Green Energy and Shipping

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CHAPTER 1: Introduction

1.1 Preamble

Modern science through years of evolution has developed significant breakthroughs in managing technology associated with the exploitation of energy resources, but the dramatic rise of technological activity in all its forms during the previous decades has caused significant degradation of the natural environment. The escalating climate change is the manifestation of said degradation, which has led countries worldwide to unite and make a unanimous decision to reduce carbon dioxide (CO_2) gas emissions as much as possible in all sectors, including shipping, "*deep decarbonization will require financial incentives and policies at an international and regional level given the maritime sector's ~3% contribution to greenhouse gas (GHG) emissions*[1] *".*

There are several ways that renewable energy can be generated on and off shore in order to power vessels. The proposed ways that can be exploited in order to reduce and eventually replace fossil fuels, are principally the usage of biodiesel, wind turbines, photovoltaic modules, hydrogen fuel cells and secondarily kites and cold ironing. The above alternative power sources - which can generate power on and off board, using exclusively renewable or clean energy- can be used solely or combined with each other under the application of hybrid systems, *"the modernization of shipping in a sustainable direction is called green shipping and is the ecological, as well as the financial vision of the future. Green shipping includes strategies to*

[1] Mallouppas & Yfantis (2021).

reduce the pollutants released by ships and is directly linked to innovation and the use of renewable energy sources[2]*."*

The goal of this thesis is to analyze all the ways which the shipping industry can use to turn green and to demonstrate how new laws regulate this eco-friendlier way of transport with the help of technological innovations. The effects brought by the new legal regime on the economy world-wide shall also be showcased herein. Furthermore, the present thesis will study the variables that induce shipowners chose the most profitable to their interests' way for reducing CO_2 emissions.

1.2 Structure of thesis

Chapter 2 presents the levels that green energy and shipping correlate, along with the results produced by such correlation. There is also a demonstration of the "Green and Blue economy" and how they interconnect and affect the over-all economy, leading to "Green Growth".

Chapter 3 discusses the legal framework that has been adopted and enforced, starting from worldwide organizations that enforce laws for the reduction of carbon dioxide (CO_2) emissions globally, leading up to laws adopted in the USA and in the E.U.

Chapter 4 presents the technological innovations that harvest renewable energy resources and how they can be implemented on the shipping industry. Each of these technological achievements are thoroughly analyzed both solemnly and in relation to the shipping sector. The advantages and disadvantages that come with this new era of energy are showcased as well, after the presentation of each renewable energy resource.

[2] (Lun et al., 2013)

Lastly, Chapter 5 examines the economic side, reviewing both international crises, the economic one of 2008 and the one caused by the pandemic 2020-2021, which have affected greatly the world economy as well as the shipping industry. In this chapter a comparison between these two crises is being presented along with the employment opportunities, the creation of new jobs and the actions of key countries in this innovating field. There is also a reference to the useful technique called "Greening and performance relativity (GPR)" which evaluates the usage of green renewable energy in correlation with a company's productivity.

Chapter 2: Green and Blue Economy

2.1 Introduction

In this chapter there will be a presentation of the green and blue economy. Both focus on terminating or at least minimizing the degradation of the environment, leading to what is being described as "Green Growth". Green growth is the currently hypothetical way of economic growth that is decoupled from using non-renewable energy and protects the environment. The only way to achieve said way of progress, is through an economy based on low-carbon and sustainable development, which is the concept of green and blue economy combined.

2.2 Green and blue economy

Firstly, there must be a clear demarcation between green and blue economies. Green economy has as its goals to reduce all environmental risks and to eliminate everything that downgrades nature while achieving a sustainable economy. Specifically, according to The United Nations Environment Program (UNEP), the definition of green economy is the economy that results in improved human well-being and social equity, while significantly reducing environmental risks and ecological scarcities[3]. As blue economy has its roots in green economy, it also aims to create a sustainable economy while at the same time protecting the environment. The distinction is that blue economy focuses mainly on the exploitation, preservation, and regeneration of the marine environment.

The way to achieve these goals is through an eco-friendly sustainable development. For both green and blue economy to actually work and make a difference in today's world, there must

[3] UN environment program.

be a clear and viable plan to distinguish them from previous failed economic systems. These new versions of eco-friendly economies are, therefore, closely correlated to ecological economics, which is "a transdisciplinary field of academic research addressing the interdependence and coevolution of human economies and natural ecosystems."[4]

The term blue economy is generally used in light of an international effort towards a clean and sustainable use of fisheries, aquaculture, maritime transport and maritime tourism, to more emergent spaces such as coastal renewable energy, marine ecosystem services, seabed mining, and bioprospecting. According to The World Bank, blue economy is the *"sustainable use of ocean resources for economic growth, improved livelihoods, and jobs while preserving the health of the ocean ecosystem."* The European Commission defines it as "*All economic activities related to oceans, seas, and coasts. It covers a wide range of interlinked established and emerging sectors."*[5]

Green economy aims mostly on the sectors of energy and transport, and sometimes on agriculture and forestry. There are several pillars to green economy, like climate change, resource-saving and management, circular economy, environmental protection, ecosystem protection and recovery, water conservation and natural disaster prevention.

2.3 Interconnection between the two economies

The interconnection between blue and green economy is something natural and logical. Same has been confirmed by the EU when stating that governments see it that way as well, since "*The European Green Deal and the Recovery Plan for Europe will define the European*

[4] Ecological economics.
[5] Grude Progect. Sustainable Blue Economy – Greennovation Camp 26/10/2021.

economy for many years, or even decades. And the EU's blue economy is fundamental to both efforts. Not only should the blue economy adhere, like every other sector, to the European Green Deal. It is also indispensable to meet the EU's environmental and climate objectives. After all, the ocean is the main climate regulator we have. It offers clean energy and sustains us with oxygen, food, and many critical resources. There just can't be green without blue." [6]

2.4 Green growth

Extremely important for the sustainability of both the economy and the environment is green growth. In support of that, 34 countries signed a Green Growth Declaration in June 2009, declaring that they will *"Strengthen their efforts to pursue green growth strategies as part of their responses to the crisis and beyond, acknowledging that green and growth can go hand-in-hand."* They endorsed a mandate for the OECD to develop a Green Growth Strategy, bringing together economic, environmental, social, technological, and development aspects into a comprehensive framework. [7] Green growth means fostering economic growth and development while ensuring that natural assets continue to provide the resources and environmental services on which our well-being relies. To do this, it must catalyze investment and innovation which will underpin sustained growth and give rise to new economic opportunities. [8]

[6] Virginijus (2021)

[7] Declaration on Green Growth

[8] Declaration on Green Growth

CHAPTER 3: Legal Aspects of Green Shipping

3.1 Introduction

In this chapter there shall be presented the legal framework of green shipping. The laws which dictate all the changes that need to be applied in the shipping industry, including the relevant laws which have been adopted and enforced by the governments, the International Maritime Organization (IMO) regulations, the European Green Deal and the US Clean Air Act.

In order to stop climate change and better the environment through the elimination of carbon dioxide (CO_2) emissions, new technologies need to take the place of the polluting machinery. Biofuels, hydrogen and wind farms are only a few examples of the plethora of ways that humanity has invented so far for zero emission energy. Even though, the shipping industry only emits 2-3% of the total carbon dioxide (CO_2), the European Member States, the United States and almost all countries around the globe have taken extreme measures to turn shipping green and have funded new technologies to be implemented onto ships so that the last can abide by the new laws and regulations.

3.2 The Legal Framework

3.2.1 International Maritime Organization

The International Maritime Organization (IMO) is an agency launched by the United Nations to bear the responsibility of safe and secure shipping in order to prevent marine and atmospheric pollution caused by the shipping industry. IMO has created a strategy that has been agreed upon by virtually every IMO Member State, including all EU Member States which are parties to the IMO MARPOL, that is, *"The International Convention for the Prevention of Pollution from Ships (MARPOL)"* which *"is the main international convention covering prevention of pollution of the marine environment by ships from operational or accidental causes. The MARPOL Convention was adopted on 2 November 1973 at IMO. The Protocol of 1978 was adopted in response to a spate of tanker accidents in 1976-1977. As the 1973 MARPOL Convention had not yet entered into force, the 1978 MARPOL Protocol absorbed the parent Convention. The combined instrument entered into force on 2 October 1983. In 1997, a Protocol was adopted to amend the Convention and a new Annex VI was added which entered into force on 19 May 2005. MARPOL has been updated by amendments through the years. The Convention includes regulations aimed at preventing and minimizing pollution from ships - both accidental pollution and that from routine operations - and currently includes six technical Annexes. Special Areas with strict controls on operational discharges are included in most Annexes*[9]*."*

This strategy addresses GHG reductions from international shipping and includes a target to cut total GHG emissions from international shipping by at least 50 percent by 2050 (compared

[9] International Convention for the Prevention of Pollution from Ships (MARPOL).

to 2008) regardless of the maritime trade growth. The IMO Strategy also includes, as a mid-term measure, the development of a global market-based measure to help deliver the agreed-upon targets. In the years between 2008 and 2015 GHG emissions have been reduced by 8% despite the high volume of maritime trade.

Furthermore, the IMO created the SEEMP (Ship Energy Efficient Management Plan), which is an operational measure that establishes a mechanism to improve the energy efficiency of a ship in a cost-effective manner. Its adoption has been made mandatory and IMO has tried to enforce it henceforth as a manual to all ships, provided that except planning and implementation, it would also include monitoring, self-evaluation and improvement.

3.2.2 Clean Air Act

The United States of America established in the 1970s a federal law called the "Clean Air Act" in order to protect public health as well as the environment. For the shipping industry, this law imposed maritime diesel in 2008 and has been active throughout the years saving and improving the lives of hundreds of citizens. Nevertheless, apart from the above Act, there are more laws that affect shipping. The California Air Resources Board announced that *"New air quality regulations are now being implemented that will have major impacts on how ports and shipping companies do business in California. This includes an existing air toxics control measure that has milestone requirements that are currently in play and a new regulation with a proposed expansion of emissions reductions at ports."*[10]

[10] Easter (2020).

3.2.3 European Green Deal

The European Commission has set an aspiring goal for the EU to become carbon-neutral by 2050. For this plan to be implemented, the shipping industry will also have to go through major changes to accumulate to this legal demand. The short-term goal is to have a 55-60% decrease in CO_2 emissions from the 1990's baseline, not including maritime growth.

Moreover, there are several directives and recommendations from the EU concerning specifically the shipping industry. The recommendations are for Member States to promote shoreside electricity facilities[11] and to subsidize shoreside power by the cancelation of electricity tax[12]. The directive imposed by the European Parliament include that, since January 1st, 2010, every single ship while at berth in a European port more than two hours and it requires reducing sulphur content in the marine fuels to 0. l % by weight while docked[13] and deployment of alternative fuels infrastructure since of October 22nd, 2014.

3.2.4 International Chamber of Shipping

International Chamber of Shipping (ICS) is the world's largest trade association for shipowners and operators, representing around 80% of the global merchant fleet. Its main focus is all issues that arise from new regulations and operations. Said organization works closely with the International Maritime Organization and other inter-governmental organizations, since it is also burdened with the responsibility of protecting marine environment and all living organisms under water.

[11] EU Recommendation 2006/339/EG
[12] Recommendation EU 2003/96/EG
[13] EU directive 2005/33/E

Recently the ICS submitted a proposition to the IMO about specific emergency measures that should be adopted by governments in order for the shipping industry to achieve the aspiring goal of zero emissions by 2050. The plan is basically to double the measures they have already taken, *"The International Chamber of Shipping has submitted plans to the industry's UN regulator, the International Maritime Organization (IMO), detailing urgent measures which governments must take to help the industry achieve net zero CO_2 emissions by 2050. Just one month before the shipping industry's flagship COP26 decarbonization conference 'Shaping the Future of Shipping', ICS (which represents 80% of the global shipping industry), is pushing governments to double the ambition of the IMO's current target, which is to reduce emissions from international shipping by 50% by 2050."*[14]

[14] International Chamber of Shipping (2021).

Chapter 4: Technological Aspects of Green Shipping

4.1 Introduction

There are several ways which can turn the shipping industry into an eco-friendlier part of the economy and transportation. Those ways are by all means the product of research and innovation in the green and renewable energy sector and they will be thoroughly analyzed.

These innovations are more important now than ever before, since the growth of seaborn trade -and therefore the entire shipping industry- is interconnected with the growth of global population. The higher the population number the more active the shipping industry, which consequentially leads to a rise in carbon dioxide emissions. This affiliation makes the goal of turning shipping eco-friendlier more challenging but also more pressing.

4.2 Technological innovations

4.2.1 Kites

For starters, kites have been used for a plethora of tasks throughout the centuries, although the possibility to employ kites for commercial shipping was investigated for the first time in the 1980s after the oil crisis had proven the high dependence of the economy on oil. Due to the constantly increasing marine fuel oil prices after the year 2000, certain companies decided to carry out the project of including the use of kites into a propulsion system that could cover the needs of the globalized cargo shipping industry.

The practice of kites as means for propulsion was tested originally on a small scale on various boats and models between the years 2001 and 2006. After the prototypes had succeeded and

been established, a full-scale prototype of a towing kite was installed on MV "Beaufort" in 2008 (to experiment on larger scale ships) and sailed in the North and Baltic Sea. (Figure 1.0)

Figure 1: Cargo ship using kite as a propulsion system[15].

Shortly after this success, the prototype got improved and was implemented on several other ships, after managing to cover the energy requirements of the offshore environment more efficiently. These improvements include fully automated controls and optimization of the kite's flight pattern as well as superstructures and mechanics for its launch and retrieval procedure, a manufactured by durable materials structure which is able to endure high forces, a ship movement compensation mechanism for the main winch to work in accordance with the automated kite control during launch and retrieval, and, lastly, mechanisms that enable the ship's crew to easily and efficiently operate the kite.

There are several advantages of using kites as a way to turn the shipping industry green. According to the German company Sky Sail, who invented the towing kite, their innovation

[15] Ahstrom, D. (July 27th, 2015).

will help the shipping industry become eco-friendlier since the vessels will now be able to reduce fuels usage from 15% up to 20%. Furthermore, kites are highly cost-saving, which makes them extremely desirable to shipowners[16].

The ship building company AirSeas initially powered its own large cargo ships with its stunt kite, SeaWing, and after witnessing pleasing results, it offered the same kind of stunt kite to third parties. This way, AirSeas has helped both the environment and the shipowners since, according to the company, a ship operating with the help of a SeaWing can save up to one or even two million dollars in fuel[17].

The disadvantages of using kites to reduce pollution in shipping industry, are the relatively low speed and the limited space in the ships' cargo holds. This means that sometimes, even if exporters have agreed to a delayed shipment, the limited amount of merchandise that they could transport could make them withdraw from their initial selection of that alternative propulsion of a vessel.

4.2.2 Onshore Power Supply

An alternative to fossil fuels is also the Onshore Power Supply (OPS) or Shoreside electricity (SEE). This way of running a ship is done by shutting down its engines while berthed and plug into an onshore power source. The ship's power needs are covered by the onshore power supply without disruption to onboard services, making emissions to the nearby surroundings non-existent. This type of green shipping is mostly applicable to ships operating on specific routes

[16] Kirschbaum,. (January 19th, 2007).

[17] Reducing fuel consumption in a breeze. Cargo-partner.

and vessels that utilize significant amounts of power and therefore produce high levels of air pollutants.

In further detail, the OPS works through an extended electrical cable that extends from the pier and is plugged into the ship's receiver (Figure 2), supplying it with the power needed to operate its equipment, therefore the ship is able to shut down the diesel engines without causing any operational discrepancies.

The advantages of OPS at a country's ports come from shortening the time vessels need to spend at anchor and therefore: reducing the congestion of ships, decreasing the chance of having an accident close or within the port, while also reducing local emissions around the port. OPS improves the environment and the living standards of citizens close to the port and of workers at the port, not only as far as low emissions are concerned, but also by reducing noise pollution. This alternative is feasible and viable since most European countries have a compatible pre-existing infrastructure, so "*the implementation could happen in almost all European ports that acquire a high-power voltage (6-20 kV)*[18]."

Moreover, making ships more technologically advanced will lead towards more accurate estimations of vessel arrivals (ETAs) along with recommended arrival times (RTAs). It also offers the crew a better chance to plan their schedule and arrangements. Overall, this technique helps the ship function in a more efficient and productive way.

The disadvantages of the OPS mostly come from the high cost of its implementation, leading ship owners to use scrubbers or Liquified Natural Gas. Lastly, it is difficult to implement it worldwide, not just due to its high cost, but also due to the disruption it would cause to the operation of the shipping industry, and therefore to the entire market, until all the necessary

[18] González, (2018).

equipment has been installed and required changes have been performed in order for the OPS to run smoothly.

In November 2021, the agreement of a cooperation on common shore-side electricity for ferries between the three Baltic Sea ports, Helsinki, Stockholm and Tallinn, became known worldwide. The outcome of this cooperation was that "*all passenger car ferries between the three ports will soon be able to use the electricity generated on land during their port calls. The amount of greenhouse gases is estimated to decrease by more than 18,000 tons of carbon dioxide per year*[19]." Ville Haapasaari, President and CEO of Satama Oy, stated that one of the most important strategic goals of the port of Helsinki is to be at the forefront of sustainable development. Emission reductions require concrete measures, and shore-side electricity investments are a significant way to make the low emissions goal a reality.

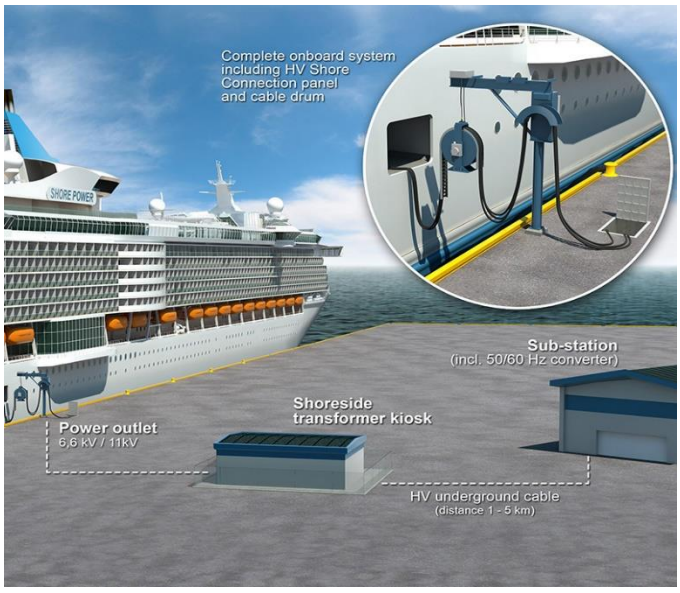


Figure 2: Graphic demonstration of how cold ironing works [20].

[19] By the Editorial Team of SAFETY4SEA (2021).

[20] Graphic demonstration of how cold ironing works, (2021, April 14).

Another way to use electricity as a way to reduce carbon dioxide (C02) emissions in the shipping industry is by electric shipping. This mainly consists of ferries and small passenger ships on inland waterways that sail completely by electric power. At present, this type of energy power can be used by vessels which sail only short distances and tend to dock often, so the energy storage units can be recharged quickly. In Norway, the world's first vehicle ferry has been operating a regularly scheduled service ever since 2015 (Figure 3)[21].


Figure 3: First zero-emission electric ferry in the world, built by Norway [22].

[21] Editorial team of The Explorer.
[22] First zero-emission electric ferry in the world, built by Norway, (2021, June 10).

4.2.3 Biofuels

The third renewable energy solution is biofuels. Biofuels are a good candidate since they are biodegradable, non-toxic, and essentially free of sulphur and aromatics. Specifically, biodiesel is a renewable, biodegradable fuel that can be manufactured domestically. Biofuels are produced by the conversion of biomass, or biomass residues, into liquid or gaseous fuels, which is a viable path towards an eco-friendlier shipping sector[23].

The advantage of biofuels consists in that, in comparison to the currently used marine fuel oil and marine diesel, bio-derived fuels are environmentally friendly, renewable, and clean. Furthermore, they can be used in many marine applications with little to no need for engine modification, which is a big benefit for ship owners. Biofuels are seen as the most viable option for reducing shipping emissions at this point. Biodiesel is the greatest option of biofuel, considering short-term economic loss for turning green.

Nevertheless, disadvantages to the usage of biofuels can be found in the economic and pragmatic side. Related obstacles include higher price of biofuels compared to other marine fuels, and insufficient logistics' support at ports for ships not compatible with diesel-type fuels. Additionally, there is limited knowledge and expertise in the shipping sector with the handling of some biofuels, including lack of long-term fuel test data, which would guarantee the safety and continued reliability of the selected fuel. Finally, safety requirements for using methanol or gaseous fuels, need to be of highest standards and are of the utmost importance.

[23] Biofuels in shipping. Wbcsd

4.2.4 Wind turbines

The fourth way to turn shipping green is by the usage of wind turbines. A wind turbine is a device that converts the wind's kinetic energy into electricity. They can be used on a large scale, for example by creating a wind farm to generate enough power to make an ecological difference, no matter how slight that may be on a global scale. On a smaller scale, they can contribute to a domestic power supply by selling back the unused power to the utility supplier, via the electrical grid. Moreover, there are wind turbines of a scale so small that can be used for battery charging, for auxiliary power to caravans, for giving power to traffic warning signs and even for providing power to boats. The first model boat to use a wind turbine sailed in 2014 and was built by Stena Rederi AB (Figure 4) and provided valuable data to scientists in order to understand and explore the possibility of using wind turbines on boats[24].

Figure 4: Boat using wind turbine to power itself[25].

[24] Carlson, O. ; Nilsson, P. (2015).
[25] Carlson, O. ; Nilsson, P. (2015).

There are several advantages to using wind turbines, since their contribution to the energy supply needed can be valuable and they are a great way to generate green energy and save money if used domestically. For starters, even though they are expensive to build, install and there must be a prior research on the place and ground that they are going to be located, they have the advantage that they require relatively low operating costs[26]. If installed at the right location, this constitutes an efficient use of the landscape but, as mentioned above, there must be an extensive and thorough research conducted before their installation, in order to avoid any disruption to the surrounding ecosystem.

As for the disadvantages, a major one is the instability of the weather, considering that the wind is intermitted and therefore not always effective on generating electricity. The low wind is not the only reason wind turbines may not generate electricity. When the wind is too strong the wind turbines must be locked in order to avoid a potential accident. Moreover, if the research that must be done before the installation is incorrect, rushed, or partial, there is a high possibility of reducing, fragmenting, or degrading the surrounding habitat for wildlife and plants. Spinning turbine blades can pose a threat to flying wildlife, like birds and bats. According to a 10 yearlong study focusing on wind projects conducted by scientists in Ontario, 13,400 birds and 30,150 bats were killed most likely by wind farms just in 2018[27]. This issue is not only directed to the environment on-shore, but it affects the fish and underwater environment if the wind farms are off-shore. Said wind farms are placed on large bodies of water in order to have a constant and stronger wind flow and generate electricity almost constantly.

The low acceptance rate from the public is another obstacle for wind turbines due to two reasons. First, the noise they unavoidably make in order to produce electricity and, second, the

[26] SURGE. How Much Do Wind Turbines Cost? (Calculations + Efficiency).
[27] Lafleur (September 14, 2019).

fact that they are aesthetically unpleasant. According to researchers, there are three additional reasons people do not accept wind turbines, the proximity, the habituation and the type of the chosen landscape. In some cases, people have been willing to pay to avoid the installation of wind turbines in residential areas[28].

4.2.5 Solar panels

Another option for utilizing green energy is the installment of photovoltaic modules/ solar panels, which are an assembly of photovoltaic cells mounted in a framework for installation. Solar panels use sunlight as a source of energy to generate direct current electricity. A collection of PV modules is called a PV panel, and a system of PV panels is called an array. Arrays of a photovoltaic system supply solar electricity to electrical equipment. The idea to create energy using the sun as a means, is not recent. It was initially implemented in 1839, when the ability of certain materials to create an electrical charge from light exposure was first observed by Alexandre-Edmond Becquerel. After several failed attempts, finally in 1954 Bell Labs created the first commercially viable silicon solar cell. The most impressive use of photovoltaic technology was in the 1960s when it was applied on a spacecraft to provide part of the needed power[29].

Unfortunately, the electricity provided by wind farms and photovoltaic panels cannot always be used to its entirety. Due to the extremely old power grid that most countries have, the extra power provided from renewable sources cannot always be transported. A characteristic example has been Vermont, where the aging transmission infrastructure, which is not able to safely carry all the extra power added from the renewable sources, led to putting a moratorium

[28] Dugstad, Grimsrud, Kipperberg, Navrud (December 2020).

[29] James. (March 24th,2021).

on new solar and wind projects[30]. The solution to this issue is to replace the old transmission lines with new and stronger ones, but this is not a cheap project. According to estimations, this specific project in Vermont would cost 2,5 trillion dollars, which would have to be imposed through taxes and utilities. The prospect of higher taxes led citizens of Vermont to object to this initiative.

Specifically, in shipping the usage of solar panels can be significantly better that the other options presented herein, for several reasons. To begin with, it can be a cost-effective solution for ships. PV systems can act as an ideal subsidiary of power sources since they are independent of the vessel electromechanical settlement. Said independence comes from the PV panels' ability to produce electric power without the need of gas or liquid fuel, while they have no by-products such as gas emissions or noise.

The advantages of the photovoltaic cells are numerous. Firstly, they are highly reliable even under unfavorable conditions. They have a long-life expectancy, as they are usually provided with a 25-year guaranty from the manufactures, and they tend to outlive it by several years. They are low cost because, although they require regular inspection and sometimes repairs, solar panels are much more profitable compared to the currently used machinery. They have relatively low maintenance costs because they have limited or no use of mechanical moving parts. Further, they consist of fewer parts compared to fossil fuels fueled engines, with easy installation and fast replacement in case of aging or defectiveness. As for the practical side, PV panels can be placed on small surfaces with no practical use, such as roofs, walls, funnels, and superstructure, making them ideal for taking advantage of every viable surface (Figure 5). Furthermore, they produce zero noise while using solar energy to generate electricity. Another aspect that distinguishes them and gives them a huge advantage over other clean energy

[30] John Oliver (November 8th, 2021).

resources, is that sunshine can be found everywhere on Earth PV panels can be used worldwide[31].

The disadvantages include the high initial installation cost as well as its exclusive dependence on the weather, which must be seriously taken under consideration as sunlight is not constant -in some areas during the winter there is not much sunlight even during the day- which makes PV panels an only slightly helpful alternative electricity provider[32]. In the case where the PV panel stores in a battery the generated electricity, the maintenance cost is higher.

Figure 5: Electric yacht[33].

[31] James, (March 24th, 2021)
[32] James, (March 24th, 2021)
[33] New looks and a new hull mean this electric yacht is full of promise. Motor Boat & Yachting, (2020, June 11).

4.2.6 Hydrogen fuel cells

Another option that is going to be analyzed is the usage of hydrogen fuel cells. To begin with, hydrogen is a clean fuel that, when consumed in a fuel cell, produces only water. It can be produced from a variety of domestic resources, such as natural gas, nuclear power, biomass, and from renewable power, like solar and wind. These qualities make it an attractive fuel option for transportation and electricity generation applications.

The advantage of hydrogen is that it can be a great substitute for fossil fuels not only in houses, but also for portable use, such as in cars and ships, among several other applications. Furthermore, hydrogen is an energy carrier that can be used to store, move, and deliver energy produced from other sources. The most common methods today are natural gas reforming and electrolysis. The typical production processes of hydrogen include thermochemical conversion and electrolysis, as well as photoelectrochemical and biological conversion. Other methods include solar-driven and biological processes, as mentioned above. As for the fuel cells, they use the chemical energy of hydrogen or other fuels to produce electricity in a clean and efficient way. In the case where hydrogen is the fuel, the only products are electricity, water, and heat.

Nonetheless, there are disadvantages of using hydrogen as an alternative source of energy. To begin with, even though it is abundant in nature, it is also expensive to turn it into an energy source, because it takes a lot of time and effort to separate said element from the others. In addition, it is very difficult and expensive to change all the existing infrastructure, since gasoline and fossil fuels are still vastly used. Hydrogen is also very costly to transport and store even in small amounts, while also being extremely dangerous due to its high flammability. There are five types of hydrogen, with one of them being the optimal solution as a non-environmentally hurtful substitute to fossil fuels.

Firstly, there is the green hydrogen which is produced by splitting water into its two components, hydrogen and oxygen, with the usage of electricity produced by renewable energy[34]. After collecting the hydrogen, the oxygen is vent to the atmosphere without any harm to the environment. This type of fuel has been characterized as "*a critical enabler of the global transition to sustainable energy and net zero emissions economies*.''[35]. A specific type of green hydrogen is yellow hydrogen, which is made through electrolysis using solemnly solar power.

Secondly, blue hydrogen is the outcome of splitting natural gas into hydrogen and CO_2. The way to achieve that is "*either by Steam Methane Reforming (SMR) or Auto Thermal Reforming (ATR), but the CO2 is captured and then stored. As the greenhouse gasses are captured, this mitigates the environmental impacts on the planet''*[36].

Thirdly, another type of hydrogen is the turquoise hydrogen. This specific type is produced by a process called methane pyrolysis, resulting in hydrogen and solid carbon. The only way for turquoise hydrogen to be considered a low-emission version, thermal process should use green energy and carbon should be safely stored[37].

Fourth, there is the grey hydrogen, which is the one currently being used and is the product of natural gas or methane, with the usage of the steam methane reformation, This type of hydrogen even though widely spread is not eco-friendly to produce[38] because the greenhouse gases that are created in the process are not captured but instead released in the atmosphere.

Lastly, there is the pink hydrogen. The electrolysis in this case is performed from energy produced by nuclear power and does not produce any CO_2 emissions. The downside is that

[34] Dr Taibi. (December 21st, 2021
[35] Barlow (December 21st, 2021).
[36] The difference between green hydrogen and blue hydrogen.
[37] Energy explained. National Grid
[38] Energy explained. National Grid.

nuclear energy has radioactive waste that must be stored under safe conditions for hundreds of years, that is why pink hydrogen is not a suitable choice for the time being[39].

As for hydrogen fuel cells used in the shipping industry, the European innovation project *Flagships* has constructed the world's first commercial cargo transport vessel operating by solely using hydrogen. The ship was set to sail in September 2021 on the river Seine in Paris (Figure 6). The ship would operate on compressed hydrogen produced from electrolysis, enabling zero-emission operations, therefore achieving its goal for green shipping. Jyrki Mikkola Flagships's Project Coordinator said *"Green and sustainable shipping is a prerequisite for reaching national and international emission reduction targets. Ships powered by renewable hydrogen will make a substantial contribution to reducing emissions from shipping and improving air quality in cities and other densely populated areas"*.

Figure 6: Hydrogen cargo vessel[40].

[39] Clifford (January 14th, 2022).
[40] World's first hydrogen cargo vessel set for Paris

4.2.7 Ammonia

The last option that is going to be analyzed is ammonia, which partially consist of hydrogen. Ammonia is a chemical element and has many purposes of usage, such as being a significant ingredient in cleaning products and in pharmaceutical products, while also being a formidable fuel for engines. Several vessels have been built and operate using ammonia (Figure 7).

The advantages of ammonia compared to fossil fuels are not only the lack of carbon dioxide (CO_2) emissions, but also the safety it provides in transportation and utilization due to its distinctive scent, which makes it notable in case of a leakage. Furthermore, the modifications that will be needed to be effected in order to make the existing engines compatible to ammonia, are relatively small. Moreover, the Korean Register (KR) has stated "Ammonia is expected to have low production, storage, and transport costs compared to other carbon-neutral fuels, and the stable fuel supply is possible as the large-capacity ammonia synthesis technologies are already mature. It can be regarded as the carbon-neutral fuel for ships with the growth potential since it is expected to be at the allowable level technically and commercially from the storage temperature, energy density, and shipbuilding cost perspective,".

The disadvantages of using ammonia as a fuel, mainly consist of its toxicity, density and flammability, although, compared to other fuels, ammonia's risk of fire is significantly lower, taking into account that "*The most dangerous property of ammonia is its toxicity. Therefore, using ammonia fuel requires a suitable sensing system and additional safety systems such as ventilation and water sprays to dissolve ammonia."* As for its density, according to KR *"Another negative alongside the toxicity issue identified by KR is its density. Liquefied ammonia has a relatively low volume energy density and requires a tank about 4.1 times larger*

compared to conventional fossil fuels, so owners would need to accept freight loss if opting for the fuel[41]."

To conclude, the production, storage and transport cost of ammonia is far lower than that of other fuels, both fossil and renewable. Moreover, the technology needed to produce mass amounts of ammonia and utilizing it commercially, is already a reality. This has led to ships being able to turn green easily, once safety conditions -like controlling storage temperature and energy density- have been achieved.

Figure 7: Vessel using ammonia as fuel [42].

[41] Chambers (2021).

[42] Chambers (Februaty 7th,2021).

Chapter 5: Economic Side

5.1 Introduction

The shipping industry has been the path to globalization and international trade. Marine transportation of merchandise is the main component that influences the market and therefore all industries and, consequently, society[43]. Shipping is the biggest way of transport of not only raw and processed goods, but also of consumable and technological products globally, since it represents 90% of trade worldwide[44]. The two international economic crises have affected the shipping industry due to its close correlation with supply and demand. Both crises and their consequences will be thoroughly analyzed below. Another aspect that will be presented in this chapter is that this new "green era", which has offered several new employment opportunities, will help a lot of unemployed people to be part of the work force and/or educate themselves for the new jobs that have been and will be created.

5.2 Analysis of crises

5.2.1 The 2008 crisis

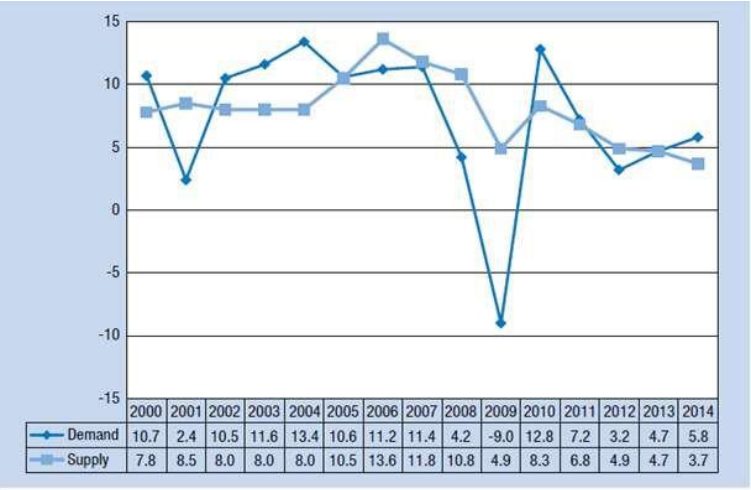
Along with the entire market, the shipping industry has been contributing to the world's prosperity for decades. The European Union being a case study, it is proven that shipping accounts, volume wise, for 80% of total exports and imports and, value wise, for 50%[45], up

[43] Glassman (2013)

[44] Official website of International Chamber of Shipping

[45] Official website of International Chamber of shipping

until the collapse of the Lehman Brothers in 2008. This collapse created a domino effect, or as is has been described a tsunami effect, based on the fact that the collapse of the financial industry fundamentally affected the entire market. The outcome was a downfall of world trade by more than 9% during 2009[46], *and "More specifically in the shipping industry, the 2008 crisis had been the longest and most severe downturn for the modern merchant in the history of the container-ships market. The freight rates in key container shipping trades have slumped to nearly all-time lows, as ship owners struggled with low demand for their vessels*[47]."



	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014
Demand	10.7	2.4	10.5	11.6	13.4	10.6	11.2	11.4	4.2	-9.0	12.8	7.2	3.2	4.7	5.8
Supply	7.8	8.5	8.0	8.0	8.0	10.5	13.6	11.8	10.8	4.9	8.3	6.8	4.9	4.7	3.7

Source: Compiled by the UNCTAD secretariat on the basis of data from Clarkson Container Intelligence Monthly, various issues.
Note: Supply data refer to the total capacity of the container-carrying fleet, including multi-purpose and other vessels with some degree of container carrying capacity. Demand growth is based on million TEU lifts. The data for 2014 are projected figures.

Figure 8: Container market variation of supply and demand from 2000 to 2014 portraying the before and during the crisis statistics.[48]

Figure 8 demonstrates the downfall of demand which inevitably led to the economic crisis due to the fact that supply could not adjust at a fast-enough rate to minimize damages.

[46] World Trade Organization (2009).

[47] Kalgora & Christian. (2016).

[48] N. Kutin, T. Vallee. (2015, June).

5.2.2 The pandemic crisis

The pandemic has affected everyone's life to a certain degree. Besides degrading and even taking people's lives, decreasing livelihood, and leading to unemployment, it has also left its prints on domestic and international trade causing market's downfall.

The shipping industry was no exception to this downfall since there was a 7% decrease in worldwide merchandise trade flows in 2020[49]. The low freight index during the first year of the pandemic, 2020, is demonstrated on Figure 9. There are several reasons as to why the pandemic affected the shipping industry, like the plethora of local lockdowns and regulations enforced by governments worldwide to prevent the virus from spreading, the impact in people's behavior on health concerns in relation to imported merchandise from infected territories, and the economic results of such impact especially to developing countries. Within the general context of rise of costs in global trade, *"the shipping costs were significantly increased reaching 350% since May 2020. Imbalances in regional trade brought about by the pandemic have contributed to the rise in shipping costs. In particular, increased demand for durable goods in locked-down economies, combined with Covid-related disruption in the ports of those countries, exacerbated the shortage of shipping containers. Containers became 'stuck' in the US and Europe rather than returned to Asia*[50]."

[49] Liu, Ornelas, Shi (2021)

[50] Official website of Bank of England, (July 23rd, 2021).

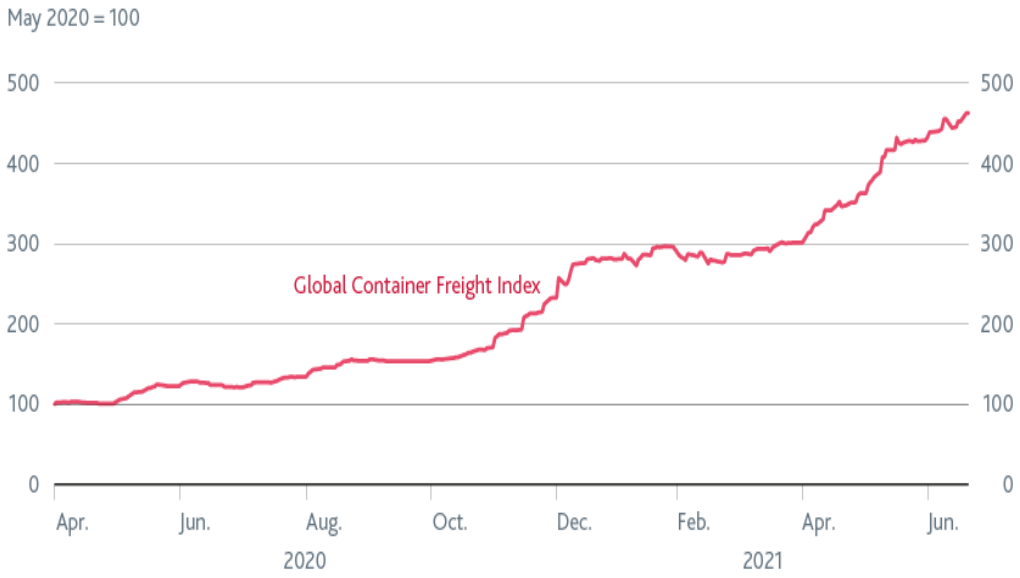


Figure 9: The effect of Covid-19 on the global market[51]

[51]Bank of England (July 23rd, 2021).

5.2.3 Comparison of the crises

Undeniably the Covid-19 pandemic caused major damage to global trade. For example, in 2020, global trade fell by 8.9%, the steepest drop since the global financial crisis of 2008 (Figure 10).

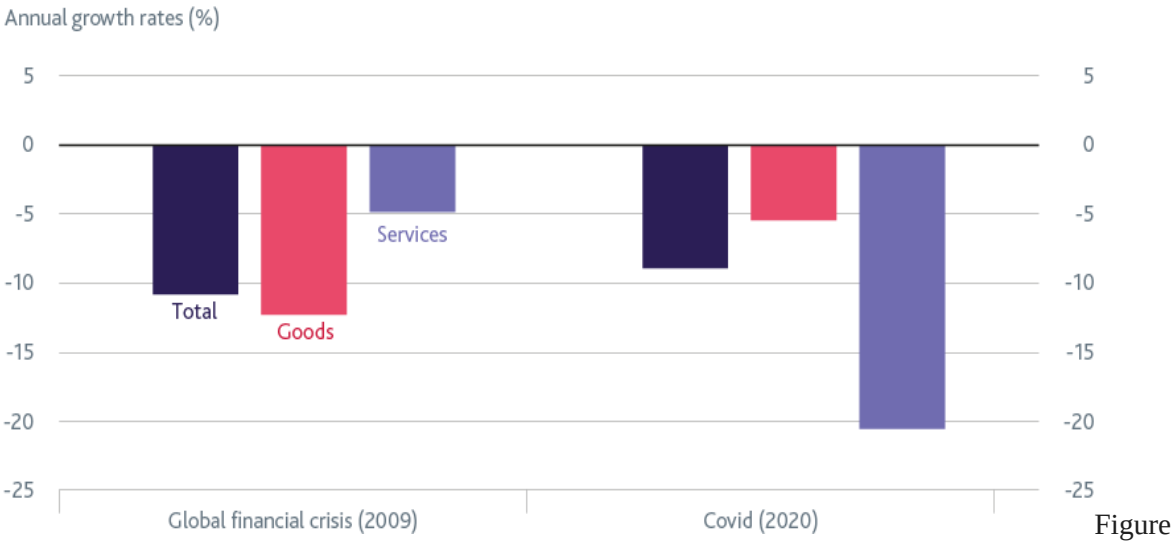


Figure 10: Annual growth rate during the crisis of 2009 and the pandemic[52]

As it is demonstrated above, the total growth rate during the economic crisis was significantly lower, since the demand for goods was two times lower than that during the pandemic. The service rate was four times lower in 2020 compared to 2008-2009, due to lockdowns and public health concerns. The pandemic affected services trade more than goods trade. Services trade fell by more than 20% in 2020, almost four times the decline in goods trade[53].

[52] Dickinson (August 8th, 2021).

[53] Official Website of Bank of England (July 23rd, 2021).

5.2.4 New employment opportunities arising from green energy

In an attempt to decrease and eventually eliminate climate change and environmental degradation, governments have pursued the goal of zero carbon dioxide emissions in the last decade more than ever before. This attempt is a great opportunity for the creation of a plethora of new jobs that are going to be highly needed in order to support and execute this worldwide effort. These new job opportunities arise from the creation of new machines and equipment, the research of the contracted area and the possibility of their implementation. Besides the experts who guide and implement this great goal, there is also a need for workers and contractors, which gives the unemployed part of the population a chance to earn a living again.

Specifically, the sector of green energy is a vast one and includes several job opportunities. Said sector according to Renewable Energy and Jobs – Annual Review offered 11.5 million jobs just in 2019, with one third being in the solar energy sector[54]. New career opportunities include solar engineering – which develops and operates machinery and equipment that use the sun as a source of energy and turn it into electricity- geophysical engineering – which discovers resources and proceeds with their safe exploitation- wind energy engineering -which creates and constructs wind farms- and, lastly, mechanical engineering -which in general creates all kinds of machines that can make green energy a reality.

There is expected to be an even higher demand for employees with expertise in the implementation of technological innovations, that is why companies already offer an extensive training program to their employees. Most of the accidents that happen on high seas (80 to 85%) are due to human error[55]. This is even more concerning nowadays, since we are dealing with billions of dollars' equipment and, on some occasions, with prototypes. It is therefore

[54] Official website of IRENA (2020).

[55] Sánchez-Beaskoetxea, Basterretxea-Iribar, Sotés, Machado (2021).

evident that the need for knowledge and expertise of the highest level over the matter at hand, is of the utmost importance.

5.3 Actions of the most important players

Major shipyards around the world are working hard on eco-friendlier ships and related equipment. For example, China, one of the biggest exporters, is cooperating with several organizations who are dedicated to turn the shipping industry green, focusing on the project "Clean Sky", which is being developed by COSCO Shipyard Group.

In Europe, where 13% of transport emissions are cause from maritime shipping[56], several countries are combining their efforts to create as many eco-friendly ships as possible while incorporating the plethora of ways to do so. A characteristic example is the one in Europe, where "*under the leadership of the Dutch Damen Group, 46 European shipbuilders, equipment manufacturers, and research institutes from 13 countries have officially launched a joint research project to develop eco-friendly shipping technologies. This project, called "Lean Ships" (low energy and near to zero emissions ships), is an energy-saving and eco-friendly technological collaboration that is working toward effectiveness and reliability. The aim is to reduce ships' fuel consumption by up to 25%; CO_2 emissions by at least 25%; and SOx, NOx, and particulate matter (PM) emissions to zero*[57]."

In the case of U.S., the pattern is similar. The maritime transport eco-friendly project is the Navy's Ship Service Fuel Cell (SSFC) which has two goals, one economical and one

[56] Ceurstemont (2021)

[57] Nam (2017).

environmental. The project's main focus is to reduce the fuel budget by developing eco-friendly power generation systems to increase combat power[58].

5.4 Greening and Performance Relativity

Greening and Performance Relativity (GPR) is a way to examine the correlation between green sustainable power and a company's productivity. This method is used before a company decides to strive for renewable energy sources. More specifically, *"Shipping firms use business routines to achieve desirable outcomes in terms of environmental performance and financial performance. The GPR concept establishes the relationships between green shipping practices (GSPs) and firm performance.*[59]."

The outcome of the GSPs evidences that the financial side of the shipping industry will benefit from turning green. This should encourage enough the related companies to reevaluate their efforts towards becoming more environmentally friendly. This positive impact rises from the fact that turning green is equivalent to lower energy consumption and operating costs. Further, no fines will be imposed as vessels will not emit above the allowed GHG limits. Additionally, the need for evaluations and restoration will be decreased. Lastly, within the general concept of the Corporate Social Responsibility (CSR), the overall perception people have of the company will be improved once it turns eco-friendlier.

[58] Nam (2017).

[59] Lun & Lai & Wong, & Cheng, (2019).

Chapter 6: Conclusion

6.1 Summary and conclusions

In conclusion, as it has been shown in detail above, the interconnection between green energy and shipping is a multifaceted issue. Due to the global effort to reach zero carbon dioxide emissions, every industry must become eco-friendlier. As far as the shipping industry is concerned, even though it produces only 2-3% of the total carbon emissions, it still has to go through severe changes in order to help pave the way towards the goals set by governments and international organizations. The ways green shipping can be achieved, have been analyzed from a legal, economic and a technological point of view.

The legal side of the zero-carbon emission plan, as it has been examined, includes laws and regulations set by most countries and several international organizations, like the International Maritime Organization, that have been enforced during the last few years. The ambitious plan that many states have embraced for the future has already brought a drastic change in many aspects of the economy, including shipping. From the European Green Deal to the U.S Clean Air Act, such enactments -as well as new ones which are expected to come in force- have triggered and shall continue to trigger worldwide changes towards an eco-friendlier future.

As for the economic aspect, it is common knowledge that the economy has suffered greatly in the last decade and a half, which has caused the shipping industry, like many other sectors, to suffer capital deficiencies. Both crises, the economic one and the COVID-19 pandemic one, share similarities but they also display distinctive differences. The most important of such differences being that during the economic crisis there was an annual growth rate reduction in goods, whereas during the pandemic there was an extreme reduction in services. These

economic setbacks have made shipowners more reluctant to implement new machinery and equipment to their well-running ships, choosing to pay fines instead of investing on a less pollutant future. Even though, in the long run, the application of new technologies can be profitable, the initial loss has proved to be discouraging enough to invest on eco-friendly equipment. This approach cannot but change in the future, as time limits for complying with the above laws and regulations shall become stricter and eventually non-negotiable.

On the other hand, the green initiative has a very important and beneficial effect on the economy, consisting in the creation of several new jobs that are crucial for bringing it to fruition. Furthermore, the publicly funded education on already existing jobs is also extremely important for assisting workers to effectively transition to this new era of green energy, meaning more opportunities for the workforce and a chance to demand higher salaries. The domestic economy of some countries will also benefit due to the mere fact of their geographic location, which allows them to either produce or transport/distribute renewable energy.

An aspect of major importance, as it has been analyzed in length, is the technological innovations that have been invented in order to take advantage of natural elements and turn them into energy. Said energy can be used to cover humanity's ever-growing power needs. In regard to the shipping industry, there are complications that still require greater scientific study, effort and improvement. For example, the implementation of some of the new ways and means of harnessing renewable energy and using it on ships is more challenging compared to industrial facilities. Installing solar panels is a relatively easy task comparatively to the rest green energy means and appliances. The main reason is that it has a low cost to maintain and utilize, unlike using ammonia or hydrogen. The latter two, besides being more difficult to implement, are also costly and unsafe due to their high flammability.

The interconnection of all three aspects of green energy -in short, laws, economy and technology- with shipping, shows that the world is going to become overall eco-friendlier in the decades to come and even though there will be challenges to surpass, this path is going to lead to a safer world for humanity. With scientific help, specific legal framework and economic solutions that can be used to assist this transition, positive ecological changes have never been so close to becoming a reality.

6.2 Limitations and recommendations

The fact that most of the new ways and means for using renewable energy, especially on ships, are quite innovative and are still in a very early stage of conception, implementation and production -while some of them are still in the initial stage of a prototype- inevitably leads to the lack at the present time of any substantial empirical data. Therefore, at present the conclusions of this study can only be considered and evaluated through the prism of the ongoing progress and development of the ways and means of green energy, as presented herein.

All new information and empirical data on the subject to be studied and analyzed in the future by any party, preferably should originate from well reputed organizations and trustworthy sources, first choice certainly being the IMO.

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