable for all types of ports.

• The necessary electrical infrastructure on ships, whether retrofitted or new.

• Connection and control solutions for ensuring personnel safety and uninterrupted power transfer

• Equipment to ensure that the load is automatically transferred from the ship's power plant to the shore source and back.

However, significant obstacles that arise during this process and should be known to those involved include, first and foremost, the high costs associated with the port electrical infrastructure of Cold Ironing, which is more expensive than a conventional terminal. Another impediment could be a lack of standardization, which leads to technical issues because not all ships have the same voltage and frequency requirements. Furthermore, the lack of legislation may be a factor in the use of this technology in a few European ports.

In conclusion, the Cold Ironing system aims to protect the environment, and many shipping industry experts believe that this system can be used by reducing polluting gases, reducing noise pollution, and lowering maintenance costs, which are the operating and cost advantages presented over the old type of diesel-powered ship. Although it has proven to be a highly efficient solution, it is not yet fully implemented in shipping due to safety concerns regarding the operation of fuel cells. The weight of cells, which is heavier than diesel engines in terms of producing equal power, is one of the issues that must be addressed during their use. However, there is a problem with the fact that, at least initially, ships using fuel cells will cost twice as much as conventional ships - which is understandable given that this is what happens when a technology is transitioned from an old to a new one.

Fuel cells generate electrical and thermal energy through an electrochemical reaction, which is essentially an electrolysis reaction between oxygen and hydrogen to create water. The anode, cathode, electrolyte, and external circuit are the four major components of a cell. The cathode sector is constantly supplied with air, while the anode sector is constantly supplied with fuel. In the anode sector, hydrogen is oxidized to electrons and protons, while in the cathode sector, oxygen is converted to oxygen ions, which react with the hydrogen ions to produce water. In turn, the electrolyte can take the form of a liquid or a solid. Its primary function is to bridge the anode and cathode, but it also separates the reactants in both areas of the cell. However, in the case of shipping, other fuels (e.g., natural gas, methanol, ethanol, etc.) can be used in addition to hydrogen. 2016 (Proukakis).

6. Wind energy

The use of wind energy to propel ships is not a new technology, though it has evolved significantly in recent years. Using the Magnus effect, German engineer Anton Flettner developed the idea in 1920 of placing giant rotating cylinders on the decks of a ship and rotating them, creating a pressure difference and converting it into energy to move the ship. The idea was not implemented at the time because it was too heavy and slowed down the ships. The cylinders are now much lighter in weight. Wind propulsion technologies are classified as follows:

• Hard Sail fixed sails combined with solar panels for additional propulsive power

• Flettner or Rotor Sails where cylinders are used, taking advantage of the Magnus effect

• Suction Wings a technology based on the Magnus effect but consisting of fixed suction wings

• Kites on the bow of the boat where a computer-controlled sail is placed so that with the force of the wind there is auxiliary propulsion and a reduction in fuel consumption

• Marine adapted A/C for the production of electricity or a combination of electricity and propulsion

• Hull Form the redesign of the boat's hull to achieve the greatest possible thrust from the force of the wind.

Wind propulsion has the potential to provide more than 50% of the required thrust for a vessel, according to research conducted by Lloyd's Register's Technical Research department on Bulk Carriers in various wind directions. It could save a typical bulk carrier up to 30% on fuel costs on a single trip under the right conditions (Zikou, Zafeiriadis 2018).

7. Solar energy – Photovoltaics

As you may have guessed, solar energy is the type of energy provided by the sun. The basic idea behind using solar energy is to immediately reduce fuel consumption and carbon dioxide emissions. Photovoltaic installation is the most recent and correct application of solar energy. A typical photovoltaic system includes the PV panel or solar power generator as well as the electronic systems that manage the electricity generated. There is also an energy storage system in batteries for autonomous systems. The following are the primary characteristics of PV that set it apart from other renewable energy sources:

• the direct production, even on a very small scale, of electricity

• can be extended at a later stage to cover the increased user needs, without making any changes to the original system

• their operation is silent, and they also emit zero pollutants in the environment

• they have almost zero maintenance costs while their requirements are as well few

• there is reliability during their operation

Because of the rapid advancement of technology, photovoltaic cells are now available for use in maritime transport, with greater potential and prospects for their use in propulsion systems on ships. This is possible by placing specially shaped panels in open areas of the ship where they can be exposed to the sun. These, in turn, collect solar radiation and transfer it as heat to water, air, or some other fluid. Only on short trips has the application been able to use PV to charge battery systems, which in turn support rechargeable electric propulsion units. Primary limitations to their use in shipping are initially the lack of a large area - space for placing the panels on ships and then for the storage systems of the generated energy. However, it is worth mentioning that since the air, like the sun, is abundant and free, scientists still have a large part of research, so that their exploitation can be achieved to the fullest (KAPE 2020).

8. Charting more effective courses with the continued assistance of the WMO (World Meteorological Organization)

According to an IMO directive, governments have had since 1983 to propose routes that have previously been approved by the WMO (World Meteorological Organization). Ship owners notice a reduction in ship consumption by following the optimal route suggested to them (for distance and weather), sailing at the speed at which the ship should ideally move during the voyage. Weather forecasting systems are now installed on all ships, and the crew can receive timely weather forecasts both during their voyage and for subsequent voyages. They can also tell the difference between winds blowing in the opposite direction, which will increase their consumption, and winds blowing in the opposite direction, which will save them fuel. Finally, reducing port waiting times during loading and unloading can also significantly reduce CO2 emissions and increase port efficiency.

It is worth noting that, in addition to the methods of application, environmental awareness of those who operate these systems is an important factor in the development and preservation of green shipping. Environmental awareness can be developed primarily in schools through courses or seminars, as well as through training to combat shipping pollution.

4^{th} Chapter – Procedures and Projects for Decarbonization and Energy Efficiency in Shipping Industry

4.1 Plans and Projects for Commitment to Energy Efficiency

In 2011, the International Maritime Organization's committee for the protection of the marine environment, also known as the MEPC - Marine Environment Protection Committee, recognized and adopted a new chapter in the international convention MARPOL for the prevention of pollution from ships. The new chapter mentioned the intention of improving ship energy efficiency through performance standards, which will eventually lead to a reduction in emissions of gaseous pollutants derived from fossil fuels during the combustion process (Karageorgos, 2015).

4.1.1 SEEMP-Ship Energy Efficiency Monitor Plan

In October 2016, the International Maritime Organization's Committee for the Protection of the Marine Environment (MEPC 70 - see Annex 2) adopted guidelines for the development of a Ship Energy Efficiency Monitoring Plan (SEEMP) in ships owned by ship-owning companies. In more detail, it is a mechanism designed to improve energy efficiency on ships through the use of various monitoring tools and methods included in this plan. Depending on the company and the circumstances, it may be part of its safety management system (SMS - Safety Management System) or even its environmental management system (EMS - Environmental Management System) in accordance with the ISO 14001 standard, if such a system is available. SEEMP is divided into two parts based on the specifications. The 1st part deals with the approach to improving the ship's overall energy efficiency and the 2nd part lists the ways used to collect the data related to fuel consumption and the procedures followed to report all the data per ship to the competent body (Dulebenets, 2018).

The Energy Efficiency Operational Indicator (EEOI) is a common example of a monitoring tool that can be included in a company's energy efficiency monitoring plan. It is a supplementary indicator that can be used on both new and existing ships. The EEOC indicator is a tool provided by an International Maritime Organization circular (MEPC.1/Circ.684 - see Annex 1) that includes all of the guidelines for its use. The EEOI is calculated using information about the ships, the types of cargo and the quantities transported, the types of fuel and their specifications based on delivery notes, and the distance traveled over the same time period. The EEOI index can be expressed simply as follows (Dulebenets, 2018):

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

Picture No.4 - Basic EOEI calculation equation

The total mass of fuel consumed times the fuel factor associated with carbon dioxide emissions is added to the amount of cargo transported by the total distance traveled by the ship in the above equation. It expresses the amount of carbon dioxide emissions into the atmosphere per ton of cargo per mile as a result. Every monitoring tool, such as the EEOI index, is essentially an evaluation tool for businesses, as the results can influence how effective the plan is and indicate areas where corrective action is required. More generally, regarding the use of SEEMP, it is worth noting that this is a measure that has direct application and concerns the operation of the ship, reflecting the company's policy towards improving performance at the energy level and the global effort of the maritime community to reduce of carbon pollution from ships (Karageorgos, 2015).

4.1.2 EEDI- Energy Efficiency Design Index

Following the Kyoto Protocol as an international treaty, the International Maritime Organization's first legally binding tactic was the energy efficiency index on ships, which was endorsed in 2011 by the corresponding committee for the protection of the marine environment and incorporated into Annex VI of the MARPOL Convention. On ships, the EEDI index defines the use of more energy efficient equipment in order to reduce pollution. A fundamental requirement is a minimum limit of energy efficiency per mile and capacity (capacity mile) for various types of ships and size classes. Starting in 2013, phase zero began for the implementation of EEDI in which newly built ships must comply with the reference limit set for each type in terms of design. The reference limit is set in stricter frameworks gradually, with a review every five years and the use of the index in design continuously stimulates technological development and innovation in all levels that affect fuel efficiency (Fakiolas, 2021).

EEDI is a non-prescriptive index that measures design performance regardless of the technology used. This means that the shipping industry can select the most cost-effective method of designing a ship in order to meet the index's benchmark for that type. The design reference limit is defined by a mathematical formula that contains the design parameters for the specific ship and is a quantity that expresses the grams of carbon dioxide emissions per mile and tonnage (Walker, 2019).

With the end of the zero phase in 2013, the first phase took effect in 2015, requiring a 10% reduction in the existing EEDI index calculated for each ship. The reduction limits are reviewed every five years, and a 30% reduction rate of the index is established based on a reference value calculated from the average energy efficiency of ships built between 2000 and 2010. This index was created for ships in the global merchant shipping fleet with the greatest capacity and the greatest energy footprint. The following types of ships were originally included in this regime:

i. tankers,
ii. bulk carriers,
iii. gas carriers,
iv. general cargo ships,
v. container ships,
vi. refrigerated cargo carriers and combination carriers.

At the meeting of the International Maritime Organization committee in 2014, the application of the EEDI index was extended to the following types of ships: i) LNG carriers, ii) Ro – Ro cargo ships (vehicle carriers), iii) Ro – Ro passenger ships and iii) cruise passenger ships with non-conventional propulsion (Dulebenets, 2018).

4.1.3 DCS – Data Collection System

The International Maritime Organization's Committee on Environmental Protection (MEPC 67) unanimously agreed in 2014 to adopt and develop a data collection system for ships that includes data collection, an operational role for the flag state in the process, and the creation of a central database. In 2015, i.e. during the commission's conference the following year (MEPC 68), it was decided that the already established data collection system should work in such a way that the data collected, analyzed, and, by extension, the picture they present can determine whether or not additional measures to limit emissions are required. Finally, during the conference of the same committee in 2016 (MEPC 70), Annex VI of the MARPOL Convention was amended with regard to the collection of data on fuel consumption on board ships with effect from 1 March 2018 (Dulebenets, 2018).

According to these amendments, all ships (with a capacity of 5,000 GT or greater) and ship-owning companies are required to collect data on the consumption of each fuel used while on board or in port. The aggregate data covers the entire calendar year and is submitted to the ship's flag state for validation and confirmation that the specifications are followed. After the flag state validates that the procedure was followed and issues the relevant declaration of compliance with the applicable regulation, all data for the year per ship is transferred to the International Maritime Organization database, which is then requested to issue a relevant consolidated report to be submitted to the committee environmental protection (MEPC).

The new database created by the International Maritime Organization was integrated into the platform of GISIS (Global Integrated Shipping Information System), the global shipping information system, and is accessible to all member states. The data is managed confidentially and submitted to the platform only by the competent, authorized entities with permission from the platform administration. Regarding the time frame that has been set, the authorized bodies are invited to submit all the data of the calendar year up to the first five months of the following one so that the corresponding declaration can be issued per ship. In this way, the calculation of emissions in tons of carbon dioxide per year is based on real data based on the specific ships that are carried out (Fakiolas, 2021).

4.1.4 EEXI – Energy Efficiency Existing Ship Index

Additional amendments to Annex VI of the international convention MARPOL regarding the reduction of greenhouse gas emissions from ships were made during the 2021 conference of the International Maritime Organization's Committee for the Protection of the Marine Environment (MEPC 76). The proposals concern the improvement of energy efficiency on ships, which is approached from two perspectives: technical and operational.

A basic condition of the new measures is the calculation of the existing energy efficiency index (EEXI – Energy Efficiency Existing Ship Index) and the establishment and relative classification of an annual carbon intensity index (CII) for each ship. These new measures are categorized in the short-term tactics adopted by the International Maritime Organization in the context of achieving the goal of reducing carbon pollution by 40% by 2030. The specific amendments enter into force on November 1, 2022 and the certification for the new measures will be a requirement from 1 January 2023. The GVW index is a requirement that concerns all ships of 400 GT and above according to different parameters and size categories. It is an index that expresses carbon dioxide emissions per transport capacity with theoretical data (Karageorgos, 2015).

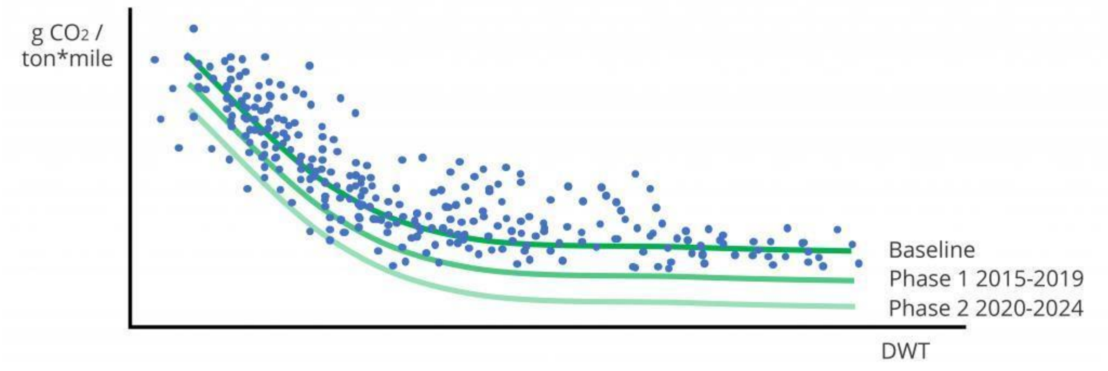
$$EEXI = \frac{CO_2 \ emissions}{Transportation \ work}$$

$$EEXI = \frac{Main\ engine\ emissions + Auxiliary\ engine\ emissions + (PTI\ - Innovative\ electrical\ energy\ technologies) - Innovative\ propulsion\ energy\ technologies}{Capacity\ * Reference\ speed\ * Reduction\ factors}$$

$$EEXI = \frac{(\prod_{j=1}^{n} f_j)(\sum_{i=1}^{nME} P_{ME(i)} C_{ME(i)} SFC_{ME(i)}) + (P_{AE} C_{AE} SFC_{AE}) + \left((\prod_{j=1}^{n} f_j \sum_{i=1}^{nPTI} P_{PTI(i)} - \sum_{i=1}^{neff} f_{eff(i)} P_{AEeff(i)}) C_{FAE} SFC_{AE}\right) - (\sum_{i=1}^{neff} f_{eff(i)} P_{eff(i)} C_{FME} SFC_{ME})}{Capacity\ V_{ref}\ f_i\ f_c\ f_l\ f_w\ f_m}$$

Picture No.5: Calculation Equation of EEHI

In practice, it is the same index as EEDI, but EEXI is an index that concerns existing ships and is one of the most notable measures of the International Maritime Organization to reduce shipping's carbon footprint. As the global fleet's energy efficiency improves, there is a threshold value that represents the maximum that the EEFI index is expected to approach. The desired outcome is for the index value to be less than this value. In practice, beginning in 2023, all existing ships must adhere to a certain emission limit per carrying capacity in order to stay below the critical curve.



Picture No.6: Limits of EEDI, EEXI indicators during phases 1,2.

Moving down the road to decarbonization with increasingly stringent specifications it is easy to understand that much of the world's aging fleet will not be able to keep up with the new regulations. In conclusion, the EICHI index affects the shipping industry from two different perspectives, both technical and commercial. From a technical point of view, shipowners and management companies are required to organize an action plan to install new, "clean" technologies on ships that will enable them to comply with the new regulations in order to remain operational (Fakiolas, 2021).

Simultaneously, having achieved compliance with current regulations, the prevailing uncertainty about what comes after 2023 is set to shake international charter markets, with charterers declining to invest in longer-term deals and shipowners being forced to reduce fare prices in order to close the deals. Finally, the entire shipping industry is attempting to forecast in the most efficient and profitable manner how such new regulations for existing fleets will affect operational and financial aspects.

Despite this, protecting the climate and eliminating the greenhouse effect continues to be the highest priority. Thus, the incorporation of regulations that concern only newly built ships (EEDI index) is not capable of bringing about the desired results in a short period of time as the renewal of the global fleet is gradual. By extension, it is imperative for the existence of indicators that also concern existing ships so that the interest around energy efficiency remains undiminished. EECHI is such an indicator – an incentive actively contributing to the decarbonization of shipping (Dulebenets, 2018).

4.1.5 CII – Carbon Intensity Indicator

As the goals set by the International Maritime Organization on the road to decarbonization are very ambitious, the entire maritime community must work on innovative solutions in order to conquer a sustainable future. Thus, during the conference of the committee of the International Maritime Organization for the protection of the marine environment (MEPC 76) it was decided that together with the EECI index which enters into force in 2023, another index is established to strengthen this effort, the intensity index carbon (CII – Carbon Intensity Indicator). While the EECI index is derived from how existing ships are equipped and designed, the CII index is an index based on how the ships operate. The carbon intensity index is an index based on the numerical calculation of an annual efficiency ratio (AER – Annual Efficiency Ratio) which is defined as the total amount of carbon dioxide emissions of a ship per year divided by the total transport capacity and distance traveled by the ship in the same year ( ).

$$AER = \frac{Annual\ CO_2\ emissions}{Deadweight \times Distance\ sailed} = \frac{\sum_j FC_j \times C_{Fj}}{DWT \times D} = \frac{g_{CO_2}}{DWT\ mile}$$

Picture No.7: Eq save AER Calculation

As previously stated, the International Maritime Organization has already established a data collection system that requires ship-owning companies to submit all data per ship related to fuel consumption at sea and in port, as well as the hours spent in each state and the distance traveled per trip, on an annual basis. As a result of having all of the data in the global shipping information system database, the annual AER efficiency index for all ships can be calculated.

Based on the results of the AER, ships are categorized into different tiers of the carbon intensity index, starting from 'A' and ending at 'E'. The "A" index makes the ship "green" - environmentally friendly, while the "E" index is the exact opposite, i.e. a high-risk polluter. The evaluation of the index is based on some initial thresholds that have been established, while these thresholds become more and more strict over time. The first period in which the index reduction factor of 5% will be set is 2023. At the same time, the criteria of the index are becoming more and more strict and the score received by the ship does not remain constant if over time, each company does not optimize the efficiency of its ships. Thus, the intensity index coal can start moving towards "E" if the energy performance of the ship remains stable compared to the previous period (Walker, 2019).

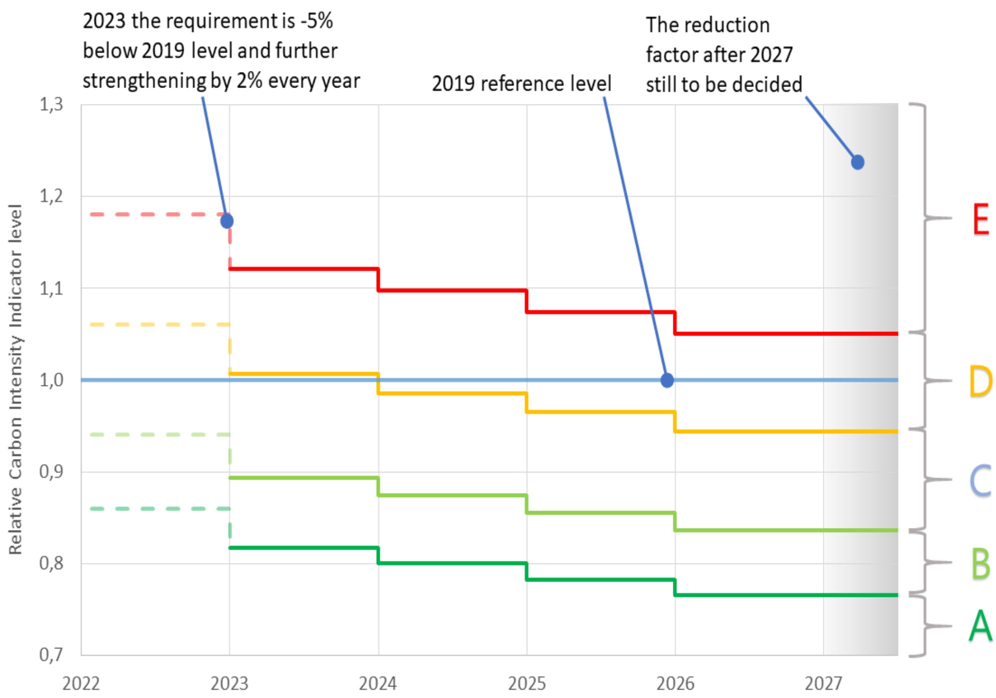


Diagram No.2 - Changes in CII Thresholds by Year

As a result, if a ship's carbon intensity index is "D" or "E" and remains constant over time, it means that the ship-owning company has not taken sufficient actions to comply with the regulation and, by extension, to combat climate change. As a result, it is being forced to restructure its energy efficiency plan to include the measures it will put in place to improve the carbon intensity index while also reducing carbon dioxide emissions from its ships. To meet the requirements of the regulation, a ship-owning company must understand that any action that reduces carbon dioxide emissions per annual distance traveled on the ships can also improve the ship's rating. The improvement may concern technical or functional aspects without further commitment as to how it will be chosen to be done (Karageorgos, 2015).

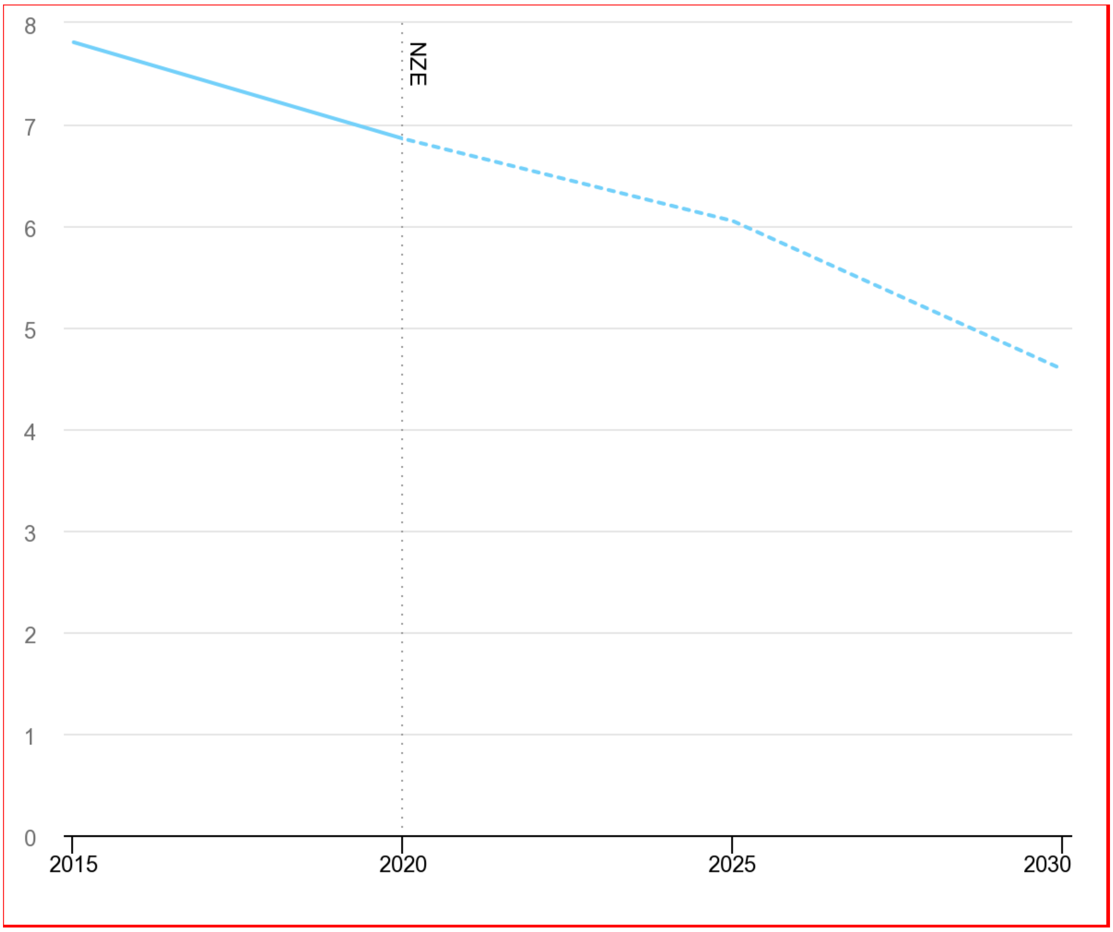


Diagram No.3 - Carbon footprint trajectory of international shipping during 2015 – 2030 (Source International Energy Agency)

In conclusion, the carbon intensity index is an index that evaluates carbon dioxide emissions from ships in a global way, i.e. taking into account all operating states of the ship and based on actual data every 24 hours for every day of a calendar year. As the ship continuously produces gaseous pollutants, the use of the carbon intensity index and caps in combination with the existing energy efficiency index enables a more accurate monitoring of carbon dioxide emissions from ships. Thus, the International Maritime Organization has a complete picture of the reduction of carbon dioxide emissions from the global merchant fleet and the simultaneous contribution of shipping to the effort to combat the greenhouse effect, within the framework of the strategy it has established as a result of the Paris Treaty (Fakiolas, 2021).

Finding and implementing optimal technologies to reduce carbon emissions from shipping is one of the most difficult challenges of our time. Following the Paris

Agreement, the International Maritime Organization has established aggressive targets for the shipping industry to combat the greenhouse effect. Reduced carbon emissions from ships are a non-negotiable process in which everyone is invited to participate and take action in the context of this campaign.

5th Chapter – Decarbonization Process of Marine Fuels and Ships Voyage Optimization

5.1 The Use of Appropriate Fuels for Decarbonization in Shipping

One of the most important decisions of ship-owning companies that affects the carbon emission rates of shipping, is the choice of the appropriate fuel. Nowadays, a suitable fuel is defined as the fuel that contributes to reducing the amount of emissions into the atmosphere from the combustion process and its use is in harmony with international standards. As it is very difficult to single out a single fuel as suitable to the exclusion of all others, companies are in a position to choose between different types (Karageorgos, 2015).

In light of the stricter regulations that will be gradually implemented over the next few decades, liquefied natural gas (LNG - Liquified Natural Gas) appears to be ahead of the other alternative fuels on the market. Nonetheless, the range of options includes low-sulfur fossil fuels, such as those already in use as of early 2020, as well as bioethanol, ammonia, and hydrogen, which are expected to be reduced to a promising solution in the coming decades. This is essentially an industry-wide energy transition that has already begun, with alternative fuels steadily gaining ground over conventional fuels over the last two years.

According to the International Energy Agency (IEA), the need for zero-carbon fuels is vital for the decarbonization of shipping. In practice, however, no low-carbon fuel is widely used in shipping today as biofuels are the only non-fossil option in operation, however, making up 0.1% of total energy consumption. According to the current policy framework, it is predicted that by 2030, low- and zero-carbon fuels will constitute only 2% of total energy consumption and will reach 5% by 2050. However, the zero-emission scenario predicts that it is imperative to achieve a percentage of 15% and 83% for 2030 and 2050 respectively (Walker, 2019). As already mentioned, natural gas is at the center of attention when it comes to the decarbonization of shipping through the use of alternative fuels. It is a fuel that is characterized by high reserves available in nature, low price, safe operation and low levels of greenhouse gas emissions during its combustion compared to oil.

Based on the benefits listed above, it has the potential to contribute to a 25% reduction in carbon dioxide emissions in the atmosphere without affecting ship efficiency, and when combined with combustion in an advanced technology engine, it has the potential to reduce carbon intensity in the atmosphere by 40% by 2030. Currently, a corresponding reduction is not feasible with existing fuels and technologies on the market, so natural gas appears to be the only sustainable fuel capable of meeting increasingly stringent regulatory requirements in the near future (Dulebenets, 2018).

Heading into the new carbon-free era, it is necessary to find additional types of fuel that can be applied to propel ships. Thus, under intensive research, the global community is considering four alternative fuels among which ship-owning companies can invest for use on their ships. It is now widely accepted that oil will be replaced by multiple fuels such as hydrogen, ammonia, methanol and biofuels. As they are all in an early stage of development there are only some general conclusions about them.

Biofuels are currently the most popular alternative fuel solution, with the potential to power approximately 30% of the world's fleet, primarily bulk carriers and container ships. These are renewable fuels made from biomass and vegetable oils as the primary component. They are considered carbon neutral because a portion of the carbon dioxide emitted during combustion was already absorbed during cultivation. Furthermore, they can be used directly without requiring modifications to the ships' existing engines, and the first tests have already begun since the beginning of 2020 (Karageorgos, 2015).

Ammonia is another option under study which, however, presents many black spots for now. Despite the fact that it is available in sufficient stocks, the way of refueling through suitable facilities and consumption through specially designed engines on ships, the toxic vapors emitted during its storage and the regulatory framework are points that still concern the scientific community. In addition, it is produced using a method that has a carbon footprint on the atmosphere, which affects the tendency for ships to use it.

The prospects for methanol and hydrogen use in ships are moving in the same direction. Concerns have been raised about their safety, as well as their low energy density, the high cost of storage, and the lack of refueling stations. They are inherently unsuitable for long-distance shipping due to the need for large amounts of fuel during the voyages. Dual fuel methanol engines, on the other hand, are a viable option.

In addition to studies around alternative fuels, the International Maritime Organization has already implemented new rules from January 1, 2020 for fuels with a limited sulfur content from 3.5% to 0.5%, as part of the campaign for the gradual decarbonization of shipping until 2050. This is a new category of fuel that includes a wide range of products, available in many parts of the world. The refining industry had the primary role in this process as it carried out the study and design for the new fuel production with a compatible composition for the existing marine engines. The use of these fuels remains active in the marine transport industry continuously to this day while the marine community's experience of their stability is gradually increasing with continued use, precautions and trial methods (Fakiolas, 2021).

At the same time, regardless of the scientific research surrounding alternative fuels, it is necessary to consider the need for the corresponding technological systems that will support propulsion with fuels other than oil. Despite the fact that ship-owning companies must invest billions of dollars each year to ensure a proper response to the new institutional framework, it is a given that fuel is the most important component of shipping operations and the most decisive factor in reducing carbon dioxide emissions.

5.2 Use of Ammonia as a Marine Fuel

Emitting zero CO2 during combustion, ammonia has long been regarded as one of the most promising alternative fuels for reducing greenhouse gas (GHG) emissions in the shipping industry, which is in line with the International Maritime Organization's (IMO) strategy for reduction of CO2 emissions by 2050. In particular, green ammonia has great potential as it is produced only from renewable sources of electricity, water and air without CO_2 emissions. There are also three categories of ammonia (Georgoulis, 2021):

A) Green ammonia: Carbon-free ammonia synthesized from carbon-free nitrogen and hydrogen produced from renewable energy sources.

B) Blue Ammonia: Carbon neutral ammonia produced from natural gas, with the CO_2 produced by the processes captured and prevented from entering the atmosphere

C) Brown ammonia: conventional ammonia produced from natural gas.

Ammonia has been identified as a zero-carbon fuel that can enter the global market quickly and contribute to the IMO's 2050 decarbonization target. Regardless of fuel source, ammonia provides ship owners and operators with a zero-carbon profile. Ammonia is typically formed by the combination of nitrogen and hydrogen atoms. As a result, emissions from the production of hydrogen as a feedstock, as well as emissions from ammonia synthesis, should be included in the ammonia fuel life cycle emissions. Ammonia, in its entirety, is less friendly to greenhouse gas (CO_2) emissions than pure hydrogen at the production stage, while it is just as friendly at the combustion stage.

Despite the toxicity and stringent handling requirements, ammonia engines have been developed in the past and today marine engines are currently being developed applying existing dual fuel (DF) technologies for ammonia. Designs for ammonia tankers were also presented by consortia involving designers, classifiers and shipyards. It has better emissions reductions than most other alternative fuels, such as natural gas, nuclear power and biomass. It is a globally available fuel and there are currently many smaller natural gas carriers that can support ammonia fueling services on ships. However, to make ammonia a commercially viable long-term fuel choice, comprehensive and vertically integrated supply-side infrastructure will need to be built and strict new safety regulations developed and enforced (Georgoulis, 2021).

Picture No.8: MOL plans an ammonia fuel supply ship Source: https://www.isalos.net/2022/01/i-mol-schediazei-ena-ploio-efodiasmou-kafsimou-ammonias/

Ammonia transport has an advantage over hydrogen transport in that it is liquid at room temperature, requiring less storage space. The cost of hydrogen transportation can be reduced by producing ammonia from hydrogen at the source, transporting the resulting ammonia, and then reforming back to hydrogen at the destination, but this requires more work to calculate.

Finance has long-term potential. Ammonia is a global commodity with transparent pricing, so there is already a market. Most of the current supply is "grey" ammonia, produced from hydrogen created from natural gas, which produces significant CO2 emissions. The aim of shipping is to produce "green" ammonia from renewable energy sources. Although this will be much more costly in the short term, prices should drop significantly as production scales up (Georgoulis, 2021).

There is already a global ammonia distribution system in place, but the fuel must be available in the right places and quantities. The existing ammonia transportation network connects industrial production and storage sites. It does not reach ports in such a way that ships can refuel. Outside of fleet operators, the general public's perception of ammonia will need to change before it can be used as a fuel. Because of the toxicity risks, port authorities and regulators are currently reluctant to allow ammonia bunkering, and public reaction to large-scale ammonia storage in ports has not been tested. While current regulations preclude the use of ammonia as a shipping fuel, taxonomists and other groups are working to assess the risk and provide guidance that will lead to new rules and standards.

While ammonia is not highly flammable, concentrations in air as low as 0.25% can cause death, making the fuel highly toxic to humans. Today's fuel oil residues and distillates (and even natural gas) all present lower risks than ammonia. Fuel systems must be designed, constructed, operated and maintained to ensure the safety of ships' crews, port personnel and fuel suppliers. Today's ships are built in standard configurations in which engines and fuel systems are often located in confined spaces on lower decks. Different ammonia requirements could change the layout of ships or even lead to a complete redesign. Ammonia handling on ships will require a whole new set of safety skills and procedures. There is a need to understand the potential negative impacts on human lives, water and soil in the event of a spill or accident, and how to mitigate these types of risks. A new safety pathway for ammonia uptake is therefore needed.

Fortunately, there is the option of using existing ammonia transport rules (Haskell, 2021). In addition, burning ammonia in engines produces nitrous oxide (N2 O), an even more potent greenhouse gas than CO2. As a result, additional equipment on board will be required to control NOx emissions. Overall, ammonia appears to be a promising alternative fuel with the potential to significantly reduce carbon emissions from shipping. Now, stakeholders in the industry must work together to develop and demonstrate the viability of practice solutions.

5.3 The Use of Hydrogen as a Marine Fuel

Of the various clean fuel alternatives currently being piloted, hydrogen is the clear leader. A World Maritime Forum study from March 2021 looked at 106 projects looking at zero emissions at sea and found that nearly half of those initiatives focused on hydrogen as a low-carbon fuel source. A key advantage of hydrogen over other alternative fuels is the relative ease of retrofitting existing ships with hydrogen fuel cells. Hydrogen could replace 43% of trips between the US and China without any changes and 99% of trips with minor changes in capacity or fuel functions.

Hydro-powered ferries and smaller ships have also been tested in the US, Belgium, France, and Norway. Royal Dutch Shell, the world's largest oil company, has invested in several hydrogen production projects in Europe and China, claiming that hydrogen has advantages over other potential zero-emission fuels for shipping (Reinsch, 2021). The most abundant element in the universe is hydrogen. Future low-carbon hydrogen will almost certainly be produced from water via electrolysis, which emits almost no carbon emissions. Depending on the carbon intensity of the production process, hydrogen is classified into three types:

A. Gray hydrogen is produced from fossil fuels through steam reforming.

B. Blue hydrogen, which is produced via steam reforming, but the production units are equipped with carbon capture, utilization and storage technology.

C. Finally, green hydrogen is produced by electrolysis, which breaks down water into hydrogen and oxygen using electricity. Since electrolysis does not emit CO_2 as a by-product, green hydrogen is the only form of hydrogen with an essentially carbon-free production process.

The electrolysis using electricity produced from renewable energy sources (solar or wind energy) produces less than 5% of the CO_2 emissions of gray hydrogen (non-zero due to emissions produced during the transport and production of electricity). However, the cost of producing green hydrogen is significantly higher than for blue or gray hydrogen. Hydrogen from electrolysis using renewable energy sources offers the only sustainable and mass-produced fuel-neutral solution for the shipping industry. Once hydrogen gas is produced, it can be stored and transported in fuel tanks. However, since hydrogen has a very low energy density, it must be compressed and cooled in a similar way to the compression of methane to produce liquefied natural gas (LNG).

Despite the cost challenges, hydrogen is the most promising clean fuel option for the global shipping industry. Many leaders in the transportation and energy sectors have realized this and are beginning to invest in research and development (E&A) to reduce production costs and explore scalability. However, the drastic cost reductions necessary to make green hydrogen cost-competitive with traditional fuels are unlikely to be possible in the medium term without government support.

Figure No.9: The Hydra, ship of the year - The first in the world with liquid hydrogen fuel Source: https://www.naftemporiki.gr/finance/story/1773603/to-hydra-ploio-tis-xronias-to-proto- sto-kosmo-me-kausimo-ugro-udrogono

Since the fuel that has been used in submarines and rockets for many decades was implemented, albeit timidly, a decade ago by Toyota, the pioneer in hybrid automotive systems, it became clear that hydrogen as a fuel, primarily as a clean and unwashed, is available raw material for the production of electricity - and thus electric propulsion - gave a shaky present for a sustainable maritime future (Spanos, 2020).

Now, hybrid ship technology can include electric propulsion in conjunction with new dual biodiesel and LNG engines, and meets sulfur emission regulations as well as the advent of new e-Fuels. The pioneers in all of this are once again the Norwegians and recently all the Baltic countries, which with the support of the Norwegian-German classifier DNV-GL and also their national legislation (that is, their flag) have incorporated for many years now the necessary regulations for the operation and safety of hybrid ships, so that more and more ferries operate either as purely electric or as hybrid (diesel-electric). Although hydrogen is considered a "fuel" because it can be "burned" by an internal combustion engine, it has already come a long way in recent years and the greatest emphasis is now on so-called "green" hydrogen.

Green H2 is that which can and is produced through electrolysis of water, which uses renewable energy sources (RES), is driven directly or through storage tanks to fuel cells, and is chemically converted into readily available electrical energy as well as kinetic energy, rather than thermal combustion. Also significant is the energy content of hydrogen, i.e. the energy that it conceals in itself, which is many times greater in weight than any other common fuel. The energy density of hydrogen is not only impressive in and of itself, but it can also completely replace a large portion of battery arrays (Spanos, 2020).

5.4 The Use of Electric Vessels for Decarbonization

Some inland waterway vessels already sail on electricity, mainly ferries and pleasure boats. This is because they travel shorter distances and can therefore use smaller batteries. Several boat builders are also designing hybrid cruisers. However, batteries are still not efficient enough, instead they are too heavy for ships traveling long distances in the open sea. In many cases, environmentally friendly alternatives to oil are suitable for inland waterways - and also for seagoing ships in the distant future. An advantage of running ships with batteries is that electricity is much cheaper than oil and especially marine diesel.

Electric ships will become more prevalent in the near future. Because of our reliance on fossil fuels, conventional ships emit more pollution. Despite the advantages of an all-electric boat, there are numerous obstacles to overcome before electric boats are widely adopted. Electric boats have a small market share in many countries. Various barriers to relatively low competitiveness have been identified through research, including real and perceived costs, risks, technological conservatism, familiarity, and a lack of knowledge. According to an IDTchEx report, the market for hybrid and pure electric boats and ships will rapidly grow to more than $20 billion globally in 2027 for consumer ships. The recreational boat market is large and expanding quickly, particularly for electric watercraft. There are many obstacles to the implementation of electric boats in the market, from technical challenges to acceptance of an electric boat. It is important to find innovative ways to reduce the environmental impact of pleasure boats, as a typical family boat consumes a huge amount of petrol when travelling. Boats need to be more efficient to allow electric propulsion.

The world is looking for new, more efficient energy sources, ushering in a new energy age. Tighter regulations, combined with lighter and more powerful batteries, help to make electric propulsion an appealing option, according to Lucy Gilliam, an aviation and shipping expert at the non-governmental organization Transport and Environment. One of the reasons why batteries cannot be used on ships is a lack of capacity. That is not always the case, according to Lucy Gilliam, who explains that, especially on short trips, batteries do not add weight when compared to traditional fuel ships. Jan Kjetil Paulsen, Senior Maritime Advisor at the Bellona Foundation, expressed optimism about the future of electric ships in an interview with SAFETY4SEA (Walker, 2019).

In most cases, electrification of shipping will be a profitable business case: energy from renewable sources of electricity can compete with energy from fossil sources in most European countries. Electric motors are less complex than combustion engines, which increases equipment lifespan and reduces maintenance and upkeep costs. The initial investment in technology, as well as the investment in the required infrastructure for shore connection and charging infrastructure, can be difficult.

The latter should be seen as a public responsibility funded by the government and managed by local port authorities. Forward-leaning suppliers will be easily able to adapt to new technology where applicable - simply motivated by the profitable business case. IDTechEx analysts have also released a new report, called Electric Boats and Ships 2017-2027, looking at this fragmented but often highly profitable and growing sector. According to the report there are already more than 100 manufacturers of electric boats and ships. The report also finds that the hybrid and clean electric boats and ships market will grow rapidly to over USD 20 billion globally in 2027 for civilian versions.

Electric boats are becoming more popular as a result of environmental and health concerns, and electric transportation is a response to this. Electric boating and sailing have grown in popularity, particularly in Austria, as the use of marine combustion engines is prohibited in some areas and strict restrictions are imposed in others. As a result of these restrictions, more Austrians are requiring electric or solar boats, which are permitted. Electric and solar boats are estimated to account for one-quarter of all boats in Austria. The fully electrified green ships of the future, which will even be charged from the power grid of the port they are in, will utilize renewable energy sources such as photovoltaics or use various forms of sails to run their routes with minimal pollution. In these ships of the future, the engines that set it in motion (diesel engines) turning the propeller will be replaced by electric motors.

Electricity will also be used in all power consumption devices such as pumps, compressors and control systems, as well as air conditioning. "*The fully electrified ship is characterized by significant advantages, such as increased maneuverability, precise* *control of the ship's speed and position, space savings, as well as lower levels of noise and air pollution emissions*," (Karageorgos, 2015). Upon this technology, most of the electricity will be stored on the ship, or generated on board and spent as it sails. Although electrification is currently quite developed, since it is already applied to cars and trains, in the case of ships, electric motors should be much more powerful (Energy In, 2015).

Picture No.10 - Electric ships: The Electra project and investments in Greece Source: https://www.newmoney.gr/roh/palmos-oikonomias/nautilia/i-ellada-proselkii-

ependisis-gia-ilektrika-plia/

The following lists the pros and cons (Dulebenets, 2018):

<u>Advantages</u>

1.Environment friendly

2. Avoiding engine noise

3. Less vibration

4. Less engine maintenance- no oil change, rotor change, diesel filter change etc.

5. Fuel economy

6. Avoid local contamination

7. The electric motor weighs much less from the internal combustion engine, if no long distance is needed considerable weight saving is achieved

8. The fire risk in battery storage is less than the fire risk associated with petrol and diesel storage.

<u>Disadvantages</u>

- ✓ <u>Fairly limited battery operating range</u>. Batteries are nowhere near competing with Diesel or gas when it comes to the fate of energy and for example, solar cells do not provide enough power to achieve what is considered normal sea speed.
- ✓ <u>Low power consumption and speed</u>. A shift hook that goes for speed without looking at you requires some energy.
- ✓ <u>Electric boats that are powerful cost a lot.</u> In order for there to be more electric ships in the future, a key challenge must be overcome. Batteries for storing Electricity must be much more efficient. To date, their energy density is still very low. This means that batteries cannot store enough energy for their size and weight. Large ocean-going vessels must travel long distances on a single battery charge. Batteries for this are generally still too big and too heavy.

Furthermore, charging infrastructure is required at ports. This is already an issue with electricity ashore, as cruise ships require electricity for hotel operations when docked. They frequently produce it using engines and auxiliary power units, which emit pollutants. Buying electricity directly at the ports would be much more environmentally friendly. However, such coastal power plants are still uncommon. As a result, ports will have to invest heavily in charging equipment. Finally, batteries continue to be prohibitively expensive for many shipping companies.

5.5 Sea Navigation and Minimization of Fuel Consumption

The safety-related green technologies under research and development are effective marine course mapping and ship performance control and behavior optimization. In 1983, the IMO adopted the Sea Course Charting Directive. The directive recommended that governments should advise ships to sail on a course recommended by the guidelines of special services approved by the WMO (World Meteorological Organization) (Deggim, 2020). By choosing the most efficient sea route, adjusting the ship's speed and avoiding bad weather conditions, it can lead to a significant reduction in the ship's consumption. Installing a navigation guide can significantly reduce fuel consumption. Force Technology and DFDS installed a relatively new sea route tool and the result was that even a small reduction in fuel consumption but voyage can lead to a significant overall reduction over time (Dulebenets, 2018).

Ships' crews can have valid weather forecasts as well as a complete picture of the weather ahead of the voyage thanks to new technological means of navigation and communications, while masters and officers can assess dangerous meteorological conditions. Storms are examples of changes. Similarly, by optimizing navigation systems, which can take advantage of favorable currents or avoid adverse weather conditions based on region. External meteorological services also help with this, allowing them to improve their safety and reduce their fuel consumption. A fuel economy calculator can also help with route planning and efficient sea operations. Furthermore, reducing port waiting time during loading and unloading can reduce CO_2 emissions and increase port efficiency (Karageorgos, 2015).

5.6 Ships Performance Control and Voyage Optimization

Trim is defined as the difference between the bow and stern draft of the ship. When the drafts are equal, then we say that the ship is even keel, when the stern draft is greater, then we have trim by stern, while when the bow is greater, when we have trim by bow. The propulsion resistance of the ship is related to its behavior. If the ship is traveling with the appropriate behavior, then the frictional resistance with the water is reduced, resulting in a reduction in fuel consumption. Relevant has already been developed software which is installed on the ship and displays graphically the fuel consumption in relation to t the conduct and drafts. Thus, in any case and depending on the loading state of the ship, the master can choose those parameters that enable him to save fuel. The positive consequences are obvious both in saving resources and in the environment. The company Force Technology has developed the relevant computer program, which has been placed on trial in six Ships managed by the company CLIPPER. The results so far are positive as we have a 3% reduction in CO_2 emissions, a 3% reduction in NO_x and a 3% reduction in Sox (Karageorgos, 2015).

5.7 Sea Staff Training and Development of Enviromental Awareness Issues

As previously discussed, a number of green ship technologies have been developed in recent years, and numerous studies are ongoing to reduce the environmental impact of shipping. However, technological advancements alone are insufficient to qualify a ship as green in order to provide better shipping quality. Man himself is a key factor that complements the overall effort for a "cleaner" shipping industry, and when these technologies are used by environmentally conscious people, they perform optimally. Environmental awareness is generally developed as part of the education provided by universities and maritime schools. But the effort should be intensified, this human resource, whether it is at sea or on land, should be committed to protecting the environment and saving energy on ships (Fakiolas, 2021).

A well-organized and specialized staff knows that every action or work carried out on a ship can have an impact on the environment. The properly trained crew is able to perceive this so that they can take the required actions every time and judge whether the work they are performing has an environmental impact. Therefore, maritime education should connect theory with practice. On the one hand to provide knowledge at a theoretical level about green technologies and on the other hand to give the appropriate background for staff to apply them correctly and produce results useful in research and further development of new technologies. Many of the research programs of universities or companies rely on the results and measurements made on board. So, researchers have access to practical data and ships' personnel come into contact with research projects on green technologies.

Finally, some of the branch's key areas of environmental education include the following: Seminars provided by various taxonomists that contribute to environmental protection, safety in the execution of work, and proper ship maintenance are an extremely important initiative. Also included in the surveys is a review of the ship's certification and environmental performance (Green Passport, Lloyds). To attempt to estimate the life cycle of a green ship, we can say that it consists of six stages, each of which is a series:

1) Materials of construction

2) Shipbuilding process

3) Placement of equipment

4) Installation of energy efficient Systems

5) Safety at sea

6) Operation in the marine environment

7) Decommissioning

The life cycle of the ship starts with the raw materials, where in shipbuilding the main raw material is shipbuilding steel. In European countries mainly manufacturers prefer different materials, trying to reduce the ship's ecological footprint. The second stage in the life cycle of the Green Ship is its shipbuilding process. At this stage, all the issues related to the environmental issues regarding the construction of the ship arise. In particular, European ship equipment manufacturers make sure to comply with strict environmental standards during the green ship design stage. The introduction of electronic communication tools increases efficiency of the supply chain, while at the same time contributing to the reduction of volatile factors from the external environment.

The third stage is to outfit the ship with environmentally friendly systems. Because the ship's equipment accounts for nearly 70% of its value, it must be ensured that it meets safety standards and can operate safely and efficiently in the environment (Khoo, 2011). The fourth stage involves the installation of energy-saving systems. The shipbuilding industry's short-term goal is to increase energy efficiency by 30%. It has been calculated that green ships can improve their energy efficiency by 60% over time, depending on the years of service. These lofty objectives, however, are attainable through a continuous process of technological innovation.

The fifth stage of a green ship's life cycle concerns safety at sea. The experience gained by the shipbuilding industry over many years has led to the construction of increasingly safer ships for crews, passengers and the environment. In the design of the ship's safety systems, many factors must be taken into account, such as for example the harsh weather conditions of the marine environment. Special equipment can be an important factor in avoiding accidents at sea. Furthermore, through the development and safety systems, it is ensured that the chances of a marine accident will be minimized, which will result in the mitigation loss of animals and marine pollution.

The sixth stage of the ship's life cycle is the process of operation at sea. The ship must undergo regular annual inspections as well as a special inspection every four years where it is docked. Timely and correct ship maintenance, as well as compliance with environmental regulations, ensure an increase in energy efficiency. Maintaining the ship's hull and other systems not only makes ships more environmentally friendly, but it also increases the value of the ship.

Finally, once the ship's useful life has passed, the seventh and final stage of its life cycle begins. This stage is the stage of the withdrawal of the ship. When recycling the ship, the design of the hull and other systems, as well as the choice of materials, facilitate the process. Most parts of the green ship may remain useful and in good condition even after the ship is broken up. Specifically, 98% of the ship can be recycled in contrast to airplanes, where only 60% of the aircraft is recyclable (Khoo, 2011).

6th Chapter – Conclusion

According to what has been stated above about shipping decarbonization, it should be stated that shipping transport is by far the most energy efficient mode of transport in terms of energy/tonne kilometer. Ships currently consume only 3% of the world's final energy demand, including 7% of the world's oil, primarily for international cargo shipping, also known as ocean liners. The IMO sulfur cap regulation went into effect in 2020, requiring the use of fuel with reduced sulfur to 0.5% or the use of a fuel catalyst for ships that use the old type of oil as fuel. This has resulted in a significant shift in the type of fuel used by the fleet. - However, a large and appreciable proportion of heavy fuel oil is still used on ships with scrubbers installed.

In the long term, the International Maritime Organization - supported by both shipowners and governments - aims for an absolute reduction of CO2 emissions by 50% by 2050 compared to 2008. The specialists' prediction is that a mix of improved energy use and efficiency, combined with a major fuel shift that includes switching from oil to gas and ammonia and other low and zero carbon alternatives, will enable this goal to be achieved. In the short term, the implementation of the IMO target and the measures it implemented from 1-1-2020 to reduce sulfur emissions will lead to an increase - not a decrease - in carbon emissions, as the use of scrubbers requires additional energy use. In fact, the efficiency and supply chain improvements resulting from digitization, sensors and smart algorithms will increase the efficiency of the merchant fleet.

However, in a world where GDP doubles by 2050, the demand for cargo transportation will far outpace efforts to improve efficiency and reduce shipping's environmental footprint. As a result, kilometer loads will rise in almost all ship categories, with a total increase of 28% between 2019 and 2035. In short, maritime commercial routes will expand, as will ship energy consumption. According to a Commission report to the European Council and Parliament on the implementation of Directive 2014/94/EU on the development of alternative fuels infrastructure, the development of alternative fuels for shipping is still paperless and lacking.

Characteristically, the report finds, there is limited availability of data on the spread of biofuels, vessels using alternative fuels and shore-based power supply for berthed ships in relation to maritime transport. Therefore, although the European Green Deal also points to the great need for decarbonization in the shipping sector, very little has been done in this direction, both in terms of the development of new fuels and in terms of their disposal infrastructure, with the result that the proposal to the International Maritime Organization (IMO) of a group of countries with strong shipping, including Greece, for the creation of a $5 billion fund that will finance research into new alternative marine fuels becomes even more important.

According to the E.E. report, the scenarios underlying the 2030 climate target plan, which aims to reduce greenhouse gas emissions by at least 55% across the economy, include a significant share of alternative fuels, such as renewable and low-carbon liquid fuels. Other alternative fuels that will be primarily used after 2030 include hydrogen or hydrogen carriers such as ammonia, as well as bio-LNG, electricity, methanol, and eco-fuels, all of which, with the exception of eco-fuels, will necessitate different infrastructure. The Fuels EU Maritime initiative, which will be implemented by 2021, will look further into the maritime sector's decarbonization and pollution reduction options.

However, it is clear that significant and long-term efforts are required to ensure the provision of sufficient infrastructure to supply such fuels. Member States' current planning in this area falls far short of what will be required to meet the short- and medium-term greenhouse gas and pollutant reduction requirements associated with the implementation of the European Green Deal.

Furthermore, substantial additional investment is required to provide the necessary recharging and refueling infrastructure, particularly for zero-emission vessels and port infrastructure. As reported in the national implementation reports, these resources are not currently planned for by the Member States, and additional funding may be required to meet the climate target. According to the report, the total number of fuel and liquefied natural gas (LNG) vessels ordered globally in 2019 was around 300. Only half of these ships are in service. The other half is still in working order. The number of electric vessels (including hybrids) in operation worldwide is also small, but it is growing: in 2019, 160 vessels were in active service, with another 104 under construction. At the end of 2019, approximately 50 inland and sea ports in the E.U. had at least one point of connection with a shore power supply. However, only around a third of Member States have set targets for LNG ship refueling and land-based energy for both maritime and inland waterway transport.

Finally, data on maritime and inland waterway vessel estimates and infrastructure development provided by Member States was limited. As a result, the report concludes that it is impossible to make a coherent assessment of the current and projected growth of LNG ship bunkering and shore-based energy provision across the EU. As a result, assessing the directive's impact on the spread of alternative fuels and land-based energy supply in relation to maritime and inland waterways is difficult. According to available data, the majority of Member States have made limited investments in alternative fuel infrastructure for refueling ships with LNG and supplying energy from shore to ports. However, especially in these areas, the directive is likely to have a significant impact as the target dates for their implementation in 2025 or 2030 approach.

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