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Carbon footprint levels and recommendations for sustainable shipping industry.

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ABSTRACT

Maritime transportation account for the most efficient and economic transportation of goods across the globe but many environmental impacts are to be considered. According to the latest International Maritime Organization (IMO) reports, maritime transportation accounts for 2-3% of all global greenhouse gas emissions. IMO has recommended bringing down 50% of these emission levels by 2050. This has created a greater demand among shipbuilders and industry to adopt sustainable methods that can reduce carbon emissions. This study aims at bringing a sustainable alternative approach that can be implemented in the shipping industry to bring down carbon emissions. Carbon footprint (CF) is the tool used here to study the sources of greenhouse gas (GHG) emissions and their quantities. Analysis of carbon footprint during each stage of the ship's lifecycle is carried out and alternative approaches are implemented at three levels. The first approach is applied on operation level, second on type of fuel used, and third on powering. The result shows that streamlining the ship's hull brings a 1% reduction in total carbon emission. Switching from fossil fuel to biofuel and renewable fuel shows a significant reduction in GHGs, also renewable alternatives are highly effective and go at pace with environmental sustainability. Reducing the shipping speed and slow steaming can bring down two-third of the total carbon emission. Electric propulsion not only serves as a reduction in carbon intensity but also has immense potential for future developments.

Keywords— Carbon footprint; Shipping industry; Greenhouse Gases; Green Technology; sustainability; Green Engineering; Carbon Emission; Green Shipping.

RESUMEN

El transporte marítimo representa el transporte de mercancías más eficiente y económico en todo el mundo, pero se deben considerar muchos impactos ambientales.

Según los últimos informes de la Organización Marítima Internacional (OMI), el transporte marítimo representa el 2-3% de todas las emisiones globales de gases de efecto invernadero. La OMI ha recomendado reducir el 50% de estos niveles de emisión para 2050. Esto ha creado una mayor demanda entre los constructores navales y la industria para adoptar métodos sostenibles que puedan reducir las emisiones de carbono. Este estudio tiene como objetivo aportar un enfoque alternativo sostenible que se pueda implementar en la industria del transporte marítimo para reducir las emisiones de carbono. La huella de carbono (FC) es la herramienta que se utiliza aquí para estudiar las fuentes de emisiones de gases de efecto invernadero (GEI) y sus cantidades. Se lleva a cabo un análisis de la huella de carbono durante cada etapa del ciclo de vida del barco y se implementan enfoques alternativos en tres niveles. El primer enfoque se aplica al nivel de operación, el segundo al tipo de combustible utilizado y el tercero al encendido. El resultado muestra que la racionalización del casco del barco trae una reducción del 1% en las emisiones totales de carbono. El cambio de combustibles fósiles a biocombustibles y combustibles renovables muestra una reducción significativa de los gases de efecto invernadero; además, las alternativas renovables son altamente efectivas y van a la par con la sostenibilidad ambiental. La reducción de la velocidad de envío y la vaporización lenta pueden reducir dos tercios de las emisiones totales de carbono. La propulsión eléctrica no solo sirve para reducir la intensidad del carbono, sino que también tiene un inmenso potencial para desarrollos futuros.

Palabras llave— Huella de carbono; Industria naviera; Gases de invernadero; Tecnología verde; sustentabilidad; Ingeniería verde; Las emisiones de carbono; Envío verde.

INTRODUCTION

Saying NO to shipping is impossible as 90% of trade and transportations are done by the shipping industry. The quantity of goods and services transported via shipping has increased tremendously through the decades. Marine exhaust gas accounts for 2-3% of the global greenhouse gas emissions [1]. Due to the increase in fuel pricing as well as IMO regulations, there is an urgent need to limit their emission and shift to sustainable green technologies. These gases can trigger the heating of the earth's surface leading to drastic climatic changes. This can act as a threat to several life forms and be the impetus for their extinction. There are a plethora of measures that can be adapted to control their emissions.

To control this emission, International Maritime Organization (IMO) has introduced the Kyoto protocol, EEDI, and SEEMP. Energy Efficiency Design Index (EEDI) is a performance-based regulation that focuses on energy efficiency standards and designs on new ships. Ship Energy Efficiency Management Plan (SEEMP) focuses on the operational efficiency of the existing ships.

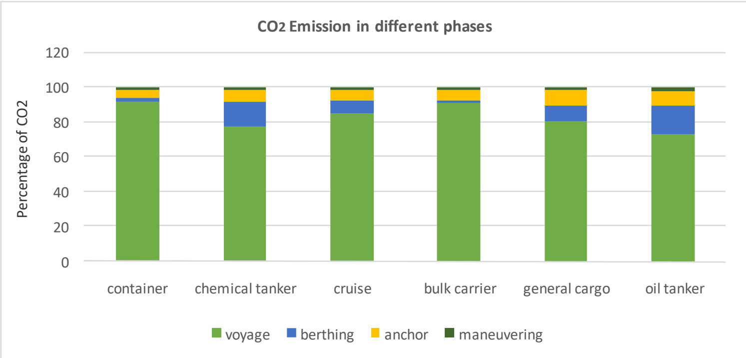

Fig 1: Percentage of CO_2 released during different phases.

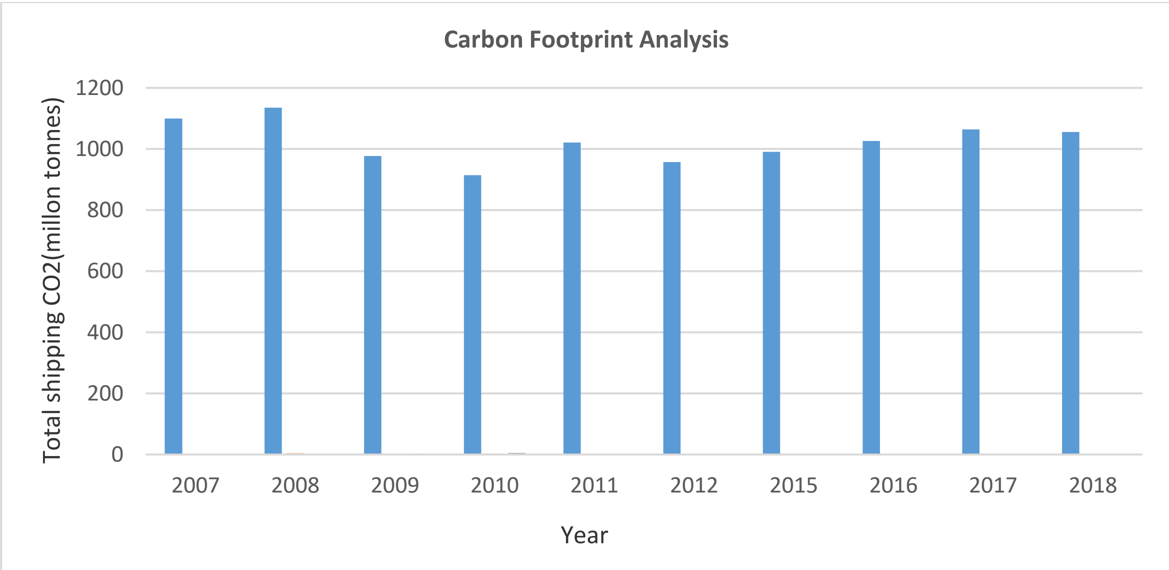

Fig 2: The level of CO_2 emission by shipping industry at different years.

The International Maritime Organization (IMO) has recommended bringing down the greenhouse gas emissions to at least 50% by 2050 compared to 2008 emissions, and carbon intensity levels by 40% by 2030, also up to 70% by 2050 compared to 2008 emission levels [2]. This has triggered most of the shipbuilders and owners to possibly adopt all such green approaches that can be implemented from basic to operational levels. Switching to sustainable shipping methods can not only reduce the emission level but also increase efficiency as well as bring benefits to the ship owners.

This paper aims at bringing all possible ways that can be adopted by the future shipping industry to reduce the GHG emission levels. Carbon Footprint (CF) is a tool used to quantify greenhouse gas emission levels. It can be defined as the sum of all greenhouse gasses produced by our deeds and it is expressed in tons of CO_2. Carbon footprint at each level of shipping is analyzed using the latest data and more efficient green approaches are proposed that can be implemented at different levels.

This paper divides the shipping industry into three levels and each level is carefully analyzed. The first level is the operational level where various alternative and sustainable approaches that can be implemented by the shipping industry to improve its efficiency as well as to reduce its carbon emissions are included. Sustainable approaches always come with win-to-win conditions where it's environmentally appealing and also improves the efficiency of the vessel. The second level is the type of fuel used. Fuel selection plays an important role in the reduction of greenhouse gases, as the type of fuel used can largely influence the efficiency, performance as well as greenhouse gas emissions. The third is powering, which can be the main pillar in carbon emission reduction approaches as the main source of greenhouse gases while in operation is from the engine exhaust.

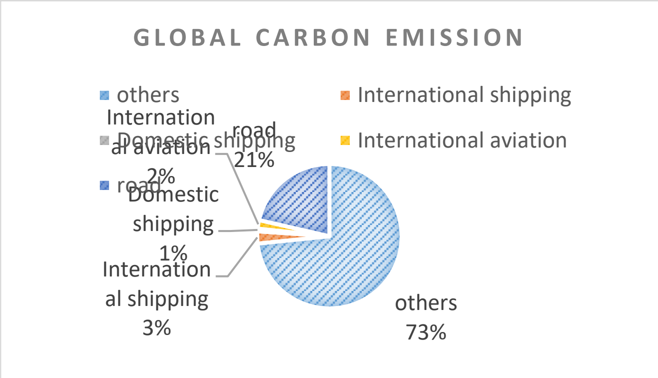

Fig 3: Global Carbon Emissions from Road, Domestic Shipping, International Shipping, and other sources.

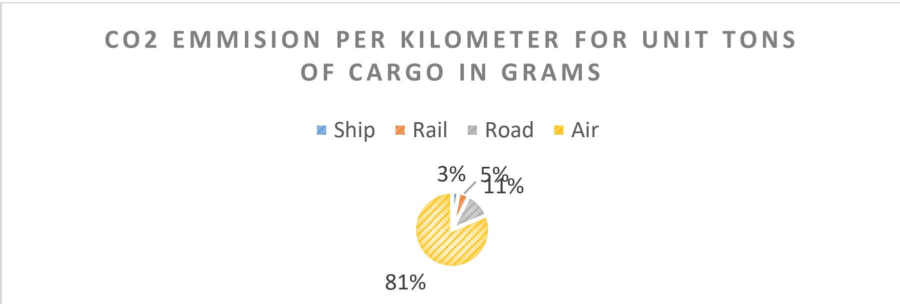

Fig 4: CO_2 emissions per kilometer for unit tons of cargo.

FIRST APPROACH: OPERATION

Slow Steaming -Slow steaming is the deliberate reduction of steaming speed to bring a reduction in power consumption as well as carbon emission reduction. It is done by bringing down the speed to 10-12 knots [3]. In the beginning, it was used by container ships only but now it is adopted by various types of shipping. Slow steaming can not only provide higher fuel savings but also shows a significant reduction in power consumption as well as a reduction in carbon footprint. The major concern is time for cargo transportation as when speed is reduced cargo transportation takes much more time than usual. Slow steaming can sometimes cause damage to the proper working of engines but these can be solved effectively using good technologies and retro fittings.

Trim optimization- Ship experiences different water resistance at different trim conditions. When the chosen trim condition is showing minimum resistance, it is called trim optimization, which will reduce power consumption, fuel-saving, and carbon footprint. Traditionally, trim optimization was done through towing tank tests using some hull forms but nowadays many software's are available and trim optimization can be done effectively. Trim can be maintained either with ballast water or using some shifting of weights.

Weather Routing-Weather routing is a service provided by commercial shipping companies to cargo ships. It is an important factor that determines the performance of a ship at sea, safety of life, power consumption, navigational efficiency, time for the voyage, et cetera. The existing weather conditions, currents as well as the weather forecast is considered in a combined form to provide the ship with the best route that can save fuel as well as reduce carbon emissions. There are many technologies used today to do route mapping such as satellites and the services are provided by respective commercial companies.

Autopilot Upgrade- Autopilot is an advanced technological system used by modern-day ships. Traditionally, the merchant ships were controlled and steered by the 'Quarter master' who takes orders from the masters and helmsman officers. The prime responsibility of the quartermaster was to stay by the steering all day and taking turns on helms. Later in the 1920s, the automated steering was introduced on board which replaced the quartermaster [4]. An autopilot system is an automated system that has been synchronized with the gyrocompass to control the steering as well as rudder movement according to the input conditions. Autopilot is capable of being synchronized with an electronic chart system which enables it to follow the path that is prescribed in the voyage plan. This takes care of the wind, water, and other weather conditions which in turn reduces the ship resistance that subsequently leads to a reduction in carbon emission, usage of fuels and brings down the carbon footprint.

A. Air Lubrication

Air lubrication is a system that uses micro air bubbles to reduce the resistance between the ship hull and the seawater. Compressed air is supplied at the bottom of the ship along its length. Micro bubbles are generated by the air release unit (ARU) at the bottom of the hull. This air bubbles measure about 1-3 mm in diameter. These generated micro bubbles cover the flat bottom surface of the ship's hull like a carpet. This method can reduce frictional resistance between the ship's hull and water thereby reducing the power consumption by the ship. It also brings a reduction in carbon emission as well as carbon footprint. The carbon emissions and fuel consumption can be reduced up to 10% by this method [5].

B. Fleet Management

Fleet management is simply an organization or company whose aim is to coordinate the business vessels. They take complete control of the fleet using the latest technology to know the complete life cycle of the vessel. They use Global Positioning System (GPS) trackers to know the real-time positioning and have additional software that can know the location, the path followed, performance, vehicle speed, fuel consumption, etc. They also have a maintenance tracking system that alerts them if any maintenance or repair is required. Hence this method helps in reducing fuel consumption, carbon emission as well as carbon footprint.

C. Bow Optimization

Modifications on the ship's bow can significantly reduce the power consumption of the vessel. Different modifications can be done on bulbous bow shape which in turn can reduce fuel consumption and increase efficiency. This design modification can bring a significant reduction in carbon footprint.

D. Hull Optimization and maintenance

Choice of hull material, hull coating, and streamlining of the hull has a great impact on efficiency, power consumption, and fuel consumption as well as carbon emissions. Streamlining of the hull can reduce friction thereby reduce fuel consumption. Anti-fouling paints can be used as coating of the hull which can give a smooth finishing and also retard the growth of marine organisms. Applying the advanced antifouling paints with good hull forms causes a significant reduction in resistance, thereby increasing the saving of fuel by about 3-8%.

E. Just-in-Time Arrival

Just-in-time arrival can be implemented by the ports using an effective communication system in the shipping industry. This reduces congestion in the port areas. Studies show that about 9% of the ship's time is wasted while waiting for the anchoring. This Just-in-time arrival can be achieved with good communication from the port regarding the availability of berthing, fairway, and other services. Spending minimum time at the port can result in the reduction of carbon emission as well as carbon footprint. Carbon emissions up to 1-5% can be reduced using this method [3].

SECOND APPROACH: TYPE OF FUEL

Heavy Fuel Oil (HFO) is widely used in shipping industries since the 19th century. Marine engines use low-grade fuel oil to reduce their operating cost as it accounts for 30-50% of the total cost. HFO has high carbon content as it is a residue from the refining industry. Figure 5 shows various fuels used by ships in the marine industry. There is an urge to switch to an alternative fuel to bring down the level of pollutants released, attenuate the climatic changes, and protect various life forms. Liquefied natural gas (LNG) is most viable with more than 250 ships in operation. Besides LNG, methanol and biofuels are thriving on their path to this modern world. Electric and hybrid vessels are also being used as passenger and offshore ships [6].

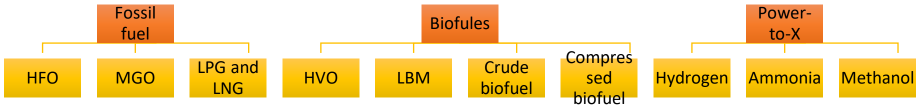

Fig 5: Various types of fuel used by the shipping industry

F. Hydrogen

It makes the concept of zero-emission practical with the use of fuel cells. It can be produced from electrolysis near ports, contributes the least to noise pollution, and is found to be the most efficient among the alternatives. The challenges of hydrogen as a fuel are the high price, unavailability of infrastructure, and to store the fuel at extremely low temperatures as liquefied hydrogen. The usage of hydrogen is limited to short sea shipping due to its low density and its highly flammable nature. It emphasizes the need for additional safety measures leading to an additional cost.

G. Methanol

The main advantage of methanol is its good performance and low capital cost. It allows the usage of modified existing bunker systems. It is easier to store and has a high energy density compared to hydrogen. The fuel is priced close to Low Sulfur Fuel Oils (LSFO) and marine gas oil (MGO) in today's market. Besides the pros, it is derived from fossil fuels and has emissions similar to conventional marine fuels [6].

H. Ammonia

The main advantage of ammonia is its ability to be a carbon-free source with a better density than hydrogen. It is also considered to be viable in deep-sea conditions. However, the absence of a bunkering infrastructure and high cost limits its feasibility. In case of any leakage, it can have a drastic environmental effect and lead to a marine disaster. It must be kept in mind that the safety mitigations required in this case can turn into a disadvantage, due to its high toxicity [6].

I. Liquefied petroleum gas (LPG)

Despite having low energy costs and capital costs, its applicability is limited. Liquefied petroleum gas (LPG) is produced from fossil fuels and can cause an adverse effect on the environment. There is no particulate emission and has a high energy density. It is non-toxic and can be easily stored. Usage of LPG increases the output efficiencies by approximately 11 % [7].

J. Hydrotreated vegetable oils (HVO)

Studies show that Hydro treated vegetable oils (HVO) fit well as an alternative to conventional fuel. Its production capacity is highly limited and hence, makes it expensive. A high level of Nitrogen Oxides (NOx) and particulate emissions make it less feasible. In addition, there is a lack of bunkering facilities at major ports.

K. Liquefied natural gas (LNG)

Liquefied natural gas (LNG) is the only alternative fuel available in sufficient quantities to meet the industry's needs. A switch from Heavy Fuel Oil (HFO) to LNG can bring economic and operational benefits. It is one of the safest alternatives with a cheaper cost compared to the other alternatives. The bunkering facility for LNG is improving and thus making it more feasible. It is readily available, portable, and easy to handle. Pressurized tanks are used to store them and are made accessible at different terminals across the world. It contributes to a lower level of CO_2 emissions and complies with the existing regulations. It brings down Greenhouse gas (GHG) emissions by 20% and avoids chances of ocean contamination [8].

Energy		Fossil fuel		Bio		Renewable	
Parameter	LNG	LPG	Methanol	HVO	Ammonia	Hydrogen	Electric
GHG emissions	🟠	🟠	🟠	🟢	🟢	🟢	🟢
Energy Cost	🟢	🟢	🟢	🟠	🔴	🔴	🔴
Toxicity	🟢	🟢	🟢	🟢	🔴	🟢	🟢
Bunkering availability	🟢	🟢	🟢	🔴	🟠	🔴	🟠
Technological maturity	🟢	🟢	🟢	🟢	🟠	🟠	🟢
Energy density	🟢	🟢	🟢	🟢	🟢	🟠	🔴
Regulations	🟢	🟢	🟢	🟢	🟢	🟠	🟢

Figure 6: The viability of different alternative fuels based on various parameters are highlighted using green, orange and red colors where, 🟢 - excellent, 🟠 - acceptable, 🔴 - undesirable [6].

THIRD APPROACH: PROPULSION

The type of propulsion system depends on the vessel type, size, and trade. Renewable options are being incorporated into the ship's primary and auxiliary propulsion systems to achieve sustainability. A wide variety of marine propulsion can be considered from conventional sails to battery-electric propulsion and hydrogen fuel cells.

L. Wind propulsion

The propulsion of early boats and ships was met using wind energy which can be harnessed using sails, kites, rotors and, turbines. With the advent of the steam engine, the proportion of vessels using wind-assisted propulsion diminished over the years. The rising fuel price brought a renewed interest in using wind power. Soft-sails and fixed sails were considered to be efficient in harnessing the energy needed to propel the vessels. Using wind turbines and rotors in deep-sea can save about 20% of fuel in deep-sea operations. The major drawback of this approach is variations in wind force. In such cases, it's advisory to use a hybrid wind or motor system [9].

M. Solar Propulsion

Solar propulsion technology is getting advanced every year. Here, electricity is generated using photovoltaic (PV) cells and stored in a rechargeable battery for future use. Even though technology offers a better energy storage facility, a complete solar propelled ship requires further technological developments. Wind and solar power along with the ship's main engine can bring a change in the amount of fuel consumed and gases released.

N. Electric propulsion

Electric propulsion consists of a prime mover, generators, and motors. During the Second World War, electric propulsion was widely used with the steam engine as prime movers. Nowadays, the steam engine is replaced by the diesel engine. Both the systems contribute to lesser pollutions and Greenhouse gas (GHG) emissions. The main disadvantage is its low mechanical efficiency that causes more fuel consumption and higher cost. For ships consuming a larger amount of power, an electric propulsion system can cause a reduction in cost as it involves the integration of propulsion motors with power generation motors. It also helps in reducing noise pollution to a great extent. These systems are often used in icebreakers and cruise ships [10].

O. Fuel Cell Propulsion

The main component of this system is hydrogen. Energy is generated in these cells via electrochemical reactions. The mechanism involved is clean since electricity is produced without combustion. Water vapor and heat are the only emissions from a fuel cell. The complete energy chain can be kept clean by using renewables in the production of hydrogen fuel. This can ensure a true zero-emission fuel. Fuel cells are characterized by a minimum number of moving parts indicating a lower maintenance cost and ensuring optimum lifetime. They are capable of generating electrical energy about 10 times that of a Lithium-ion battery and have higher efficiency than the conventional ones [9].

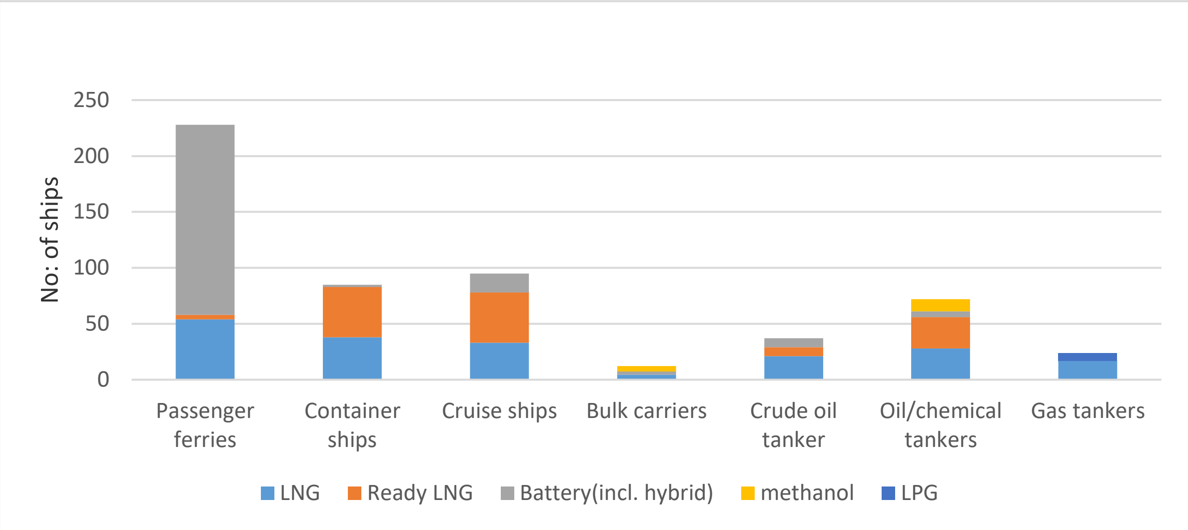

Fig 7: Number of vessels operating on alternating fuels and propulsion systems till the year 2020.

Lack of proper information regarding various alternative fuels limits their usage. Still, vessels powered by these alternative fuels and propulsion systems are entering the market and will remain an integral part of this modern world (see Figure 7). For vessels using HFO, LNG can be considered as the stepping stone in achieving sustainability. Even though they are capable of improving the air quality and reducing Greenhouse gas (GHG) emissions, a significant development is needed in their field to study these fuels to meet the industry's needs.

As conclusion, the Shipping industry is flourishing by leaps and bounds. It is the cheapest and most efficient way of transporting heavy cargoes. The carbon footprint of the shipping industry is very less compared to other modes of transportation, thus it makes an environmentally friendly choice in terms of carbon emissions. The shipping industry has grown 10% from 2012 to 2018 and thus it produces 940 million tons of CO_2 annually. International Maritime Organization (IMO) has raised consciousness on this emission rate and if no prior actions are taken, these rates are likely to double by 2050 [1]. Sustainable methods shouldn't hinder the development of any industry. Sustainability and development should go hand in hand. Bringing sustainable developments at the operational level can reduce carbon footprint to a great extent. This paper suggests some alternative approaches that can be implemented in the shipping industry that not only reduce carbon emission but also increases the efficiency of the ship. The second area is the fuel and propulsion level. One single fuel cannot be the future of the shipping industry instead a variety of alternative fuels must be in use. Adopting this fuel by future shipping requires huge financial investments and various equipment which is a great concern.

Ships under electric propulsion consume less fuel. Electric propulsion not only serves as a reduction in carbon intensity but also has immense potential for future developments.

REFERENCES

International Maritime Organization (IMO), "Third IMO GHG Study 2014," 2014

International Maritime Organization (IMO), "Initial IMO GHG Strategy," 2018

Salma Sherbaz and Wenyang Duan, "Operational options for green ships," J. marine Sci. Appl. (2012)

Marine Insight, "Marine Navigation - 10 Things to Consider While Using Auto-Pilot System on Ships," April 9, 2021

Wartsila, "Air Lubrication System," December 2, 2019

DNV GL AS Maritime, "Comparison of Alternative Marine Fuels," July 2019.

M. Tsikouras, M. Papoutsidakis, D. Papachristos, and N. Nikitakos, "An Introductory Guide in Marine Propulsion and Green Shipping," June 2019

Paivi Aakko-Saksa and Guangrong Zou, "Green Ships and Alternative Marine Fuels," October 2015

Linus Mofor, "Renewable Energy Options For Shipping," 2015

M. Tsikouras, M. Papoutsidakis, D. Papachristos, and N. Nikitakos, "An Introductory Guide in Marine Propulsion and Green Shipping," June 2019.

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