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ΝΑΥΤΙΛΙΑΚΗ ΔΙΟΙΚΗΤΙΚΗ

DECARBONIZATION OF INTERNATIONAL SHIPPING: PERSPECTIVES AND CHALLENGES

A.M: MND20014

Δέσποινα-Βασιλική Κουβάτσου

Διπλωματική Εργασία

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ΠΕΡΙΕΧΟΜΕΝΑ

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ABSTRACT

The purpose of this dissertation is to discuss one of the most crucial topics in modern shipping industry which is the road towards shipping decarbonization. International maritime industry is a major part of the global economy. However, vessels release emissions that contribute to air pollution and finally result to the problem of global warming. Reducing these emissions is a key factor to keep the environment safe, healthy and limit climate change.

In 2018, the IMO announced the initial strategy to reduce greenhouse gas (GHG) emissions. The strategy outlines an ambition to halve international shipping GHG emissions by 2050, while reducing CO_2 emissions by at least 40% by 2030, and pursuing efforts towards 70% by 2050. Following the latest IMO rules, we discuss the main causes of marine pollution and what are the main measures that need to be implemented to achieve that target. We will also discuss their advantages along with the obstacles that their implementation will bring to all parties involved in the green transition of international shipping.

Key Words: Decarbonization, GHG emissions reduction, IMO regulations, Environment

ΠΕΡΙΛΗΨΗ

Σκοπός της παρούσας διπλωματικής εργασίας είναι η συζήτηση για ένα από τα πιο επίκαιρα θέματα της σύγχρονης ιστορίας της ναυτιλίας, την απαλλαγή δηλαδή της ναυτιλίας από τις εκπομπές άνθρακα. Η βιομηχανία της ναυτιλίας παίζει ένα τεράστιο ρόλο στην παγκόσμια οικονομία. Τα πλοία όμως συμβάλλουν στη ατμοσφαιρική ρύπανση και στο φαινόμενο της υπερθέρμανσης του πλανήτη. Η μείωση των θαλάσσιων εκπομπών είναι ο παράγοντας που θα βοηθήσει στο να διατηρήσουμε το περιβάλλον ασφαλές , υγιές και θα περιορίσει το φαινόμενο της κλιματικής αλλαγής.

Το 2018, ο IMO ανακοίνωσε την στρατηγική σχετικά με τη μείωση των εκπομπών των αερίων του θερμοκηπίου. Η προσδοκία είναι να μειωθούν οι εκομπές άνθρακα 40% μέχρι το 2030 και μέχρι 70% το 2050. Έχοντας σαν βάση τους νέους κανονισμούς του IMO, θα αναλύσουμε αρχικά τις βασικές πηγές μόλυνσης στο τομέα της ναυτιλίας και θα συζητήσουμε για τα μέτρα που θα πρέπει να εφαρμοστούν για να επιτευχθούν οι παραπάνω στόχοι. Επιπλέον, αναφορά θα γίνει στα πλεονεκτήματα των νέων μέτρων εφόσον αυτά μπορούν να εφαρμοστούν καθώς και τις προκλήσεις που θα επιφέρει η εφαρμογή τους, σε όλους όσους αποτελούν μέρος της βιομηχανίας και της πράσινης αυτής μετάβασης.

Λέξεις Κλειδιά: Απανθρακοποίση, Μείωση εκπομπών άνθρακα, Κανονισμοί Διεθνούς Ναυτιλιακού Οργανισμού , Περιβάλλον

Introduction

Shipping is one of the many industries that are affected by economic, social and political variables. Maritime sector is experiencing an increasing pressure to decarbonize its operations and reduce its emissions. The environmental targets that draw the line for a more sustainable future, set rules which the shipping industry needs to follow and adapt. This set of new laws and legislations, create an ever changing environment that also defines the business strategies and decisions of shipping companies worldwide.

Based on the third study of the International Maritime Organization (IMO), it has been estimated that international shipping accounts approximately 2.2% of global annual CO_2 emissions. Furthermore it has been estimated that these emissions can grow between 50% - 250% by 2050, as a result of the growth of worldwide trade.(1). It is therefore clear that these predictions will have a tremendous impact on the life we know today and it is very important to make quick steps in order to develop feasible technologies to reduce emissions.

In the first chapter we analyze what the impact of international shipping is on the environment and the reasons why it is necessary to discuss decarbonization of the shipping sector. In the following chapter we discuss what are the laws and policies of the IMO and the EU and how they have been implemented until today, in order to regulate shipping and limit marine pollution. In the third chapter, and in accordance with IMO requirements, an analysis is given of the reduction measures that can be implemented in shipping along with the disadvantages accompanying each measure. Furthermore, we attempt to understand the challenges and barriers that the implementation of new measures will bring to all parties (shipping companies, shippers, freights and facilitators) and finally we conclude by presenting the actions that must be taken in the future to achieve shipping with zero-carbon fuels.

1. Marine Pollution

Maritime transport is by far the most cost effective and environmental friendly way of transport compared to other means of transport like rail and air transport. A large vessel emits 1% of the CO_2 per ton-km that is emitted by a plane and 14% of the CO_2 emitted by the next most efficient transport alternative – a cargo train. However, maritime transport accounts more than 90% of global trade (2) and the huge volume of the global marine transport is connected with huge environmental effects on the marine environment that need to be taken into account.

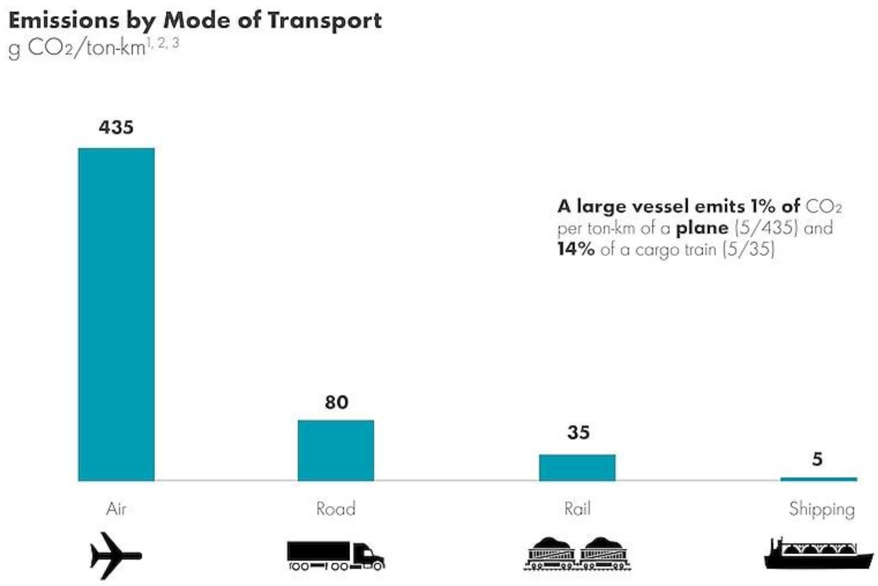

Figure 1: Emissions by Mode of Transport (Source IMO GHG study 2009)

Marine pollution is the combination of chemicals and trash originate from various human activities, eventually ending up into the marine environment. This pollution results in damage to the environment and it is harmful for the life of organisms with in the marine environment and as well as to, humans. Marine pollution is a growing problem and as long as there are activities that take place in the sea, pollution is inevitable. On the other hand, it must be stressed that eighty percent (80%) of marine pollution comes from terrestrial sources.

Chemical contamination, or nutrient pollution, involves health, environmental, and economic reasons. This type of pollution occurs when human activities, notably the use of fertilizer in farms, lead to the runoff of chemicals into waterways that ultimately flow into the ocean. The increased concentration of chemicals, such as nitrogen and phosphorus, in the coastal ocean promotes the growth of algal blooms, which can be toxic to wildlife and harmful to humans.

Marine trash encompasses all manufactured products, most made of plastic, that end up in the ocean. Littering, storms, and poor waste management all contribute to the accumulation of debris, 80 percent of which originates from sources on land. Common types of marine debris include various plastic items like shopping bags and beverage bottles, along with cigarette butts, bottle caps, food wrappers, and fishing gear. Plastic waste is particularly problematic as a pollutant because it is so long-lasting. Plastic items can take hundreds of years to decompose. Fish become tangled and injured in the debris, and some animals mistake items like plastic bags for food and ingest them. Small fishes and organisms feed on microplastics and absorb the chemicals from the plastic into their tissues. Microplastics are less than five millimeters (0.2 inches) in diameter and have been detected in a range of marine species, including plankton and whales. When small organisms that consume microplastics are eaten by larger animals, the toxic chemicals then become part of their tissues. In this way, microplastic pollution migrates up the food chain, eventually becoming part of the food that humans eat.

In order to protect the ocean from marine pollution, policies have been developed internationally. There are different ways to pollute the oceans. As a result multiple laws and policies have evolved, that have been put into action. The International Maritime Organization (IMO) uses various instruments to protect the marine environment from shipping activities. Although the IMO has responsibility for safety and security of global shipping, it has also recognized that marine transportation and port activities have unintended impacts on the environment (3). Fifty years ago, the IMO became increasingly concerned about the large volumes of oil transported by sea in tankers. The Torrey Canyon Disaster of 1967, spilled 120,000 tons of crude oil, killing > 25,000 seabirds and other marine organisms, demonstrating the global impact of marine transportation on the environment. IMO introduced the International Convention for the Prevention of Pollution from Ships (MARPOL) to prevent tanker accidents and minimize their consequences, including pollution prevention of routine operations, such as cleaning cargo tanks and disposal of oily engine room wastes. MARPOL also covers pollution by chemicals, packaged goods, sewage, garbage, and air pollution .Other international legislation to reduce environmental impacts of marine transportation includes the United Nations Convention on the Law of the Sea (UNCLOS). Other frameworks that have been adopted in order to reduce environmental effects are European Sea Ports Organization (ESPO), EcoPorts (www.ecoports.com), Port Environmental Review System (PERS), PORTOPIA (www.portopia.eu), and the Green Marine Environmental Program (GMEP).

1.1 Main Causes of Marine Pollution

In order to understand better the extent of marine pollution and their effects, we need to analyze first all the sectors that human activities take place that result in pollution. Our analysis will include the causes of ship pollution, deep sea mining, land runoff, acidification, eutrophication, plastic debris, underwater noise and oil pollution. Atmospheric pollution will be analyzed in a different chapter as it the cause that our study focuses on.

1. Ship Pollution

Marine vessels can pollute with many different ways. Major pollution originates from oil spills, continues with the discharge of cargo residues and ballast water and ends up with problems caused by shipbreaking and scrapping.

Oil spills is the most common marine vessel pollution. It includes the releases of crude oil from tankers, drilling rigs and wells. It also includes spills of petroleum products like gasoline, diesel and their by-products such as bunker fuels or waste oil. Spills may occur for many reasons through exploration, extraction or transportation processes and the biggest contributor to oil spills is the operational discharge from tankers. Marine accidents are also connected to major oil spills such as the Exxon Valdez in 1989.

Garbage Pollution produced by ships has also major environmental impact on the ocean. Ship generated waste include glass, metal, and plastic containers, organic waste, cardboard and paper packaging waste, oily bilge waters, wastewater, and hazardous waste (e.g., batteries noxious liquids, paint waste, pharmaceuticals) .Food is often the largest waste stream in ships, but because food waste can be discharged directly at sea, many of its components can have deleterious impacts on coastal waters. In addition, food waste can reduce water and sediment quality, damage marine biota, increase turbidity, and nutrient levels. Waste generated by ships is now legislated through MARPOL 73/78, its Annex III-Hazardous waste and V-Garbage, and the International Safety Management (ISM).

Moving on to the ballast water issue, it must be stressed that is connected to the transport of various marine species to unwanted places. As marine transport increases globally due to increased demand of cargo transport, the risk of introducing invasive species creates threats to global biodiversity. Most invasions of aquative invasive species occur via ballast water exchange at port, with ships traveling and dispersing their ballast internationally, nationally and locally. The probability of organisms surviving ballast water exchange depends on waters of origin and where they are discharged. An example of species that have been spread by ballast water are the European green crab which is native of the European Atlantic coast and has reached Southern Australia, South Africa, the United States and Japan.

2. Deep Sea Mining

Deep-sea ocean mining also causes pollution and disruption of marine ecosystems. Drilling for substances such as cobalt, zinc, silver, gold and copper creates harmful sulfide deposits deep in the ocean. Deep sea mining is a relatively new field, the complete consequences of which are unknown. However experts are certain that removal of parts of the sea floor will result in disturbances to the benthic layer, increased toxicity of the water column, and sediment plumes from tailings. Removing parts of the sea floor disturbs the habitat of benthic organisms, possibly, depending on the type of mining and location, causing permanent disturbances. As of 2021, the majority of marine mining efforts are limited to shallow coastal waters only, where sand, tin and diamonds are more readily accessible.

3. Land runoff

Nonpoint source pollution comes from a variety of different locations and sources. The result of this is runoff, which occurs when rain or snow transports pollutants from the terrestrial environment into the ocean. This nutrient-rich water can cause fleshy algae and phytoplankton to thrive in coastal areas; known as algal blooms, which have the potential to create hypoxic conditions by using all available oxygen. Polluted runoff from roads and highways can be a significant source of water pollution in coastal areas. About 75% of the toxic chemicals that flow into Puget Sound are carried by storm water that runs off paved roads and driveways, rooftops, yards and other developed land (5).

4. Acidification

One of the major effects of ocean pollution is ocean acidification. Ocean acidification is the rapid reduction of the pH levels in the Earth's oceans over a period of time, with serious consequences for the marine food chain. Ocean acidification is caused by the ocean absorbing large amounts of carbon dioxide – almost 30 percent - from the atmosphere which are produced by the burning of fossil fuels and deforestation. Carbon dioxide is slightly acidic. As the amount of carbon dioxide increases in the ocean, the pH level of the ocean decreases. Oceans require a certain level of pH to maintain the natural biochemistry essential for a healthy ecosystem to remain unbroken for the different species living in the water.

Because the levels of atmospheric carbon dioxide are increasing, the oceans are becoming more acidic. The potential consequences of ocean acidification are not fully understood, but there are concerns that structures made of calcium carbonate may become vulnerable to dissolution, affecting corals and the ability of shellfish to form shells. For the time being, the pH of surface ocean waters has fallen by 0.1 pH units. This might not sound like much, but the pH scale is logarithmic, so this change represents approximately a 30 percent increase in acidity.

Ocean acidification is already impacting many ocean species, especially organisms like oysters and corals that make hard shells and skeletons by combining calcium and carbonate from seawater. However, as ocean acidification increases, available carbonate ions (CO32-) bond with excess hydrogen, resulting in fewer carbonate ions available for calcifying organisms to build and maintain their shells, skeletons, and other calcium carbonate structures. If the pH gets too low, shells and skeletons can even begin to dissolve.

5. Eutrophication

Eutrophication is an increase in chemical nutrients, typically compounds containing nitrogen or phosphorus, in an ecosystem. It can result in an increase in the ecosystem's primary productivity and further effects including lack of oxygen and severe reductions in water quality, fish, and other animal populations. Advanced eutrophication may also be referred to as dystrophic and hypertrophic conditions. Eutrophication in freshwater ecosystems is almost always caused by excess phosphorus.

The visible effect of eutrophication is often nuisance algal blooms that can cause substantial ecological degradation in water bodies and associated streams. This process may result in oxygen depletion of the water body after the bacterial degradation of the algae.

Approaches for prevention and reversal of eutrophication include: minimizing point source pollution from sewage, and minimizing nutrient pollution from agriculture and other nonpoint pollution sources. Shellfish in estuaries, seaweed farming and geo-engineering in lakes are also being used, some at the experimental stage.

6. Plastic Debris

Marine debris, also known as marine litter, is human-created waste that has deliberately or accidentally been released into the sea. Floating oceanic debris tends to accumulate at the center of gyres and on coastlines, frequently washing aground, when it is known as beach litter or tide wrack. Deliberate disposal of wastes at sea is called ocean dumping. Naturally occurring debris, such as driftwood and drift seeds, are also present. The largest single type of plastic pollution estimated around 10%, and majority of large plastic in the oceans is discarded and lost nets from the fishing industry. Plastics accumulate because they don't biodegrade in the way many other substances do. They will photodegrade on exposure to the sun, but they do so properly only under dry conditions, and water inhibits this process. In marine environments, photodegraded plastic disintegrates into ever-smaller pieces while remaining polymers, even down to the molecular level. When floating plastic particles photodegrade down to zooplankton sizes, jellyfish attempt to consume them, and in this way the plastic enters the ocean food chain.

Many animals that live in the sea consume flotsam by mistake, as it often looks similar to their natural prey. Plastic debris, when bulky or tangled, is difficult to pass, and may become permanently lodged in the digestive tracts of these animals. Especially when evolutionary adaptions make it impossible for the likes of turtles to reject plastic bags, which resemble jellyfish when immersed in water, as they have a system in their throat to stop slippery foods from otherwise escaping. Thereby blocking the passage of food and causing death through starvation or infection.

In efforts to prevent and mediate marine debris and pollutants, laws and policies have been adopted internationally, with the UN including reduced marine pollution in Sustainable Development Goal 14 "Life below Water".

7. Underwater Noise

Underwater ocean ambient noise levels have increased in the past 50 years due to increased marine transportation, resource extraction, fishing, recreational activities, and other anthropogenic sources. The noise produced by ships can travel long distances, and marine species that may rely on sound for their orientation, communication, and feeding, can be harmed by this sound pollution. Hearing ranges and sensitivity of noise vary between marine species and thus the impact of underwater noise can result in a wide range of effects including behavioral changes such as swim direction, speed, and respiration patterns, physical injury or harm, and even death in some cases. Changes in swim patterns, including surfacing and dive duration, decreased time searching for food, avoidance behaviors as well as disruptions in breeding, nursing, and migration are all recognized behavioral changes in marine mammals. (24)

The most striking consequence of ocean noise pollution is the stranding of whales and dolphins. Strandings have been observed to be particularly frequent after naval sonar maneuvers. Extreme sound events like these inflict vascular damage on the rain, lungs and other organs. Further, animals may panic and surface too fast, which causes nitrogen bubbles to form in the blood – the so-called bends. As is the case for humans, extremely loud sound may cause hearing damage in marine animals. This is a grave problem for the many marine creatures that depend on their hearing for communicating, sensing danger, finding a partner and hunting prey. Other physical consequences of ocean noise pollution include disruption of the schooling structure of fish or impaired growth of shrimp.

Voluntary guidelines proposed by the IMO in 2013 focus on maintenance of vessel, ship design, onboard machinery, and vessel operational considerations, such as speed and route choices, to help reduce underwater noise pollution and alleviate associated detrimental impacts. Propellers are the main source of underwater noise, due to cavitation, which is the formation of water vapor cavities as water passes over propeller blades. Choosing noise-reducing propellers when available and suitable for the vessel and carefully considering propeller characteristics including diameter, number of blades, pitch, and sections to reduce cavitation could help reduce noise.

Regular maintenance and cleaning of propellers to ensure a smooth surface would also help reduce cavitation (6).

8. Ship Breaking

Shipbreaking is the method of ship disposal, in which marine vessels are cut into pieces. This process can negatively impact the marine environment and the human life due to release of oil, lubricants and other chemical that are used in ship construction.

The main sources of pollution arising from shipbreaking activities include fumes, noise and vibration from welding and cutting, flammable or explosive substances, metal fragments, and other solid wastes. The longer a ship remains in situ, the greater the risk of contamination to the surrounding marine environments. In large quantities, metal fragments and iron rust precipitates, sticking to eggs, larvae, and blocking delicate feeding or respiratory systems. Solid wastes and garbage accumulated during dismantling have the potential to release plastics and small pieces of scrap metal into the water, posing threats to fish, seabirds, and seals. Up to 80% of international shipbreaking takes place in Bangladesh, India, and Pakistan, and lower levels take place in China and Turkey.

9. Ship Sinking

Shipwrecks, ocean acidification and the dumping of waste into oceans are among the biggest sources of marine pollution. Some 75% of sunken wrecks date back to the Second World War; their metal structures are ageing and their metal plates are deteriorating, thus threatening to release their contents into the ocean due to the effects of corrosion. The North Atlantic Ocean contains 25% of the potentially polluting wrecks in the world. These wrecks are estimated to contain nearly 38% of the total volume of oil trapped in sunken vessels. The Mediterranean has 4% of the world’s sunken vessels and around 5% of the estimated oil volume. These numbers are high, considering its size and the fragile marine environment of landlocked seas.

However, accidental shipwrecks carry unintended environmental consequences artificial reefs are purposefully created by sinking old vessels with local economic benefits in mind, an effective tool to improve the local underwater habitat for marine biota. Artificial reefs improve fish habitat, enhance coastal erosion protection, and provide marine research opportunities. Creation of artificial reefs can increase local heterogeneity and biodiversity by adding novel habitat structures (25), but to maximize environmental benefits all vessels must be properly stripped down and hazardous materials appropriately disposed of.

10. Ship Strikes on Marine Megafauna

Worldwide, there are more than 750 recorded ship-strikes to large whales in 2007, up from 300 in 2002 (1). However, strikes often go unreported due to a lack of reporting requirements in different jurisdictions. Furthermore, with larger vessels the crew often does not realize a strike has occurred until they reach the port. Between 1986 and 2005, the right whale population was estimated at approximately 300–400. In the same time frame, there were 50 confirmed right whale deaths, 38% of which were a result of ship-strikes. Right whales are particularly vulnerable to ship-strikes and are often found in high traffic areas. As a result, ship-strikes are a major threat to the survival of the species.

Through this brief analysis of the main causes of marine pollution, it is easy to understand that the consequences of human activities can be severe. We need to found ways to limit the ecological footprint left behind by humans. That requires social and political will, together with a shift in awareness, so more people become accustomed to respecting the environment and therefore avoid abusing it. At an operational level, regulations, and international government participation is needed. It is often very difficult to regulate marine pollution because pollution spreads over international barriers and regulations are therefore not as efficient as at a regional or local level. Balanced information on the sources and harmful effects of marine pollution need to become part of general public awareness, and ongoing research is required to fully establish, and reveal the magnitude of the various issues.

1.2 Air Pollution and Emissions

The shipping industry is also a big source of air pollution. The industry accounts for 33% of emissions from fossil fuel combustion, including 2.7% of global CO_2 emissions (7). Between 2000 and 2018, global GDP increased by approximately 65% while international shipping volumes increased by 93% over the same period.

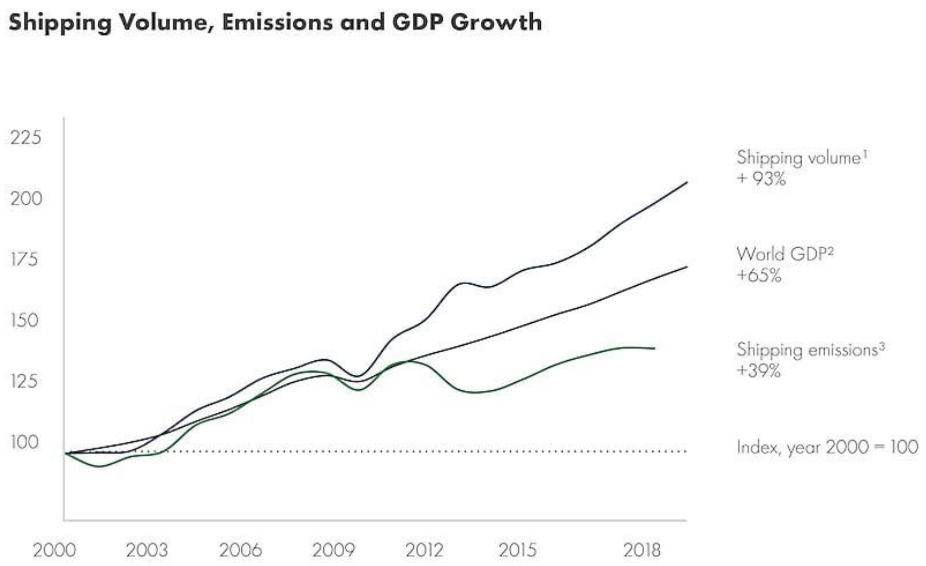

Figure 2: Evolution of Shipping Volume, Emissions and GDP Growth (Source UNCTAD)

Exhaust gases from ships is a significant source of air pollution both for conventional pollutants and greenhouse gases. Factors that affect emissions are the fuels and the type of the engine of marine vessels. Fuels can be MDO-Marine Diesel Oil, MFO - Marine Fuel Oil and HFO-Heavy Fuel Oil.
Shipping emits various pollutants like:

1. Carbon dioxide (CO_2): It enters the atmosphere through burning fossil fuels (coal, natural gas, oil), solid waste, trees and other biological material and also as a result of other chemical reactions. It is the most significant greenhouse gas (GHG) released by the ships and is the main reason for global warming.
2. Sulfur oxides (SO_X) and nitrogen oxides (NO_X) contribute to the phenomenon of acid rain and create hazards on human health.
3. Carbon monoxide (CO)
4. Volatile organic compounds (VOC)
5. Black carbon (BC)

1. Conventional pollutants

Air pollution is generated from ships by diesel engines which burn high sulfur fuel oil, producing sulfur dioxide, nitrogen oxide, carbon monoxide, carbon dioxide. All these emissions lead to the formation of chemical reactions in the atmosphere and contribute to severe health effects. Of the total global air emissions, shipping accounts for 18 to 30 percent of the nitrogen oxide and 9% of the Sulphur oxides. According to a study (8) marine transportation accounts for 10%–15% of the worlds anthropogenic SOx and NOx emissions.

These harmful emissions create problems both to the environment and human health. Trees are being destroyed by high concentrations of sulfur and their growth is decreased. Sulfur in the air creates acid rain which damages crops and buildings. Moreover, chemical reactions in the atmosphere reduce visibility, create haze and it is something that happens more in large cities where higher concentration of oxides is noticed. Exposure to SO_2 can also have negative effects on the human respiratory system, as well as it contributes to an increased risk of heart attacks.

In order to control Sulphur emissions and their hazardous impact, International Maritime Organization – IMO has set new regulations. These rules known as IMO 2020 set the limits of sulphur in fuel oil used on board ships operating outside designated emission control areas to 0.50% m/m (mass by mass).

The advantages of the new rules that have been implemented since January 2020 are given below. Cleaner air can be succeeded with 77% drop in overall sulphur oxide emissions from ships. The annual reduction is estimated around 8.5 million metric tons of SO. Regarding marine vessels fuels, higher quality will become a fact as the majority of ships switch to better fuel with lower sulphur oil in order to meet the limits. On the other hand, we will have positive impacts on human health as premature deaths and respiratory diseases will be reduced. Since these regulations will be under the control of authorities like Flag and port state, this will ensure that ships, ship owners and ship operators will comply.

2. Greenhouse Gas Emissions

Greenhouse gas emissions from marine transport include CO_2, methane CH_4 and nitrous oxide N_2O, all of which contribute in a large extent to atmospheric pollution. These emissions strengthen the greenhouse effect and contribute to climate change. In 2012, the number of total emissions coming from the shipping sector accounted for 961 million tons of CO_2.

Bulk carriers, oil tankers and container ships account for around 85% of all shipping activity, while around 45% of international maritime trade passes through the 20 largest global ports. Studies have shown that HFO and MDO fuels emit similar levels of greenhouse gas pollutants, LNG can reduce emissions by 25% but has higher emissions of CH_4 (9).

Also ports contribute to GHG emissions i.e. in 2008 the port of Barcelona emitted 331,390 tons of CO_2. Data from the Los Angeles County Health Survey reveal that Long Beach communities in close proximity to the Port of Los Angeles experience higher rates (2.9 percentage points on average) of asthma, coronary heart disease and depression, compared to other communities in Los Angeles (10).

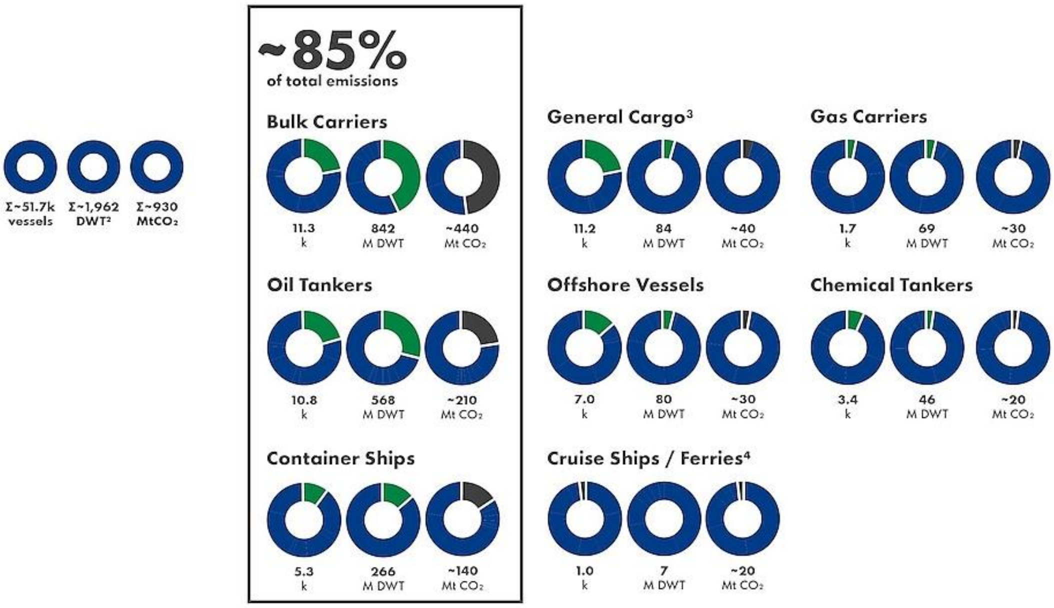

Figure 3: Emission Percentages per type of Marine Vessels (Source UNCTAD)

Even though shipping volumes have been increased by 101% over the last two decades, we need to notice that emissions have grown only by 40% on the same time frame. Factors responsible for this are the increase in technical innovations and of course operational improvements. However, the environmental impacts deriving from the shipping industry are still significant that new technologies need to be found in order to meet decarbonization targets.

Strategies to lower GHG emissions have been initiated from International and EU authorities. Furthermore, IMO is responsible for regulating GHG and conventional emissions from marine transportation and this will be the subject of our discussion in the second chapter.

1.3 Environmental Effects of Shipping

The environmental effects impact not only the marine environment but also the surroundings as well as the human health. In order to understand how significant the impact is, we use numbers of the many different types of ships sailing the globe. In 2016, there were almost two million registries of marine vessels that included: 778.890 bulk carriers, 75.258 multipurpose vessels, 503.343 oil tankers, 244.274 container ships, 44.347 chemical tankers, 5950 passenger ships and 1800 LNG tankers. The top five ship owing countries - Greece, Japan, China, Germany, Singapore – control more than half of the world marine vessels and this is something that illustrates the extent of the global commercial trade and transportation(11).

As stated earlier, the categories of the effects of marine transport in the environment are: Oil pollution, Air pollution, GHG Emissions, release of ballast water that contains aquatic invasive species, release of cargo residues, oil spill from ships, garbage management, underwater noise, ship strikes on marine megafauna, ship groundings and sinking, and widespread contamination in ports during transshipment and ship breaking activities. Each category brings enormous changes in the marine environment and to aquatic species.

Starting with oil pollution, oil spills from vessels may not be the most polluting activity in as far as marine pollution is concerned, but once a major spill of crude oil occurs at sea it is indeed disastrous. The world witnessed the first biggest oil spill through the Torrey Canyon in 1967. Furthermore, to name but a few, the Exxon Valdez (grounded in Prince William Sound, Alaska, spilled approximately 40,000 tons of crude oil), the Erika (spilled approximately 30,884 tons of fuel oil and polluted over 400 kilometers French coast), the Prestige (broke in two and sunk west of Vigo – Spain. Approximately 63,000 tons of heavy fuel oil was spilled. These adverse effects of hydrocarbons release demonstrated the enormous damage caused to the marine ecosystem of the coastal zone, to fisheries and other coastal amenities. Oil slicks pose the greatest threat to sea birds and marine mammals, fouling skin or feathers. Severity of oil spills on marine organisms depends on the type of oil, exposure pathway, and degree of weathering (12). Oil harms marine organisms via acute toxicity, sub lethal health effects reducing fitness, and disruption of marine communities. Moreover, the oil that covers the sea due to the spills, blocks O_2, CO_2 and other gas exchange and causes the destruction of the ocean dissolved gas cycle balance. Also, photosynthesis is affected as oil hinders the penetration of sunlight into the ocean, water temperature drops, thus further undermining the ocean O_2, CO_2 balance. Due to this, marine fisheries resources gradually decline.

Human health is also affected by marine pollution. Problems of anesthesia and suffocation, chemical pneumonia and dermatitis are also observed in humans. Respiratory system damage; inhaled large number of diesel oil droplets in the short term can lead to chemical pneumonia. Studies have found that children living near gas stations or auto repair shops have a fourfold higher risk of developing acute leukemia than those who have children who are at risk of developing acute leukemia. These children are at risk of developing acute leukemia. The risk of acute non-lymphocytic leukemia is seven times higher than that of children living in the same area but not near the gas station.

Aquatic organisms are also affected by marine pollution, as their growth and reproduction are threatened. Toxic compounds in pollutants can change cell activity of algae and other plankton causing even death due to acute poisoning. The damage of petroleum hydrocarbons to marine organisms is mainly manifested by destroying the normal structure and permeability of cell membranes and by interfering with the enzyme system of organisms, thus affecting the normal physiological and biochemical processes of organisms within them.

Cruise ships, tankers and bulk cargo carriers use a huge amount of ballast water which is taken often from coastal waters and discharge at the next port of call, which may be very far away. Many different biological materials like animals, plants, bacteria are included in ballast water and therefore its discharge into a new and very different environment can cause severe ecological damage to the ecosystem, along with human health problems. Underwater noise produced by ships, can travel long distances and harm the orientation of species that rely on sound. As a result, many species face communication problems, ending up to environments that cannot support them. Moreover, marine species are harmed, injured or killed by the solid waste that are generated by the ships i.e. glass, paper, aluminum and plastics. It has been estimated that a large cruise ship can generate 8 tons of solid waste in a period of one week and thus the impact during the lifetime of a ship can be tremendous.

To sum up , despite the fact that the marine environment is capable of self-recovery after oil spill, further revision is needed on both mode of assessment and admissibility of claims to allow more claims of environmental damage and preventive measures to be taken for cleaner oceans. Coastal states should become more involved in marine environment research and studies to better understand the value of the marine environment should be implemented. Such research will help to highlight and in some cases eliminate problems arising from oil spill incidents, especially when claims for compensation are in stake.

2. International and EU policies

2.1 IMO Regulations over the years

Many international organizations have set the goal to preserve human life and protect the environment. The International Maritime Organization along with EU has imposed regulations in order to put some limits to emissions by ships and reduce the hazardous impacts of pollution.

The efforts of protecting the environment have not started in 2020 but go back some decades. During the years, regulations have evolved, have become more strict and new parameters were added. The implementation of changes takes time as shipping companies need to adjust accordingly.

The first milestone was set in the 1970s, when 71 countries adopted a global convention for marine pollution prevention (MARPOL). MARPOL is a series of regulations that aim to eliminate marine pollution mostly from oil spills, either as a result of the activities of ships or as a result of accidents. Initially, the regulations were more general and were not strictly about air pollution but year by year the concerns regarding the atmosphere increased. This led to another milestone, in September 1997, when MARPOL was again revised and the International Maritime Organization (IMO), incorporated the Annex VI to the International Convention on the Prevention of Pollution from Ships (principally known as the MARPOL Convention) (Airclim.org, 2017). The objective of MARPOL Annex VI was the introduction of new restrictions that would lead to the reduction of vessel-originated emissions, most importantly Sulfur, nitrous oxides (SOx and NOx) and particulate matter particles. Emissions responsible for damaging the atmospheric ozone are considered to be root causes for several environmental and human health issues (IMO, 2016).

The International Maritime Organization (IMO) is marking a decade of action since it has adopted the first set of mandatory efficiency measures of ships. IMO has started cutting greenhouse gas emissions on 15 July 2011, as part of the International Convention for the Prevention of Pollution from Ships (MARPOL). The package of new rules has been added in Chapter 4 of MARPOL Annex VI entitled "Regulations on energy efficiency for ships" and is composed of two main measures:

- The Energy Efficiency Design Index (EEDI), which requires new ships to comply with minimum mandatory energy efficiency performance levels, increasing over time through different phases
- The Ship Energy Efficiency Plan (SEEMP), which establishes a mechanism for ship-owners to improve the energy efficiency of both new and existing ships using operational measures such as weather routing, trim and draught optimization, speed optimization, just-in-time arrival in ports etc.

The regulations entered into force on January 2013 and applied to all ships of 400 gross tonnages and above, irrespective of flag and ownership. These measures have become the first mandatory global GHG reduction regime for the shipping industry.

In 2015, the revised MARPOL planned for reduction of SO_x to 0,1% in areas outside the Special Emission Control Areas (SECAs). Outside ECAs the Sulphur limit was lowered from 3,5% to 0,5%. Two ECAs have been established in European waters, covering the Baltic Sea and the North Sea. In 2016, the IMO announced a global Sulphur cap of 0,5% in all waters except ECAs, which was put in force in January 2020. Later on, in March 2020, carriage of non-compliant fuels was banned in ships without scrubbers.

In 2016, IMO's Marine Environment Protection Committee (MEPC) adopted measurements that were made mandatory for ships of 5,000 gross tonnage and above, as well as to collect and submit fuel oil consumption data and then proceed with submission to IMO. These measures have been adopted as a plan for the IMO strategy regarding the overall reduction of GHG emissions.

2.2 IMO Strategy on reduction of GHG emissions

On 13 April 2018, MPEC 72 came up with a resolution regarding IMOs initial strategy to reduce GHG emissions from ships. IMO has committed to a structured plan that will drastically reduce emissions of international shipping in the years to come. The initial IMO strategy identifies the following measures:

1. Carbon intensity of ships to be declined through implementation of more phases of the energy efficiency design index of new vessels.
2. Carbon intensity of international shipping to decline: the target is to reduce CO_2 emissions per transport work, as an average across international shipping by at least 40% by 2030, targeting a percentage of 70% by 2050 compared to 2008
3. GHG emissions from international shipping: annual GHG emissions should be reduced also by at least 50% by 2050 compared to 2008.

In 2019, MPEC 74 proceeded with some follow up actions in order to support the initial strategy. Firstly, the approval of the amendments to MAPROL Annex VI was achieved in order to strengthen the existing energy efficiency mandatory requirements (EEDI) for some categories of new ships. A new study was initiated later on – Fourth IMO GHG Study- which included an inventory of global GHG emissions from international shipping estimates of carbon intensity of the global fleet and scenarios regarding future emissions of the shipping sector. In addition, actions have been promoted regarding cooperation between ports and the shipping sector. This plan focus on promoting technical, economic and operational actions in the port sector, the provision of bunkering of alternative low-carbon and zero-carbon fuels, the promotion of incentives for sustainable low-carbon shipping and the optimization of port calls, including facilitation of just-in-time arrival of ships.

In June 2021, IMO adopted key short-term measures that aimed at cutting the carbon intensity of all ships by at least 40% by 2030, in line with the ambitions set out in the initial IMO strategy.

These measures combine technical and operational approaches to improve the energy efficiency of ships. All ships will have to calculate their Energy Efficiency Existing Ship Index (EEXI) and ships over 5,000 gross tonnages will have to establish their annual operational carbon intensity indicator and rating. Particularly, ships will acquire a rating of their energy efficiency - A, B, C, D, E - where A is the best. These strict measures show that IMO targets can bring changes in the market and that all parties should cooperate (administrations, port authorities and stakeholders). According to this rating system, if a ship is underrated for three consecutive years (D or E) , it will be required to submit a corrective action plan, to show how the required index could be achieved.

Achievement of IMO 2030 targets can be met only with available technology through operational measures, improvements in operational efficiency, limited use of low-carbon fuels and enhanced energy efficient designs. Investments need to be made to domains of R&D, infrastructure and trials. IMO has executed many projects that focus on supporting countries to implement the energy efficiency measures. Some examples are:

- the GEF-UNDP-IMO Global Maritime Energy Efficiency Project (GloMEEP) that assisted a number of lead pilot countries to initiate legal, policy and institutional reforms and build the related capacity to start implementing the MARPOL Annex VI at national level .
- the European Union-funded Global Maritime Technology Cooperation Centre Network (GMN) project has established five regional centers of excellence and several pilot projects are ongoing. One in the Pacific has installed solar panels on a ferry - leading to fuel savings of 32% in operation and 87% reduction in GHG emissions at anchor.
- The GreenVoyage2050 project

Moreover, there are many other initiatives which support the way to decarbonisation. The United Nations-IMO backed Global Industry Alliance (GIA) supports a transition towards an energy efficient and low carbon future for shipping. The Getting to Zero Coalition, a broad alliance of companies from the maritime, energy, infrastructure and finance sectors, is seeking to put commercially viable deep sea zero emission vessels with zero emission fuels into operation by 2030.

The GreenVoyage2050 Project is actively supporting States in progressing in this decarbonization path. The project will also build capacity in developing countries, including small island developing states (SIDS) and least developed countries (LDCs), to fulfil their commitments to meet climate-change and energy-efficiency goals for international shipping. This will be achieved through supporting States in implementing the already-adopted IMO energy-efficiency measures (contained in Annex VI of the International Convention for the Prevention of Pollution form Ships (MARPOL)) and to reduce GHG emissions from ships in line with the IMO Initial GHG Strategy. Azerbaijan, Belize, China, Cook Islands, Ecuador, Georgia, India, Kenya, Solomon Islands, South Africa and Sri Lanka are partnering countries in the GreenVoyage2050 Project.

The project is supporting States to:

- draft legislation to implement MARPOL Annex VI into national law;
- undertake assessments of maritime emissions; develop policy frameworks and National Action Plans (NAPs) to address GHG emissions from ships;
- assess emissions and develop port-specific emission reduction strategies;
- identify opportunities and deliver pilot projects, through the establishment of public-private sector partnerships and mobilization of financial resources;
- access funding and investments into low carbon solutions; and
- establish partnerships with the industry to develop new and innovative solutions to support low carbon shipping.

The project is also supporting cooperation between ship and port sectors in the individual States. (13)

2.3 EU Developments

EU and IMO are almost on the same page about the regulations and initiatives on reducing emissions from ships. Regarding the SO_x limits, EU has transposed into law the IMO limits on May 2016. The EU also set the same limit for ships calling at EU ports and a 0.5% limit for all other EU waters from 1 January 2020. The NOx emissions limits for EU countries are established within EU air quality standards for air pollutants in ambient air and there is no EU shipping-specific legislation.

Moreover, in 2015 the EU has developed a system for monitoring, reporting and verification of CO2 emissions from maritime transport in 2015 (the 'MRV Regulation' 2015/757/EU), as a first step towards reducing shipping GHG emissions in EU waters. It obliges ships of all flags above 5,000 tones, calling at ports in the European Economic Area (EEA), to collect and report their CO2 emission data, based on their fuel consumption. The system covers intra-EEA voyages, as well as the incoming voyage into the EEA and the outgoing voyage to a non-EEA port, with data collection starting in 2018.The system envisaged setting GHG reduction targets for the maritime transport sector and introducing further measures including market-based ones. It was to be modified once IMO adopted comparable measures. However, since data collection under the global IMO DCS (Data Collection System), companies have been obliged to report similar data twice.

Main obligations for companies eligible under the EU MRV Regulation:

1. Monitoring: From 1 January 2018, companies shall – in line with their respective monitoring plans – monitor for each of their ships CO2 emissions, fuel consumption and other parameters, such as distance travelled, time at sea and cargo carried on a per voyage basis, so as to gather annual data into an emissions report submitted to an accredited MRV shipping verifier.
2. Emissions report: From 2019, by 30 April of each year, companies shall, through THETIS MRV, submit to the Commission and to the States in which those ships are registered ('flag States') a satisfactorily verified emissions report for each ship that has performed maritime transport activities in the European Economic Area in the previous reporting period (calendar year).
3. Document of compliance: From 2019, by 30 June of each year, companies shall ensure that all their ships that have performed activities in the previous reporting period and are visiting ports in the European Economic Area carry on board a document of compliance issued by THETIS MRV. This obligation might be subject to inspections by Member States' authorities.

The EU has also gone forward with other initiatives regarding the field of LNG. It has promoted LNG infrastructure in ports both with regulation and projects financing, with the programme of Connecting Europe Facility. It has also supported research and development initiatives advancing alternative fuels and innovative energy and transport solutions, mainly under the Horizon 2020 programme. There were included a fully electric ferry, a ferry fueled by hydrogen from local renewable sources, wind assisted ship propulsion, as well as a full-scale demonstration combining seven new technologies.

In December 2019, the European Commission published the European Green Deal, its flagship programme to make Europe the first climate-neutral continent by 2050, boost its industrial competitiveness and ensure a just transition for the regions and workers affected. The programme seeks to reduce GHG emissions from transport by 90 % across all transport modes. With respect to shipping, the Commission proposes to include maritime CO2 emissions in the EU carbon market (EU Emissions Trading Scheme (ETS)) and examine the existing tax exemptions for maritime fuels. In parallel, it wants to support the production and deployment of sustainable alternative fuels to accelerate the deployment of zero- and low-emission vessels. It also intends to regulate access for the most polluting ships to EU ports and oblige docked ships to use shore-side electricity.

3. Emission Reduction Measures

IMO regulations and targets have brought the environmental issue in the front page of the discussion of all parties associated with the shipping sector. The urgency to follow a greener behavior is a must do and all stakeholders must adapt to the new era. Shipping companies, investors, customers, need to develop new practices in order to follow and achieve the new rules. If someone stays behind, this may lead to their exit from the business.

In this chapter we will make an analysis of the possible options that international shipping must implement in order to reduce emissions, which will be divided into technological, operational and market based categories. Not all measures we talk about will be an option for shipping companies, as some measures are not that feasible or maybe some companies prefer to invest in ways that look more cost effective. The decision process will be based also on the market conditions, time variables and circumstances in which a marine vessel operates.

3.1 Technological Options

An important variable that is connected with the emissions problem are the fuels which marine vessel use and their fuel consumption. Usually, marine vessels use bunker oil which is not of top quality and leads to very high emissions per output. Since IMO regulations have changed and made mandatory the sulfur regulation, shipping companies, ship owners and ship operators need to investigate on the available desulfurization and decarbonisation requirements.

3.1.1 Scrubbers

The option of scrubbers it is a simple way to comply with the latest IMO regulation on marine fuels .Vessels will need to be equipped with Exhaust Gas Cleaning Systems (EGCS), which can be installed at any vessel of any type, size and age. This could be a costly and time consuming operation, especially if retrofitting a vessel and also there are extra costs of maintaining the scrubber exhaust gas system. Whether it is a viable option will largely depend on the difference in price between high and low sulfur fuels. Scrubbers are divided in three types: open loop, closed loop and hybrid systems.

Open loop is the easiest wet scrubber system because it uses only pumped seawater for scrubbing, then it is filtered and ultimately dispensed, while the sludge stays on deck, to be deposited in the respective port facilities. This type of scrubber can be used to comply with sulfur content by either 0.5 percent or 0.1 percent.

Closed loop scrubber system discharges just a small amount of scrubbing fluid as opposed to the open loop system. Instead, by chemically treating the liquid in the respective tanks, the fluid is circulated and re-used, fact that attributes to a decrease in the quantity needed and therefore in the size of the mechanism, amid with the energy required. The fact that a constant intake and discharge of water is required can be inconvenient at times. The fresh water intake is crucial to purification, meaning that if the surrounding water quality is not correct, the system might not perform as it should and there is also the issue of waste removal. Not all ports will permit water containing sulfur to be discharged. Closed loop scrubbers utilize the same principal. The water is chemically treated with caustic soda injection. This acts as the scrubbing agent and is circulated within the system requiring only minimal water intake. This bypasses the process of waste treatment and discharge in the ocean. However it creates a problem with the space requirements on board for the installation of the extra holding and treatment tanks.

Although continuous developments in scrubber technology, ship-owners are reluctant to invest in EGCS, since they are extremely costly (between $1–5 million USD per ship), require up to 20 days for installation and do not actually reduce sulfur, as they mainly transfer it from the atmosphere to the sea. For example, in 2018 DNV GL reported just 817 ships ordered or installed with scrubbers out a global commercial fleet of 60,000 vessels (14). The time needed for installation of the new ship will make the ship off hire for too long and this is a factor that companies with large fleets take into consideration in order to proceed with the investment. Moreover additional training of the crew will be needed which means extra costs. From the emission aspect, there is also another drawback – SO_X will be limited but no impact in reduction of NO_x will take place. The IMO is reviewing its 2015 scrubber guidelines and assessing the impact of discharges. Meanwhile environmental organizations call for a scrubber ban, to stop 'turning air pollution into water pollution', which has a cumulative impact on seawater, sediments and wildlife.

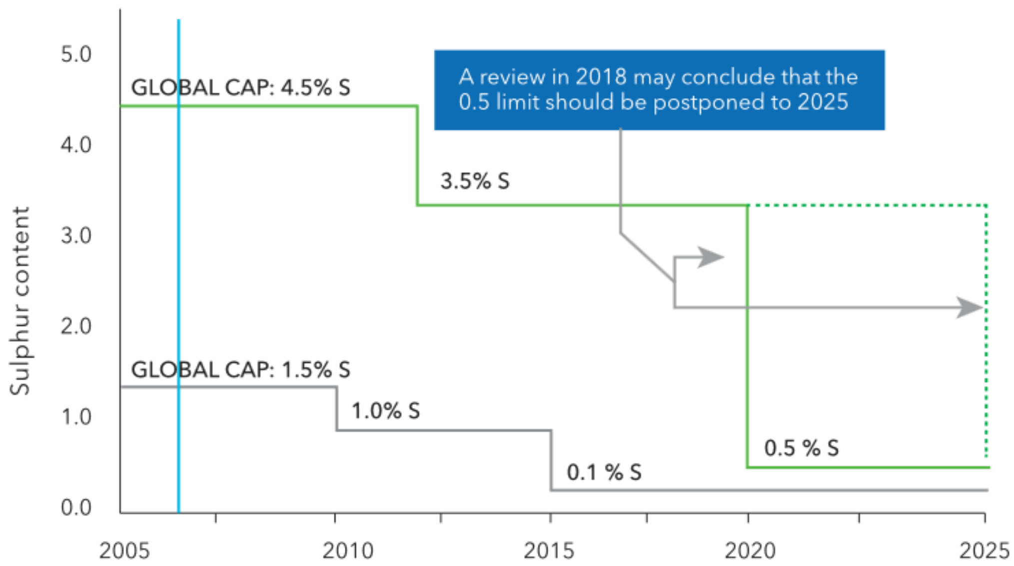

Figure 4: MARPOL Annex VI fuel sulphur content limits (DNV 2014)

3.1.2 Low Sulfur Oil

Maritime companies have the option of using cleaner marine fuel in terms of Sulfur consistency. Ships can use low-sulfur fuel oil, such as marine gas oil (MGO), instead of heavy fuel oil (HFO). Many ship-owners will switch to MGO to comply with the IMO’s 0.5% sulfur limit. Also it will be a feasible option as LSF can be used by most engines after required modifications but at the same time it is likely to expect an increase in the dependency of the vessels’ operational expenses on the anticipated rise of the LSF. This option will trigger the price of price of compliant low- sulfur oils.

3.1.3 Alternative Shipping Fuels

Apart from the installation of scrubbers**,** another way to achieve decarbonization targets is the switch to use of carbon neutral fuels. In this chapter we will make an analysis of the alternative fuels that shipping companies can invest to and what are the advantages of each alternative. The implementation of alternative fuels in the market seems to bring other risks that are connected to the safety of the ship and people on board i.e. high flammability caused by hydrogen. The key candidate fuels appear to be liquefied natural gas (LNG), liquefied petroleum gas (LPG), methanol, biofuels and hydrogen. We will also discuss the alternative of renewable energy, electrification and ammonia.

LNG – Liquefied Natural Gas

LNG is one of the most famous and preferred compliance options in marine sector. LNG's main component is methane. With a boiling point at -162°C, LNG must be stored in insulated tanks, which occupy three to four times the volume of fuel oil to provide equivalent amounts of energy. LNG reduces CO_2 by 20%, removal of SO_x and reduction of NO_x up to 85%. The selection of LNG seems to be feasible as there are available quantities worldwide to satisfy the market needs and demands. This factor is something that companies take into consideration and has an impact to the way ship owners tend to expand their fleets with LNG or even changing them. In 2018 the global LNG fleet was 525 vessels in total and by end of 2021were expected to be delivered 600 LNG vessels. Some of the world’s largest container shipping companies-MSC and Maersk already own or are reported to have ordered mega container vessels powered by LNG (15). Also LNG demand will be affected – around 20 to 30 million tons by 2030, while today it is estimated less than one million tons per annum. High demand will bring an increase also to price of conventional fuels.

On the negative side of LNG usage, one factor is the modification a ship to LNG vessel. Extensive modifications would be required to do in existing vessels so they can be efficient. LNG storage can take up to twice the space conventional fuels might require, because of the extra storage tanks for cooling and insulation and the extra pipes. LNG fueled engines in vessels can attribute to a diminution of the CO2 emissions to nearly 0%, however sufficient bunkering stations and infrastructures in ports is regarded as an imperative prerequisite for the option to be viable in a large scale in the maritime world (European Commission, 2013). Moreover, there are some concerns regarding the actual reduction of GHG emissions as LNG does not lead to CO_2 reduction as per IMO targets. The life cycle assessment of LNG as a marine fuel shows an impact on climate change of the same order of magnitude as with the use of HFO if not higher. Furthermore, depending on the fuel's supply chain used, a switch to LNG can even increase GHG emissions related to conventional fuels. (16)

Methanol

Methanol is not that known as a compliance solution but researches have been undertaken in order to see how it can be implemented. It is liquid at room temperature so it makes it easier to store compared to LNG. It can be mainly used in dual-fuel engines and offer several advantages in terms of reductions of NOx and PM emissions, it is sulfur-free and can be used in compliance with SECAs regulations. Is produced from coal or natural gas, but methanol can also be produced from lignocellulosic feedstocks such as agricultural waste, from biomass collected from sustainable managed forests to produce bio-methanol, or from gasification of municipal solid waste. Considering the life cycle of both HFO and methanol from natural gas, methanol is estimated to have 10% higher GHG emissions than HFO. There is low cost for conversion of existing engines and it is biodegradable, with a lower impact on the environment, even at the event of spill. On the negative side, there is limited availability of global infrastructure and bunkering facilities, so it will not be a solution that ship owners will tend to use. Moreover there are risks of fire and if ingested or inhaled, it can be toxic for human health.

Ammonia

Use of ammonia as shipping fuel is something that has been studied several times but there is no marine engine currently capable of burning it. Even though there are no CO_2 emissions by burning ammonia, and the conversion process is cheap and uncomplicated, it brings some technical disadvantages. There is low flammability and there are difficulties in increasing the engine input. Also large storage capacity is required and more frequent refueling. Moreover there is a huge environmental impact as there are N_2O emissions which have an enormous impact compared to CO_2 emissions. Current technology levels of ammonia fuel applications, fuel cells and combustion engine, are still in the development and research stages, with few real-world applications in the shipping industry at present.

Hydrogen

Fuel cells can efficiently produce electricity by using the chemical energy of hydrogen or another fuel and are more efficient than traditional reciprocating engines, since their fuel to electricity conversion efficiency can reach up to 60%, instead of 40% of conventional engines. Hydrogen is the smallest and lightest of all gas molecules, thus offering the best energy-to-weight storage ratio of all fuels. However, hydrogen as fuel can be difficult and costly to produce, transport and store. Compressed hydrogen has a very low energy density by volume requiring six to seven times more space than HFO. On the other hand, the drawbacks of using hydrogen as alternative fuel start with the fact that hydrogen does not exist naturally – it needs fossil fuel sources. In order to stay in liquid state it requires temperature of -235 C which creates a technological challenge itself. Bunkering technologies and infrastructure need to be developed in order to support this alternative. There also safety issues as it is highly combustible and explosive. A report by European Maritime Safety Agency – EMSA recognizes that fuel cell technology is still a diminutive business on a global scale, and several hurdles must be overcome before it can become a viable and realistic alternative for future energy solutions. Significant improvements in technology, accompanied by cost reductions are required if fuel cells are to become competitive for ships. With the recent commercialization of certain land-based fuel cell applications, there is reason to believe that costs will fall. For ship applications, reductions in size and weight are also of immense importance, while response at transient loads also remains a big issue. Fuel cells can become a part of the future power production on ships, and in the near future it might be possible to see successful niche applications for some specialized ships, particularly in combination with hybrid battery systems.

Biofuels

Biofuels can be derived from three primary sources: edible crops, non-edible crops (waste, or crops harvested on marginal land) and algae, which can grow on water and does not compete with food production. Biofuels are a potential alternative fuel in order to achieve decarbonization targets, as they are highly biodegradable. They do not require significant technical modifications so it is a feasible option for the shipping companies. They are carbon neutral - derived from biologically renewable resources such as plant-based sugars and usually blended with traditional marine fuels or used as a ‘drop-in’ fuel, compatible with current conventional marine engines. Biofuels are also flexible: they can be mixed with conventional fossil fuels to power conventional internal combustion engines, while biogas produced from waste can be used to replace LNG.

The main challenge for their adoption on a large scale concerns the possibility to secure the necessary production volume. Biofuels derived from waste have many benefits, but securing the necessary production volume is a challenge. Consider that the land required for production of 300 M Tonnes of Oil Equivalent (TOE) biodiesel based on today's (first and second generation biofuels) technology is slightly larger than 5 % of the current agricultural land in the world. Algae-based biofuels seem to be the most efficient and the process has the added benefit of consuming significant quantities of CO_2, but more work needs to be done to identify alga strains that would be suitable for efficient large scale production. Concerns related to long-term storage stability of biofuels on board ships, and issues with corrosion also need to be addressed (18).

Electrification

In recent years, battery-electric propulsion, using Lithium Ion (Li-ion) batteries, has been successfully applied on small, short-sea vessels. The potential for batteries in combination with a two-stroke main engine in a hybrid system is being evaluated for larger ocean-going vessels. The interest in switching to electrification has been increased in shipping sector as it improves energy management and also reduces the emissions in port areas. The ways that electrification can be used it is divided to power berthing ships- cold ironing and to charge batteries for full electric or hybrid ships. Cold ironing is the process of providing shore side electrical power to a ship at berth while its main and auxiliary engines are turned off. When a ship is in port, auxiliary engines –generators - are commonly used to provide required power for cargo operations, emergency equipment, and cooling, heating, lighting as well as domestic use. By simply turning off generators and plugging in to an electrical supply point in the ports, fuel consumption saving and subsequently reduction of noise and air emission can be achieved.

The alternative of electrification seems appealing to companies but there are some technical issues of implementation for deep-sea shipping. The power system of full-electric ships is based on batteries charged from the onshore grid while at berth, whereas battery hybrid ships do not bunker electricity from shore but use batteries to improve the energy efficiency. Ships that cover short distances can have electric batteries or hybrid propulsion systems but ships that cover large distances cannot be significantly energy independent. The potential of electrification to reduce GHG emissions depends heavily on the source of electricity. According to DNV GL forecast, 30% of all global electricity production will come from wind energy by 2050—12% from offshore wind and 18%from onshore wind. Today's levels are 0.2% and 4.1%, respectively, of global electricity production (19).

Challenges related to safety, availability of materials used, and lifetime must be addressed to ensure that battery-driven vessels are competitive to conventional ones, but the pace of technology is advancing rapidly. Other energy storage technologies that can find application in shipping in the future include flywheels, supercapacitors, and thermal energy storage devices.

Significant growth in hybrid ships, such as harbor tugs, offshore service vessels, and ferries should be expected after 2020, and further applications for technology may be applied to power cranes for bulk carriers or even in ports. After 2030, improvements in energy storage technology will enable some degree of hybridization for most ships. For large, deep sea vessels, the hybrid architecture will be utilized for powering auxiliary systems, maneuvering and port operations, to reduce local emissions when in populated areas.

Figure 5: Comparison of Alternative Marine Fuels (Source: DNV GL)

The decision of shipping companies for the potential alternative fuels depends on the way their fleet behaves and what kind of voyages they cover. Short sea vessels operate mostly on short routes, where they will call a port more frequently than a vessel that has a deep sea voyage. Also short sea vessels are most possible to operate in areas under environmental controls with also other regulations affecting them. These routes provide the chance to the vessels to recharge frequently and have specialized support in the ports. Thus alternative option like biofuels, methanol and hybrid ships is most likely to be appeared in short sea vessels.

Vessels that operate in oceans and tend to do longer voyages without calling in a short time period a port will need to be autonomous and use a fuel that will be globally available. Also the fact that the vessel will cover long distances means that the cargo space availability need to be big enough, something that comes in contrast with the fuels capacity, which need available space in order for their mechanism to be installed. For this category of vessels, LNG seems to be the most preferable option along with biofuels, methanol and LPG.

3.1.4 Ship Design Measures

Measures that are related to ship design can also bring results in emissions reductions. These measures include the options of hull optimization, the improvement of propulsion systems and the development of more energy efficient vessel designs. The shape of a ship's hull can impact the performance of the ship. Hull optimization focuses on minimizing the wave resistance and friction between water and hull. The reduced frictional resistance increases energy efficiency of the ship, particularly at reduced speeds. Optimization measures are generally applied on new-built ships but also applicable to retrofitting of existing ships. The optimization measures can have an impact also to CO_2 emissions, reducing them up to 15%. However hull optimization can bring results only if we have a combination of speed reduction of the vessel.

Other way of lowering the frictional resistance is to improve the smoothness of a hull by means of coatings that reduce fouling. In recent years there has been a lot of development in the coating technology, such as introduction of hydrogel. The use of hydrogel containing coatings makes the surface of the hull behave like a liquid on a microscopic level.

Also there are devices that have been designed to improve the energy efficiency of the ship. They recover as much as possible of the rotational energy in the flow from the propeller, provide some pre-or post-rotation of the in-flow into and after the propeller so they can ensure best performance. Moreover, there are wind-assisted propulsion systems like sail, kites. For such systems, the availability of wind and therefore the operation area of wind-assisted vessels is the most relevant factor.

The modifications that need to be made to the existing ships can be more expensive than the new designs. In order to make a successful ship design, you need to know the factors that are related to the ship itself like the types of goods that will be transported, the way that the process of loading-unloading will be and which market the ship will enter. Based on these requirements, the conceptual design phase starts, the dimensions and layout of the ship are determined and powering needs are decided. The design phase consists mainly of technical feasibility studies in order to decide whether the mission requirements can be translated into reasonable technical parameters and still produce a seaworthy ship.

All these measures have to do with the latest IMO regulations regarding the Energy Efficiency Design Index–EEDI, adopted in 2011. The EEDI depends on the installed engine power and the expected power at design speed and gives an estimate of CO2 emissions per dwt. Thus EEDI affects only newbuilding ships and is estimated that vessels will be covered by EEDI by 2040. The enhancement of the EEDI and the development of a Ship Energy Efficiency Management Plan (SEEMP) to reduce the energy consumption of ships are the main measures on which the IMO Initial Strategy focuses on the short-term.

3.2 Operational Options

While the biggest impact on decarbonization process will be the choice of green fuels and energy converter, these fuels and technology shifts must go together with greater energy efficiency of ships, requiring intensified uptake of both technical and operational energy-efficiency measures. All vessels can make some use of efficiency technologies and explore alternative fuels; individual strategies must be shaped based on the type of vessels, the cargo and the route. Operational measures refer to measures that have to do with the operation of the ship such as speed, ship size and route voyages. Also ship port interface can decrease ship waiting time before entering a port. Operational measures are easier to adopt compared to technical measures as they do not require major investments, are easier to be implemented and can bring significant benefits in short time.

3.2.1 Speed Management

It is a well-known fact that lower speed reduces fuel consumptions and emissions. A rule of thumb used in the literature states that engine power output of a ship is a third power function of speed. This means that a speed reduction of 10% translates into engine power reduction of 27%. As it takes longer to sail a given distance at a lower speed, a 10% speed reduction results in a reduction of the energy required for a voyage by 19%.

There are many ways that speed reduction can be achieved. Ship operators can reduce vessel's speed in order to have lower fuel consumption especially in periods that freight rates are low and fuel process is high. Of course this scenario is in contrast with the time periods in which market demand is high and vessels need to cooperate with customer needs. Moreover, ship speed also is something that can be regulated. It could be regulated globally what the average ship seed could be so speed optimization can be achieved. If there were speed limits, then there will be a total average emissions reduction as well.

Speed reduction will have an impact of course to GHG emissions. Reductions can range from zero to 60% depending on the speed decrease. If the overcapacity in shipping markets in 2009 would have been used for slow steaming, emissions by bulkers, tankers and container vessels could have been reduced by 30% compared to 2007. Slow steaming is reported in every market. On a global scale, and according to the third GHG study of the IMO, the reduction of global maritime CO2 emissions from 885 million tonnes in 2007 to 796 million tonnes in 2012 is mainly attributed to slow steaming due to the serious slump in the shipping markets after 2008. (26) Lower speed also will affect the size of the global fleet as same services and transport will still be needed. This additional ship capacity might be available in times of overcapacity. If there is no overcapacity, it means additional investment in fleets. The highest effectiveness is found when the higher ship capacity required is accommodated by existing fleet overcapacity. Slower speeds lead to longer lead times, which could mean additional supply chain costs for shippers.

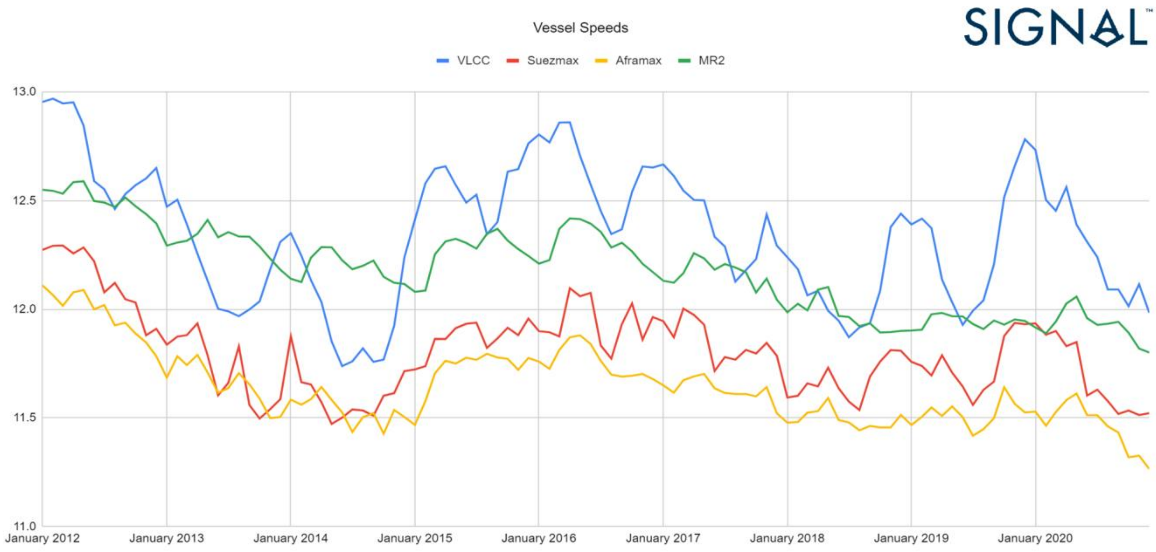

Figure 6: Speed report per vessel class 2012-2020 (Source: Signal Group)

As per above graph, the industry is used to adjusting the speed based on market conditions. The commercial decision of vessel speed follows the volatility of the spot freight market and market expectations for future earnings. We can say that with 1 knot reduction in vessel speed in the laden leg, there is potential to save around 2 million tons of CO2 on a yearly basis for tankers, however this can fluctuate with market conditions and is strongly influenced by the decisions of commercial operators as they navigate the challenges of supply and demand. Slow steaming can also contribute to reducing the shipping overcapacity, which today is the norm, but it can also have negative side-effects. Especially for short-sea trade, it could cause the shift towards alternative land-based transport alternatives, with a consequent increase of GHG emissions. Another measure that would increase ships energy efficiency is the port efficiency improvement, as this would reduce vessels turnaround time in port. With shorter time in port, the speed at sea can be reduced while preserving the transport service.

Moreover, we need to notice that reducing the vessel's speed, some risks appear concerning the function of vessels engine. Ships are built to operate within a given range of service speed, as such the potential savings related to slow steaming depend on the design speed and further speed reductions could even damage the engines. Nowadays many operators try to combine both strategies of slow steaming and gigantism of the ship size, in order to have the benefits of both slow steaming – lower fuel expenses- and economies of scale- more freight earned.

Slow steaming is an attractive option in times of economic recession with an overcapacity of ships, but the effects of slow steaming cannot be expected to be equally significant as the economy recovers and shipping services are more in demand.

3.2.2 Ship Size

Larger vessels of all ship types emit less CO_2 per ton - kilometer as long as the larger capacity is similarly utilized**.** This means that increasing ship size can help to reduce emissions. As dry bulk vessel size increases from 26 000 dwt to 46 000 dwt, the emissions per ton mile (nm) are reduced by 33%, while an increase from 46000 to 72000 dwt offers only a further 17% reduction.

Carbon emissions could be reduced by as much as 30% at a negative abatement cost by replacing the existing fleet with larger vessels. While deploying large ships tend to reduce energy consumption in the shipping leg, the total impact on overall door-to-door logistics performance may be negative unless such a move is complemented by smaller ships that can assist in the onward distribution of cargoes. With constant freight volumes, the introduction of larger vessels will tend to reduce sailing frequencies, and when sailing frequencies are reduced the total lead time from factory gate to customer will be longer (27) .But there will be limitations to implementation, as not every port will satisfy the draft and size of the vessels.

Also different ship types have different energy needs. A relevant example for the Latin American market is the transport of reefer cargo. Reefer cargo is transported in specialized reefer vessels or in refrigerated containers and demands extra energy for cooling. About 20% of the energy needed to transport food in refrigerated containers is used for refrigeration. Low freight rates have hit reefer companies hard as container ship operators have filled idle capacity in their ships by loading containerized reefer cargo. The ongoing cargo shift from specialized reefer vessels to container ships is likely to continue; there are no specialized reefer vessels on order and new-build container ships are increasing their capacity for refrigerated cargo.

3.2.3 Voyage Optimization

Voyage planning is an efficient way that helps ship operators to select optimal routes based on weather conditions, in order to reduce energy consumption. Other variables that are taken into account are arrival time and congestion in ports with target to reduce idle time. The practice of voyage optimization is very cost-effective as it allows shipping companies to reduce both their costs and reduce the carbon emissions by identifying routes in which vessels will run more efficiently and avoid bad weather conditions. A ship's voyage optimization problem can be mathematically formulated by the three components i.e., 1) decision variables, 2) objective function and 3) constraints.

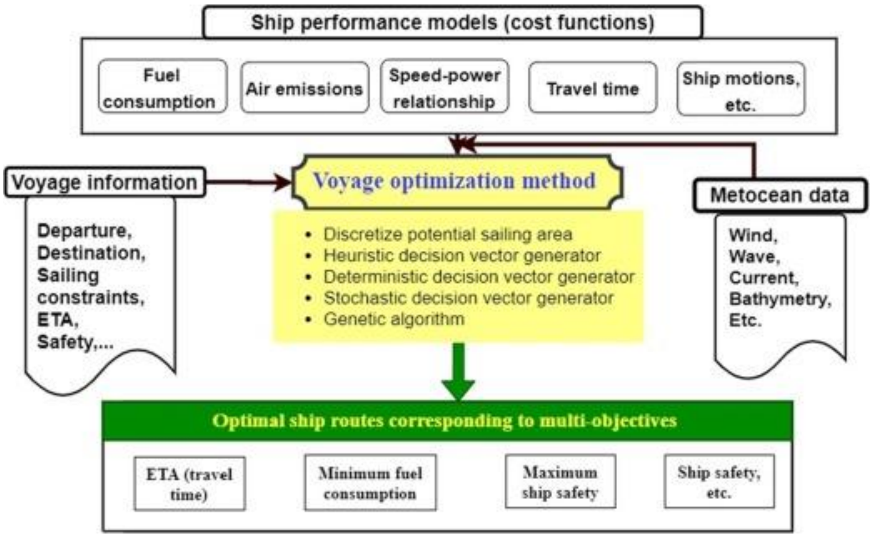

Figure 7: Voyage optimization method

Also ship-port interface means a significant reduction of the waiting time of ships. Ships use their auxiliary engines while waiting, so smoother ship-port interfaces would reduce the energy consumption during these waiting periods. In this it would help to have a more flexible berth planning. The vessel arrival time in port is considered a variable; it is assumed that the carrier will provide the terminal operator with a range of vessel arrival times – and that the terminal operator will schedule all vessels using these ranges, optimizing for vessels' arrival time. In order to achieve this, better communication between parties could take place. For example, terminal operators, port authorities and port service providers could exchange information so the berth plan can be more flexible.

If we achieve reduction on ship-port interfaces to zero time, the carbon emission reductions might amount to approximately 1% of total shipping emissions. CO_2 benefits depend on the ship waiting time reduction. Also local air pollutants will be reduced such as NOx, SOx and particles that have huge health impacts for citizens.

3.3 Market Based Measures

When we talk about market based measures, we refer to measures like laws, legislation which can be based on economic incentives in order to gain control on some matters. Our interest is the limit of emissions pollution so in our case market based measures can act:

1. by discouraging the use of high carbon fuels
2. by encouraging the adoption of low carbon practices

Price controls should take place and should be applied on global basis. Ship owners and operators pay a fixed amount based on the fuel consumption and part of this money are used for financing projects for CO_2 reduction. This type of tax cannot be controlled though. For example if a ship takes fuel onboard form a country where this is not applied, no tax will be fixed. Thus intervention of local authorities is necessary.

Also we have emissions quantity control approaches, such as cap-and-trade programs or emission trading schemes (ETS) that issue a limited number of annual allowances which allow companies to emit a certain amount of CO_2. If companies produce higher emissions than it is permitted- emissions cap- they will pay relevant tax. The cap should be carefully set: A too cautious cap may lead to skyrocketing prices when the availability of allowances is low on the market, whereas a too generous cap may undermine the original goal of the ETS.

No Market Based Measures have been applied on an international level so far, and it seems unlikely it will happen shortly. The EU proposal to include shipping in the ETS found strong opposition from the shipping industry, which claimed it may create distortions for efficient trade and hinder the global decarbonization process started by the IMO. However, in the framework of the IMO's Strategy, the implementation of these measures seem to be expected in the long-term.

Moreover incentive mechanisms can take place: Favorable tax systems or low interest loans for environmentally friendly interventions. Also ports have started to obtain a more green way of action and take initiatives that include discount to port fess for vessels that fulfill some environmental criteria. Also several shipping firms have begun to respond to environmental concerns by voluntarily embracing green shipping practices to make their operations "greener". Examples of such practices include counting the carbon footprint of shipping routes and using alternative transportation equipment to reduce environmental damage in performing shipping activities.

The International Maritime Organization is a good platform for the debate on a ruleset but it is critical that the debate begins now, in order for the industry to make the transition in time to reach our CO2 reduction targets**.** In line with the work plan adopted at MEPC 55 (October 2006), potential Market-Based Measures (MBMs) have been considered in-depth since MEPC 56 (July 2006). MEPC 55 work plan ceased at MEPC 59 (July 2009), where the Committee recognized that technical and operational measures would not be sufficient to satisfactorily reduce the amount of greenhouse gas (GHG) emissions from international shipping in view of the growth projections of world trade. It was therefore agreed by overwhelming majority that an MBM was needed as part of a comprehensive package of measure for the effective regulation of GHG emissions from international shipping. In this regard, the Committee agreed upon a new work plan for the further consideration of MBMs culminating in July 2011 at MEPC 62.

The new work plan guides the future discussions on MBMs as follows:

1. Member States, Associate Members and observer organizations should endeavor to submit further detailed outlines of possible MBMs to MEPC 60 (March 2010);
2. MEPC 60 would further consider the methodology and criteria for feasibility studies and impact assessments in relation to international shipping, giving priority to the overall impact on the maritime sectors of developing countries;
3. taking into account the outcome and conclusions of the studies mentioned in paragraph 2 above and any other contribution made, the Committee would be able, preferably by MEPC 61 (September/October 2010), to clearly indicate which MBM it wishes to evaluate further and identify the elements that could be included in such a measure; and
4. based on the outcome mentioned in paragraph 3, MEPC 62 (July 2011) could be in a position to report progress on the issue to the twenty-seventh regular session of the Assembly, to identify possible future steps.

Market Based Measures place a price on GHG emissions and serve two main purposes:

- providing an economic incentive for the maritime industry to reduce its fuel consumption by investing in more fuel efficient ships and technologies and to operate ships in a more energy efficient-manner (in-sector reductions); and
- offsetting in other sectors of growing ship emissions (out-of-sector reductions).

In addition, MBMs can generate funds that could be used for different purposes such as adaptation and transfer of technology.

MBM proposals submitted to the IMO were the following:

- The International Fund for Greenhouse Gas emissions from ships (GHG Fund) originally proposed by Cyprus, Denmark, the Marshall Islands, Nigeria, and the International Parcel Tanker Association-IPTA (Denmark, 2010).
- The Leveraged Incentive Scheme (LIS) to improve the energy efficiency of ships based on the International GHG Fund proposed by Japan (Japan, 2010)

- Achieving reduction in greenhouse gas emissions from ships through Port State arrangements utilizing the ship traffic, energy and environment model, STEEM (PSL) proposal by Jamaica (Jamaica, 2010)
- The United States proposal to reduce greenhouse gas emissions from international shipping, the Ship Efficiency and Credit Trading (SECT) (USA, 2010)
- Vessel Efficiency System (VES) proposal by World Shipping Council (WSC, 2010)
- The Global Emission Trading System (ETS) for international shipping proposal by Norway (Norway, 2010)
- Global Emissions Trading System (ETS) for international shipping proposal by the United Kingdom (UK, 2010)
- Further elements for the development of an Emissions Trading System (ETS) for International Shipping proposal by France (France, 2010)
- Market-Based Instruments: a penalty on trade and development proposal by the Bahamas (Bahamas 2010)
- A Rebate Mechanism (RM) for a market-based instrument for international shipping proposal by the International Union for the Conservation of Nature (IUCN 2010)

All measures analyzed above have different advantages and risks and every party that plays a role in the shipping sector tries to make a strategy in order to adapt to the new regulations. Beside the shipping companies that are part of this transition, another community that they will have to cooperate with is the scientific one. Scientists try to figure out how each technological and operation measure can be implemented, as there are many barriers that stand against these measures. Research and shipping community are in favor of four popular measures: speed reduction, EEDI, market based measures and LNG.

Regarding the short measure of speed reduction, which seems to be a feasible solution from the side of scientists and IMO –according to IMO initial strategy- it poses many challenges to shipping companies. Shipping owners are reluctant to this option, as reducing speed means that the delivery time will be reduced and the competition in the market will be affected. Slow steaming has become increasingly common in liner shipping as the amount of available capacity rises and the price of fuel increases- but in other markets this cannot be implemented as no advantages will appear for ship-owners side, except of reduction of fuels consumption.

Ship design measures are also a famous option for ship owners. The challenge that this option brings is safety issues. Ship design measures can refer most to owners who are willing to invest to newbuilding market. Thus this investment is not something owners prefer as it requires huge capital, not only for the construction of new marine vessels but also for the research that needs to take place in order to build a vessel that will be efficient and at the same time can cover their market needs.

Regarding market based measures, those in favor of MBMs argue that measures, such as cap-and-trade programs offer an incentive for companies to invest in cleaner technologies in order to avoid buying increasingly costly allowances and contribute to investments in low-carbon projects. Opponents argue that, by creating an exchange value for emissions, MBMs could lead to an overproduction of pollutants up to the maximum levels set by the government each year. Moreover, the implementation of an ETS, unless it is set globally, raises important controversies regarding the scope of a ship's emission liability. Some believe that ship must be charged for its emissions during the whole voyage between two ports if one of them is within ETS area. Other support that ship owners need to submit the allowances for the CO2 emitted inside the territorial waters and economic zone of the regulating authorities, which creates a total barrier to the way the monitoring system will work.

Last but not least, there is the option of LNG which is already established as a marine fuel in many vessels the last decade. Even though LNG has many environmental benefits, there are many disputes regarding its potential on decarbonization of shipping. GHG savings of LNG are reduced by upstream emissions that may arise within the LNG supply chain and during operation. According to several estimates of life-cycle GHG emissions from using LNG as a marine fuel, its global warming potential would be the same of HFO and MGO, or even higher (20). Thus, if LNG cannot achieve the IMO targets in GHG reduction, then it cannot be an option for ship owners. If LNG is an option only for a short time period, then there are many decisional and economical risks for ship owners. Firstly, those who already invested to LNG vessels will have to decide how they will use their assets in the future since vessels will not be chartered. Secondly they will have to bear the economic risks and maybe have negative cash flows. The duration of LNG as a marine fuel depends both on the possibility to achieve the needed returns on the made investments over the period it remains in demand, and on the extent to which non-fossil fuel sources will penetrate in shipping.

4. Challenges of Implementing Decarbonization Measures

Barriers are the explanations for the reluctance to adopt cost-effective energy efficiency measures derived from mainstream economics, organizational economics, and organizational and behavioral theories. There are also institutional or structural barriers to energy efficiency that do not directly affect the "gap", even though it does affect the overall level of energy efficiency.

The process of implementing the above decarbonization measures is not that simple because there are many barriers for ship owners and external stakeholders. There are high risks and uncertainties associated with the investments they will have to make as the transition to the low carbon measures is a costly one. Our analysis for the main barriers and challenges that the implementation of energy efficiency measures provoke, is divided into three categories: economic, technological and some side effects that will be categorized as general.

4.1 Economic Barriers

The economic feasibility of the implementation of new measures is one of the first variables that shipping community takes into account. Considering the transition to alternative fuels, shipping owners need to make a strategic decision on how their fleet will be structured: a fleet of newbuilding ships capable of using alternative fuels or updating the existing fleet with new engines. This is also a decision that has to do with the age of their fleet.

In any case, ship owners accessibility to the capital market is one of the biggest barriers they have to face. There are many small companies that have limited resources in order to invest in all their vessels, so as a result they will end up with less efficient fleet to operate, which will lead to market share decrease. Moreover they will have to bear the risk of market failure in terms of selecting an unsuccessful alternative fuel to proceed with. Also the investment of new equipment to secondhand vessels will not pay back the same capital back to the ship owners, as vessels of certain age will not be able to operate for longer time.

Obtaining additional capital in order to invest in energy-efficient technology may be problematic. Apart from low liquidity, limited access to capital may also arise due to restrictions on lending money. Also we need to notice that future capital is not something sure due to the fact that long term saving in operating costs can be affected by future economic conditions and future energy prices. Furthermore, shipping companies rely heavily on loans, which make up approximately 70% of capital in the sector. Smaller ship owners consider it particularly challenging to obtain funding for new ships, let alone for more sustainable alternatives that financiers currently regard them as financially and operationally riskier.

Regarding those who are interested in choosing LNG as marine fuel, they will need to invest more money compared to diesel fueled vessels. One barrier for the introduction of LNG is the increased demand for fuel tanks, leading to a decrease in payload capacity. The relatively high capital cost of the system installation is a big issue. LNG bunkering for ships is currently available only in a number of places in Europe, Incheon (Korea) and Buenos Aires (Argentina) but the world's bunkering grid is developing.

Same concerns exist also for other alternative fuels like electric solutions and fuel cell powered vessels. The installation and replacement costs of batteries are higher than traditional engines and also there is no essential shore based charging facilities.

Fuel-cell powered ships also are an expensive solution and is estimated that the capital costs will be 1.5 to 3.5 times higher than a comparable diesel vessel while operating costs are up to eight times higher.

Also the complexity of infrastructure replacement can be huge economic barrier. There is currently very limited infrastructure for the sustainable production of alternative fuels explored by the industry. A recent study by the University Maritime Advisory Services, estimates that 87% of the $1.65 trillion cost to decarbonize shipping by 2050 will need to be dedicated to creating supply and bunkering infrastructure (21).

Overall, companies are reluctant to invest on a large scale to alternative fuels unless they are forced to, either by government legislation or by consumer pressures. Depending on different countries, this means: subsidies for domestic programs, gas utilities being responsible for refueling stations and providing competitive gas prices etc. HFO, shipping's primary energy carrier today, is cheap, energy-dense and has well-established supply chains. As a by-product of the refining process, it is used by few other industries which create more certainty around cost and supply. As a result, new fuels will cost more and will require the industry to compete for supply with other industries. Without a stronger commercial or regulatory motive, operators are skeptical about their ability to find a fuel that is a viable alternative to HFO. Also stakeholders themselves must play part into developing and commercializing new technology. If a viable alternative is not found, various forms of carbon offsets will be required to reduce net emissions to levels that support the sector's ambition.

4.2 Technological Barriers

Apart from the economic barriers deriving from the process of green transition, shipping community has to deal also with the various technological issues that take place. As per above analysis of the alternative fuels that ship owners will have to adapt to, there is a big concern about the level of availability of these fuels resources. The high market demand of shipping transport is a status that will not change in the upcoming years, so alternative fuels must exist in large quantities in order to satisfy the high market needs. Especially for vessels that cover long distances, the only feasible alternative at the moment is the LNG.

Common issue of all alternative fuels is the current status of inappropriate infrastructure in the ports. In order for ports to start taking place to the shipping decarbonization process, facilities need to be developed accordingly. Their storage capacity should be high and ready to satisfy every kind of vessel and alternative fuel. This is something that needs to be developed in all ports globally, in order for marine vessels to be more feasible in their voyages and can expand their routings. Another reason that ports need to have globally developed infrastructure is that the storage capacity on board of ships is limited – thus the necessity for fuels supply is higher. For example, LNG fuel tanks require two to three times the volume of fuel-oil tanks with the same energy content. In the comparison between liquid and gaseous fuels, the former require storage tanks that are more easily integrable onboard. Conversely, storage tanks for gas fuels are typically more costly, space-consuming and challenging to integrate onboard.

Regarding the alternatives of biofuels, methanol and hydrogen, their potential for technical feasibility is very low as they are not expected to become feasible on a large scale within a short time because of several technical, economic and safety challenges. Many believe that fuel cell technology is immature. It will likely take at least 5-10 years before it becomes a viable alternative. If fuel cell technology was developed before hydrogen or ammonia are available at scale, transition fuels like LNG could potentially be used, and switched to a new fuel when it emerges. Regarding the alternative of ammonia, there is little evidence that other industries consider ammonia as a future fuel. For that reason, if shipping will select ammonia as its dominant fuel, it is likely that the infrastructure costs would be borne entirely by maritime sector.

Same technological issues arise also with the alternative of electricity and use of batteries. Electrifying small ships is great, but most emissions come from deep-sea shipping, and there are no viable options to address that with batteries. Despite major technological advances in battery capacity and efficiency, batteries must still become more efficient and less heavy to meet the needs of large ocean-going ships.

4.2 General Barriers

Following the economic and technologic challenges which green initiatives bring along, there are some other side effects that act as barriers. First variable that we can think of is the time of implementation that is needed for shipping community to adjust to green fuels or efficiency measures. For starters, the uncertainty coming from the knowledge gap regarding best green alternative, has as a result that ship owners become reluctant to start making changes to their fleets. Thus, time passes without many fleet changes and achieving the IMO regulations by 2030 will be tough. Moreover, even if there was an outcome for the best alternative for ship owners to follow, the time that will be needed to develop proper infrastructure in the ports will exceed IMO target period.

Another barrier that slows down the decarbonization process is the market and customer demand. Customers and charterers are not that willing to pay or co-fund on lower emission solutions. Main reason behind this is that sometimes they are not well aware of the green transition or even if they are aware, they are not that willing to change their buying behavior. Sustainable options are something that will increase the costs which they are not willing to pay.

Another barrier coming from the market conditions is the current lack of transparency regarding the emissions. There is no emission report conducted for regulatory purposes. As a result internal and external stakeholders- customers, investors – cannot identify top performers and verify who is reliable. As transparency grows, it will become easier for top operators to differentiate themselves by demonstrating the impact of their investments on emissions.

Moving on, there are other barriers related to unclear and unfair regulatory frameworks. The lack of binding regulation regarding the emissions creates an environment in which shipping community does not take measures until regulation becomes stricter. Also this situation has created an uneven competition. If global regulation takes too long, there is the risk that global or regional bodies move first, creating an uneven regulatory landscape and unnecessary complexity. For example the European Union could define emission regulations before the IMO, creating an uneven playing field. Companies with Europe-based operations could then end up carrying a larger proportion of the early decarbonisation costs than their competitors from other parts of the world. Thus, strict policies and regulations need to take over both international and national level in order to achieve correct green transition of shipping community and low carbon alternatives can be developed and promoted.

Last but not least, there is another challenge that has to do with the business relationship between ship owners and charterers. The contracts that parties sign in order to proceed with the shipment include agreements and clauses regarding technological and operational measures. For example, one major clause they discuss and agree is the speed management of the vessel. From one hand, ship owners are interested in slow steaming of the vessel in order to reduce emissions but on the other side charterers and customers are interested in avoiding delays- thus slow steaming alternative is not appealing to their side. In 2030 baseline scenario, time costs of transporting grains from the United States to Egypt are estimated as follows: 0.008 $/ Tonne.hour x 4.117 million tonnes x 640 hours = $21,097 million. A GHG reduction scenario would lead to 49 hours of additional sea transport time, on average, or a total journey of 690 hours. This translates into time costs of $22.725 million 63 or an increase of $1.63 million (22). So signing a contract between a ship owner and a charterer will be a more tough process in the future. Moreover, maybe contracts on spot market will be avoided as ship owners will prefer to operate their vessels in order to achieve slow steaming alternative or they will prefer to make long term agreements with charterers in order to split the costs and benefit at last in future.

5. Impact Assessment of IMO Measures

After discussing the challenges that the implementation of new IMO regulations bring to all parties in shipping community, we will try to assess what the impact will be in some categories. IMO regulations will have an effect on freight rates, fuels supply and demand will change, as well as fuels availability and their costs. Moreover ship building market will change and also parties such as charterers, flag states, and port state controls will have to adapt to accommodate the transition accordingly.

Freight Market

It is worth illustrating how freight rates change over time, and how the changes that may result from the IMO short-term measure are compared to freight rate levels and volatility. There are many factors that affect freight market: vessel size, vessel speed, shipbuilding capacity and market demand.

Shipbuilding capacity was an important contributor to the high freight market that existed in the period just before the global financial crisis. Newbuilding and freight markets in most sectors are cyclical, driven by the cash flow and balance sheets of ship owners. If supply of vessels is higher than the market demand, then we have oversupply and freight rates will drop. Fleet growth slows down and trade gets recovered. When supply and demand are in the same level, freight levels recover, ship owners start to be optimistic and order new vessels. Demand is affected by general economic growth in the world, trade in specific commodities and the distance that vessels have to sail to meet the demands. If speed is reduced across the sector in order to reduce emissions as per IMO, it will automatically reduce total fleet supply. Thus more vessels will be needed in order to satisfy market needs and freight rates will be increased extremely.

Building a new ship once an order is confirmed can take two to three years. Given the current low order book and the need for additional shipping capacity in view of the IMO short-term measure, the demand/supply balance is likely to also change**.** Depending on the rate at which new additional carrying capacity becomes available, the demand and supply mismatch that may result could potentially lead to higher freight rate levels, beyond the changes estimated solely from the changes in capital and operational costs assessed under the 2030 scenarios.

The capacity of the shipbuilding market to meet the demand for more ships will be an essential factor. Drewry estimates that the shipbuilding market’s capacity is equivalent to 7 of the global fleet and would expect that a ramp up period of approximately 5 years would be needed to ensure that an additional 13% of vessel capacity, in addition to normal fleet replacement and growth, were available in time for the implementation of IMO’s short-term measure.(22)

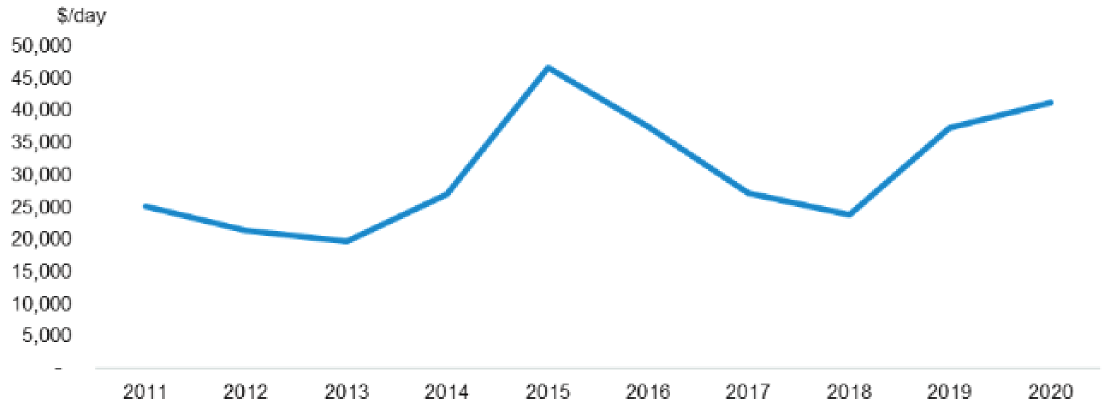

Figure 8: VLCC Time Charter Rates 2011-2020(Drewry Maritime Research, 2021.)

For example in the above graph, we can see that during the decade 2011-2020 there are some peaks and falls in the freight market of VLCC vessels. We notice that extreme high freights do happen but there are not that common. It is obvious that there is a pattern but for the reasons we analyzed above and external reasons i.e. pandemics, economic crisis, which are not easy to see coming. That's why ship owners cannot make exact prediction about the freight market in which they operate. Shipping market involves many risks and many ship owners may lose the game and drop out in case the make a false prediction.

Fuel Prices

The transition of shipping community to new alternative fuels will have also a great impact in the fuel prices and fuels availability. It is widely expected that the transition to new forms of fuel will likely result in higher fuel costs for the industry. The majority of ship owners moving to the use of blends, MGO demand will result in higher prices initially, stabilizing shortly after. Meanwhile, with HSFO seeing less vessel use, the prices will drop, creating a greater gap between the two solutions for fuel. Then we have the alternative of LNG which already has gained some part in the fuel market. If LNG is the alternative fuel ship owners will choose, then its price will be extreme higher.

The fuel prices will also be affected by the fuels that ports will start to use as well. If their infrastructure supports other fuels like VLSFO, market maybe move to this alternative. BP has already given VLSFO to most bunkering locations16 as an indicator. According to them, in the coming years, VLSFO will account for more than 50% of the market. Increase in demand of other alternative fuels like biofuels and Green H2 will be noticed and there share in the market will also affect process of fuels. IRENA 1.5°C Scenario implies that demand for advanced biofuels in international shipping needs to grow about 9%, eventually reaching a participation of nearly 10% of the total mix in 2050. (23)

Bunker Suppliers

It is apparent that bunker producers and distributors will have to adapt to the new regulations. Suppliers in terms of quantity, price, variety and flexibility will need to be able to meet the new demand. For example, the IMO MARPOL Annex VI regarding limited SOx emissions had an important impact on global bunker fuel demand in terms of volumes and fuel of choice. Also bunkering is a key aspect of port infrastructure that deals with the storage and resupply of fuel to ships. Currently the ports with the highest bunkering capacity globally include Singapore, Fujairah (United Arab Emirates) and Rotterdam (Netherlands), with the latter being the largest bunkering port in Europe. If these ports will start using as main fuels other than HFO, MGO and VLSFO, then all supply chain will be affected and adjust to the new fuels.
During 2019, the global shipping fuel supply mostly comprised un-scrubbed high-sulphur fuel oil (HSFO) and MGO, accounting for 71.8% and 20.5% of fuel demand, respectively.

Flag States

Flag states have an important role to play in enforcing IMO rules because they exercise regulatory control i.e. impose penalties in case of non-compliance over the world fleet on diverse issues, ranging from ensuring safety of life at sea, protection of the marine environment, and the provision of decent working and living conditions for seafarers. In the context of the implementation of the IMO GHG emissions strategy, flag states will have to ensure that ships are compliant with applicable IMO rules. They could also provide incentives for the ships registered under their flag to reduce CO2 emissions, and potentially play a role when it comes to ensuring the collection of future fees or contributions associated with CO2 emissions. Flag States must also issue the IAPP–International Air Pollution Prevention Certificate, which recognizes that the vessel in question uses fuel in accordance with the new regulations or otherwise has adequate equipment installed.

6. Future Steps toward Decarbonization

In this final chapter we are interested in the next steps that the shipping community must take into account so IMO targets can be achieved and humanity can start living in a more sustainable environment. In order to achieve the objective of having the first net zero ships by 2030, many actions must be taken from all parties included in shipping market and find a way to overcome all the obstacles that they seem to face at the moment. We will divide the future actions toward decarbonization in four categories: first set of actions can be met in synergies of stakeholders inside shipping community, second category will be about actions that have to do with policies regarding energy efficiency measures, third category is related to the research and development of renewable fuels and fourth category is about the high need for more investments in green alternative solutions.

What is most important to do as a fist action is the development of synergies within the shipping community. Starting from customers, charterers, till financiers and investors, common actions must be taken for the achievement of decarbonization goals. If their synergy will work, technical readiness will be achieved in a faster way, customer engagement to new sustainable measures will be increased and lower emissions in shipping will become a reality. Ship owners and operators need to collaborate with engine manufacturers, energy companies and onshore sectors to define the R&D roadmap. They also need to work closely with customers to pilot and test new technologies and fuels. Stakeholders need to be more engaged to decarbonization purpose and develop common activities. Also, policy makers that regulate the international shipping need to develop programs in order for shipping companies can meet the target for emissions by 2050. Another action that can be taken is to develop synergies not only with internal stakeholders but with parties from other sectors like aviation, power suppliers and petrochemical sector. In this way knowledge will rise within transport sector and related industries and global climate targets will be more feasible to realize and achieve.

Moving on to the second category, it is of high significance to highlight the importance the policy makers have in the transition process. International and local governments need to develop a plan that will make the shipping community adopt new measures and initiatives. A carbon levy system needs to be established- each fuel must have an implied carbon price that may be adjustable over time as the market becomes more favorable for renewable energy fuels. In this way shipping community will start using less fossil fuels and gain benefits form the renewable fuels. Moreover policies regarding the adoption of efficiency measures need to be stricter and tighten up. Minimum standards for vessels design and operation should be provided along with improvement of powers systems and optimization of propulsion systems. Also, local regulations need to promote limits of emissions in ports and make coli ironing compulsory. For example, turning off vessels auxiliary engines during shore-side operations in port areas by plugging the vessels into a renewable electricity source offered by the port authority, it can reduce the emission of airborne pollutants and GHG during docking periods. Along with the adoption of new alternative fuels by ship owners, there is the need to develop sustainability certifications like guarantees of origin, to guarantee that ship operators are using renewable fuels and can prove their origin. This will work also as a market advantage as customers will want to make business with ship owners that follow regulations and are environmentally conscious.

Another domain that needs to be supported more in order to reduce emissions impact is that of research and development. Institutions must analyze the dynamics of renewable fuel production for shipping, including the GHG life cycle analysis of the different renewable fuels and the exact production limits of the alternative fuels. In this way we can develop the technological awareness and readiness of new fuels in the shipping sector and understand what the best possible solution is. There are still many questions regarding which fuel can be the best sustainable solution for the market and can satisfy the worldwide trade. The demand for new fuels will be high, so the amount of resources should be in more than an adequate level. Green H2 produced through renewable-powered electrolysis is projected to grow rapidly, and green H2-derived fuels are expected to be the backbone of a decarbonized maritime shipping sector. Also energy providers must redefine how they support the development of new technologies and fuels. They need to offer their experience and knowledge of global markets and geographies to help build the supply chains needed for new technologies and fuel. Energy companies need to be part of R&D efforts and play a leading role in scaling up fuels and establishing the infrastructure.

Last but not least, we need to talk about the actions that need to be made on the investors' side. Investors and financiers need to lead activities that include sustainable targets in business plans and balance sheets. They have an important role to play to ensure companies set decarbonisation objectives and adhere to them. Credit incentives will assist ship owners to place orders for carbon zero vessels and moreover to make changes in terms of energy efficiency perspective to the existing fleet. Financing these decisions should be promoted for all vessels size but mainly to large vessels that produce 85% of energy in international shipping sector. Other significant action is the identification of geographical areas that have high renewable energy potential. Along with research institutions, these actions can be financed so the availability of a new alternative fuel can be reassured. Also huge investments must be supported in developing supply of fuels such as bunkering service companies. Focus should be on the identification of key investments across strategic ports and the allocation of funds for the upcoming development of renewable fuel infrastructure. The problem of the existing infrastructure for new fuels is something that needs to be overcome if we want to be ready for 2050 targets. Ports from their side can be the forcing function of the ecosystem, by creating a global coalition that supports and enables green shipping.

Conclusions

The shipping sector is currently undergoing the most significant transformation in its history: decarbonization. The environmental impact of international shipping is of significant extent and immediate actions must be taken in order to achieve a successful transition to sustainability. Protection of the environment is a major concern for all sectors worldwide and regarding the shipping community, IMO over the last years has tried to reduce the pollution impact of shipping by implementing new and strict regulations. Maritime trade bases a lot on fossil fuels use, as 33% of emissions come from fossil fuels combustion - 99% of the energy demand from this end-use sector is met by fossil fuels, with fuel oil and MGO comprising as much as 95% of total demand. As marine volume increases there is a relevant increase on emissions and of course on atmospheric pollution coming from vessels which has also a big impact on human health. Climate change needs to be limited and only by transitioning to zero carbon vessels this can be achieved.

The shipping sector has started to adapt to this new era. In the last decade, and more specifically in 2015, the installation of scrubbers has become a new mandate for vessels, in order to decrease SO_x to 0,1% from 0,5%. New legislation followed by IMO in 2018 regarding the reduction of GHG emissions - known as IMO 2030 and IMO 2050- has as a target to reduce GHG emissions by 40% and 50% respectively, compared to 2008 emissions. Lower carbon shipping can be achieved by the use of renewable fuels, the implementation of energy efficiency measures or the combination of these methods. Voyage performance management like speed optimization, weather routing, just in time arrival are in place but the long terms goals of IMO can be achieved by a total switch from fossil fuels. The alternatives of green hydrogen, biofuels and methanol already seem appealing to the market but each alternative has its risks and opportunities in terms of technological readiness and economic feasibility.

These gaps create a feeling of uncertainty to the shipping market as they are called to invest to some alternative that may not be cost effective and may lead them out of the market. The risk will be much higher for smaller companies which will not have the economic advantage to make these changes. There are questions about which fuel is best for large going vessels since there is a technological obstacle regarding its storage on both vessels and ports, and in parallel there are barriers in terms of resources availability. On top of this uncertainty, shipping companies have to take a decision fast, as the time needed in order to make the required technological alterations to the existing fleet or to order new marine vessels can take many years. From the point of view of implementing market based measures, there are other barriers that have to do mostly with satisfying, in the best of ways, the market needs. If speed optimization becomes a reality in the entire sector, market trade and increased customer needs will not be able to be satisfied.

It is of high importance for the scientific community to find ways to overcome the technological gaps that exist at the moment so that the transition to green alternatives can be achieved with economic stability and covering shipping needs. Research and development of green initiatives must be more supported and financed by shipping companies and institutions in order to change to a sustainable environment. Also common actions and partnerships need to be developed in order to promote new alternatives. Ship owners can work together with engine manufacturers and ship builders so they can accelerate new technologies and new design vessels. Same can be developed with synergies of shipping companies with fuel companies. They can launch pilots of new fuels on selected shipping routes in collaboration with their customers- in this way customers will be engaged to the decarbonization process and develop long term contracts between the two sides.

From these pilot tests small steps can be made to the implementation of green initiatives and the rest of shipping community will follow at last. The demand for new fuels will create the need for changes to port infrastructure as well-ports will play also a significant role to the decarbonization process as with their development to support new fuels, which will be available worldwide at last.

Towards the long road of decarbonization, the contribution of governments and legislation both in local and national level must be much higher and crucial in the future. If we want IMO targets to be achieved and limit the emissions in the atmosphere and the carbon footprint in the oceans, rules need to tighten up. The alternatives on efficiency measures must be formalized and emissions reports should be developed and measured directly. Also government should find ways to promote the development of green initiatives from their side too. Credit incentives should be in place to the shipping companies so ship owners can progressively proceed with ordering new green vessels. Also they should invest and finance research programs that have as a target the development of renewable fuels.

Shipping community can achieve reducing its carbon footprint in the environment and this is something we can see from real examples from the market. Big companies play a leading role to decarbonization process as have already started investments in green fuels and more specifically hydrogen, green ammonia and methanol. Maersk, one of the largest container shipping companies in the world, has ordered three vessels that will be able to run on most carbon-neutral fuels, particularly e-methanol and bio-methanol and are estimated to be delivered by 2023. MSC is also exploring methanol, in part due to its current availability at 115 ports worldwide, and company also run the MSC biofuel program from 2019 which has led to total CO_2 savings of 605,000 metric tons.

To sum up, the need to implement decarbonization is of high importance and urgency. In order to be achieved, short and long term actions need to be taken by both shipping stakeholders and regulatory institutions. Common actions will have to take place and awareness will need to be raised at all levels. The protection of the marine environment, the reduction of marine pollution and the limitation of cargo footprint on the oceans are not personal goals but a global target that must be achieved not only from the shipping sector, but from all parties involved. Green initiatives should be put forward to bring change in our world.

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