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Reduction of Shipping Greenhouse Emission by Alternative Fuels Used

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Abstract: The article examines, assesses, and analyses various types of fuels used in shipping. between the ports of Varna and Rotterdam. In order to determine the fuel that generates the least amount of carbon dioxide and is cost-effective, various types of traditional marine fuels and those that are yet to be introduced into operation have been considered. The advantages and disadvantages of bunkering, transporting, and storing various types of alternative marine fuels have been defined. The analysis shows that the lowest carbon dioxide emissions are generated when using alternative biofuels such as methanol and methane. Furthermore, if HVO fuel, which has not yet gained widespread use in shipping, is employed, emissions will be reduced by approximately 90%. From an economic perspective, methane and methanol have the lowest cost per ton of fuel compared to HVO, which is about four times higher in comparison to methane and methanol. Considering the IMO regulations for reducing harmful emissions into the atmosphere, HVO appears to be the future fuel that will normalize its prices.

Keywords: Greenhouse emission, Shipping, Alternative fuels, HVO

Introduction

According to the latest research and analyses as of 2021, greenhouse gases amount to approximately 55 billion tons on a global scale. The largest share is carbon dioxide, followed by methane and nitrous oxides (Hannah, 2020). The generation of greenhouse gases is associated with various industries and manufacturing sectors in countries worldwide. For example, in 2020, shipping generated around 700 million tons of carbon emissions. Considering the recommendations and requirements of the International Maritime Organization, measures must be taken to reduce greenhouse gas emissions from shipping by up to 40% by 2030 and up to 70% by 2050(UNCTAD, 2022). Furthermore, the EU aims to establish a system for assessing and analysing CO2 emissions from shipping in EU ports, which is set to come into effect in January 2024 (European Commission, 2018) This goal can be achieved through various measures aimed at improving the energy efficiency of existing ships, such as modernizing their hulls, retrofitting main engines, and utilizing alternative fuels, among others.

In recent years, the use of liquefied natural gas (LNG) as a fuel has become increasingly prevalent in shipping. Currently, it is predominantly used on existing vessels, accounting for around 40% of the global fleet as of January 2023. An analysis of the operational efficiency of LNG-powered ships was conducted in (Gonzales Gutierrez et al., 2023) with the aim of providing a clear assessment of the energy efficiency of these vessels and their compliance with modern environmental requirements.

Measures such as reducing ship speed, using liquefied natural gas, and retrofitting container carriers are presented in (Ammar, 2020). An assessment of the energy efficiency index after implementing these measures has been conducted, and it was found that the speed should be reduced by approximately 22% to significantly improve the energy efficiency index, resulting in annual fuel savings of around 23 million dollars.

The use of methanol as an additional ship fuel to comply with IMO regulations was conducted in Ammar (2019), meaning the ship operates with dual fuel systems. The analysis was performed on a container ship. To achieve significant reductions in generated gases, the ship's speed was also reduced. As a result, CO2 emissions decreased by approximately 18%, leading to fuel cost savings. The cost-effectiveness of dual fuel for reducing NOx, CO, and CO2 emissions is $385.2/ton, $6548/ton, and $39.9/ton, respectively.

A similar analysis with a reduction in the speed of a RO-RO ship was conducted in Ammar (2018). The results show that with a reduction in speed of approximately 40%, CO2 emissions decrease by about 73%. Although the energy efficiency index improves after reducing the speed, in accordance with IMO requirements, it must be further reduced to meet those set to take effect in 2025.

The authors, Acomi & Cristian Acomib (2014), focus on the environmental protection within the maritime transportation sector. Their study revolves around the Energy Efficiency Operational Index (EEOI), designed to assist ship-owners in assessing and reducing emissions from ships in operation. The EEOI serves as a monitoring tool, measuring the mass of CO2 emitted per unit of transport work. Using software developed by them, they analysed how the EEOI value varies for a specific vessel when different types of fuel are used during laden and ballast voyages over a three-month period, as recorded on board on ship. Their analyses aims to highlight the cost-effectiveness of the methods studied for minimizing air emissions.

With the aim of energy savings and consequently lower levels of generated gases, an attempt was made in OECD (2023) to implement a clean propulsion system for a 5000 t DWT bulk carrier. The authors have based this on a shaft generator using a dual-fuel engine, combining diesel and liquefied natural gas (LNG). By developing a simulation of the engine's RPM, it was determined that this system ensures satisfactory engine power and reduces CO2 emissions.

Greenhouse Emissions Generated by Shipping

The greenhouse gases generated by shipping are primarily CO2, nitrogen oxides, and sulphur oxides in different percentages, Figure.1. They are measured in tons of generated gas per ton of sea mile. The percentage share of CO2 is the largest, which has an adverse impact on the environment and climate change. This provides a basis for seeking measures to reduce its proportion. Distribution of percentages from transport industries is shown on Figure 2.

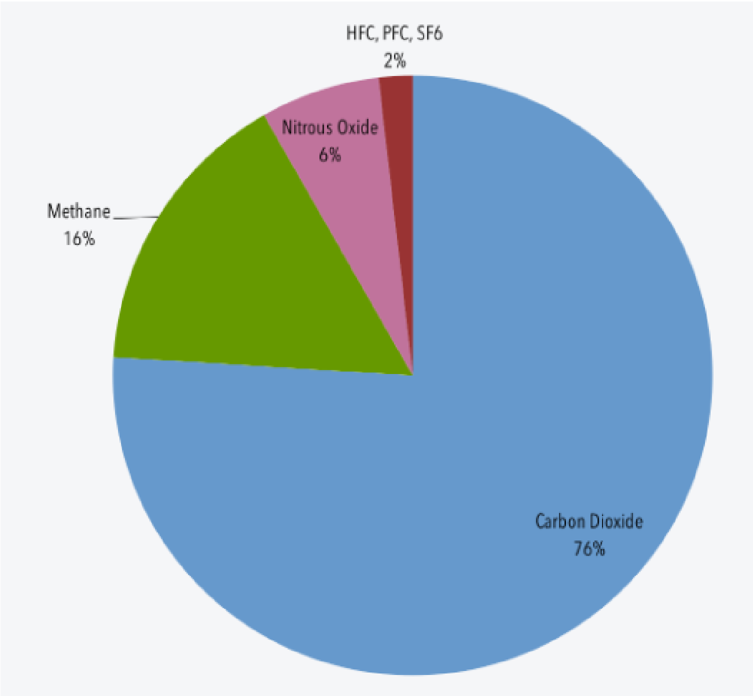

Figure 1. Percentage of GHG(CCES, 2023)

From the figure, it can be seen that the share of emissions generated by shipping, according to (EEA, 2019) is approximately 13%. This is comparable to aviation, where there are not as drastic measures to reduce harmful emissions

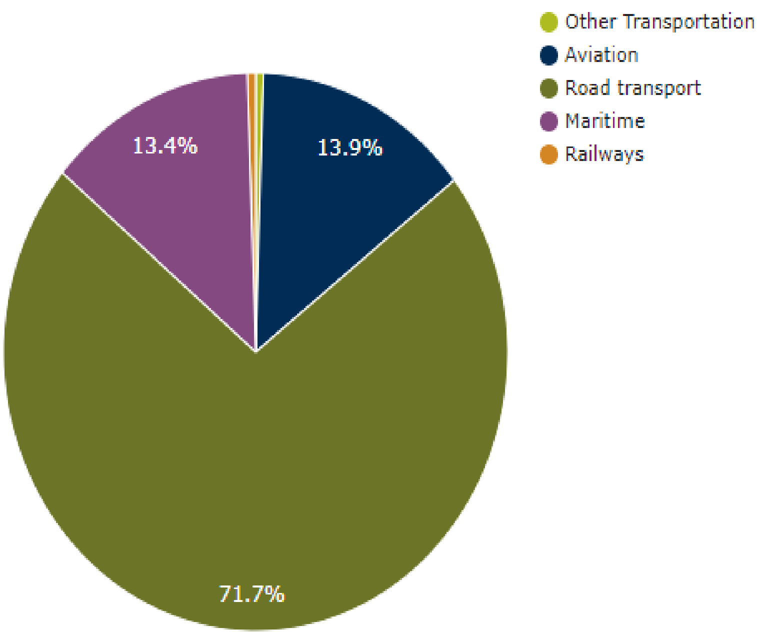

Figure 2. Distribution of emissions form transport industries (EEA, 2019)

In 2022, the generated CO2 emissions into the atmosphere amounted to approximately 860 million tons. When distributed by types of ships, the CO2 emissions are illustrated in Figure 3.

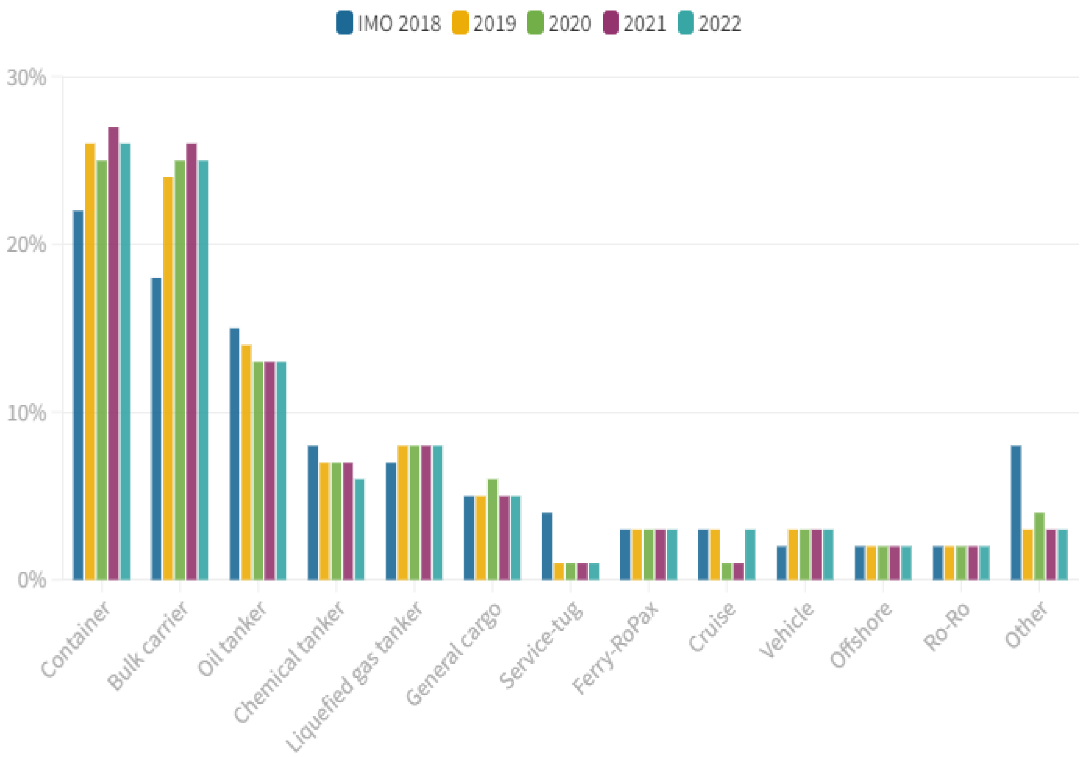

Figure 3. Distribution of CO2 emissions generated by ships (OECD, 2023)

Figure 3 presents the results of generated CO2 emissions from different types of ships for the period from 2018 to 2022. Container ships stand out prominently, ranking first in terms of the highest emissions generated. This is primarily due to their high speed compared to tankers or general cargo ships. During the period from 2020 to 2021, emissions generated by passenger ships were the lowest due to the COVID-19 pandemic. For ferries and RO-PAX ships, the emissions generated for the entire analysed period remained the same because these types of ships operate on the same route with a limited speed range.

Alternative Shipping Fuels

After IMO adopted the strategy for reducing greenhouse gases from shipping, many shipping companies have shifted their focus toward using alternative power sources (fuels) for their fleet of ships. In general, alternative power sources can be divided into two groups: renewable, fuels and combined, Figure 4.

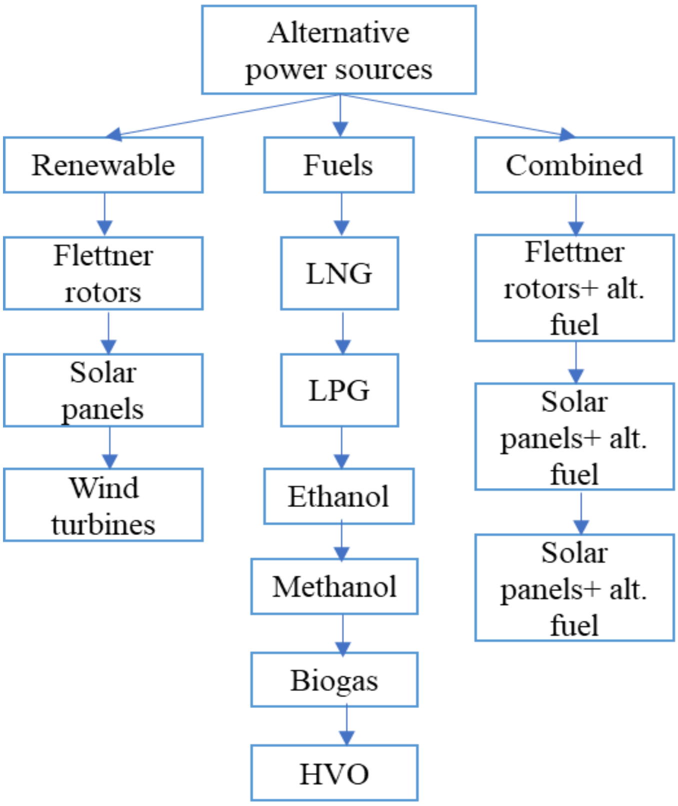

Figure 4. Classification of alternative power sources

Such alternative fuels include liquefied natural gas, liquefied biogas, hydrogen, methanol, ammonia, hydro-treated vegetable oil, renewable sources, and others. When using alternative fuels, some of them come with operational risks. For example, methane is stored at temperatures as low as -162 degrees Celsius, which can be harmful to the crew and impact the mechanical characteristics of the ship's structure. The use of liquefied gases significantly increases the risk of leaks and explosions on board the ship, which can lead to loss of human lives, cargo, and the entire vessel. In such cases, environmental pollution, especially in the sea, can be much more significant than emissions generated into the atmosphere. Properties of some alternative fuels are shown in Table 1 (Cheliotis, 2021).

Table 1. Properties of some alternative fuels

Type of fuel	Storage Pressure, bar	Liquified Storage Temperature , °C	Energy Density, MJ/kg	Volumetric Energy Density, GJ/m^3
Compressed hydrogen	700	20	120	4.7
Liquid ammonia	1 or 10	-34 or 20	18.6	12.7
Liquid hydrogen	1	-253	120	8.5
Ethanol	1	20	26.7	21.1
Methanol	1	20	19.9	15.8
Liquid methane	1	20	50	23.4

The easiest to store are ethane, methanol, and liquefied methane. This is one of the main reasons for their rapid adoption in practice. The applicability of various alternative fuels for different sailing zones varies. In (ETIP, 2023), such an analysis is presented, which to date has a different format, as shown in Table.2. The red colour means that the fuels are not so appropriate, while the blue one means that they are very appropriate.

Table 2. Applicability of alternative fuels in sailing area

Fuel	Inland	Short sea	Maritime
LPG			
LNG			
Biofuels			
CNG			
Hydrogen			
Electricity			

Liquefied natural gas and LPG are suitable for all sailing zones, whereas biofuels and hydrogen are not. CNG is also not suitable for all sailing zones, as there may not be storage opportunities everywhere. Another option is the use of biofuels. Their use can achieve a 100% reduction in CO2 emissions. Unlike other alternative fuels, biofuels are easily transported and stored, and working with them does not require special skills.

They are three generations. First-generation biofuels are produced from food crops grown on arable soil. The sugar, starch, or oil contained is converted into biodiesel or ethanol. This is currently 99% of today's biofuels. Second-generation biofuels are made on the basis of lignocelluloses, wood biomass, agricultural residues, waste vegetable oil, and public waste. Third-generation biofuels are derived from microalgae cultivation; however, most efforts to produce fuel from algae have been abandoned (MAN, 2023).

Methodology Selection

The effect of using alternative fuels is studied by calculating the EEOI (Energy Efficiency Operational Indicator) for multi-purpose ships with a deadweight of 7,000 tons. A sailing route between the port of Varna, located in the Black Sea, and the port of Rotterdam, situated on the northwest coast of Europe, has been selected, Figure.5. Traveling along this route, the ship passes through the ecological zones of four regions: the Black Sea, the Mediterranean Sea, the Aegean Sea, and the Atlantic Ocean, Figure.6.

Figure 5. Ship route map between port of Varna and Port of Rotterdam

In addition, it is important to determine the quantity of harmful emissions generated by various alternative fuels as the ship passes through these regions. Considering that the ship's speed is not constant at every moment of the voyage, it is advisable to establish the energy efficiency index for different operational periods.

Alternative biofuels also require energy, which releases CO2 emissions, and in some cases, such as biodiesel production via the Fischer-Tropsch method, the overall emissions are only slightly lower than conventional diesel.

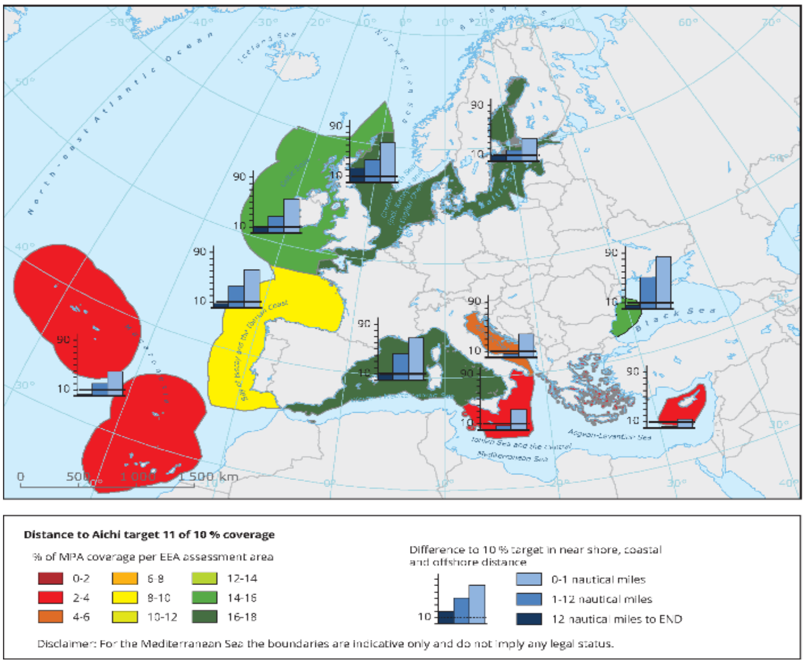

Figure 6. Marine protected areas in Mediterranean and Atlantic Ocean (EEA, 2021)

The calculation of the amount of CO2 gases per burned ton of fuel is determined by the following formulae [Engineering Toolbox, 2023] and values are shown in Table.3:

$$q_{CO_2} = \frac{c_f * M_m}{h_f * M_{CO_2}} \tag{1}$$

Where: qCO2- specific CO2 emission, kgCO2/kWh; cf - specific carbon content in the fuel, kgC/kgfuel; hf- specific energy content in the fuel, kWh/kgfuel; Mm- Molecular weight Carbon kg/kmol Carbon; MCO2 - Molecular weight Carbon Dioxide, kg/kmol CO2;

Table 3. Carbon content in different fuels (Engineering Toolbox, 2023)

Fuel Type	Carbon content, tCO_2/t fuel
LFO	3.15
Butane	3.03
Propane	3.00
Methan	2.75
Ethanol	1.91
Methanol	1.37

The generated CO2 emissions from HVO (Hydrogenated Vegetable Oil) are 0.192 tons per 1000 litters of fuel, which is practically negligible when compared to the other fuels. Based on the ship's speed of 15 knots, under normal conditions, it would cover the distance between the two ports in approximately 11 days. Using the formula... the results are presented in Table.4.

$$s=Vs*T, \text{ nm} \tag{2}$$

Where: s- sailing distance, nm, Vs- ship speed, kn; T- time for sailing, days, weeks, months, year;

Table 4. Sailing nautical miles

Sailing times	Nm
Distance, nm	3940
Distance nm/day	358
Distance, nm/week	2507
Distance, nm/m	7880
Distance, nm/y	86680

By using the results from the table, an assessment of the generated CO2 emissions into the atmosphere when using alternative and biofuels has been made.

Results

The assessment of the energy efficiency index is an important characteristic of existing ships, as it provides information about the suitable type of alternative fuel based on the operational characteristics of the ship. Using the data on sailing time in Table.4., an assessment of the EEOI (Energy Efficiency Operational Indicator) was made for potential use of alternative fuels. The results are presented in Figure 7.

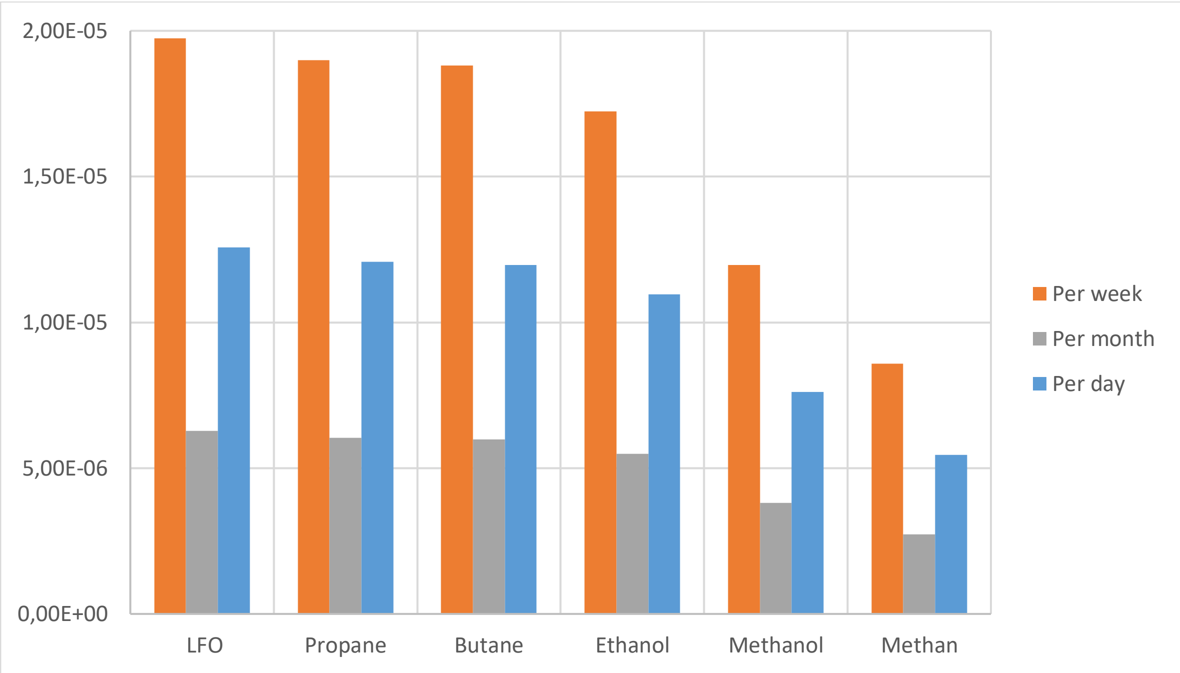

Figure 7. EEOI of different fuels

From the results in Figure 7. it can be seen that when using alternative fuels, the generated emissions are lower during different assessment periods. For example, if methane is used, CO2 emissions decrease by over 50% for all stages of operation compared to the use of traditional marine diesel fuel. There is a significant reduction in CO2 emissions with methanol as well, while for the other fuels, the effect is not very significant. Similar are the percentage reductions in the generated CO2 emissions on an annual basis. There, once again, it can be seen and becomes clear that methane has the lowest values.

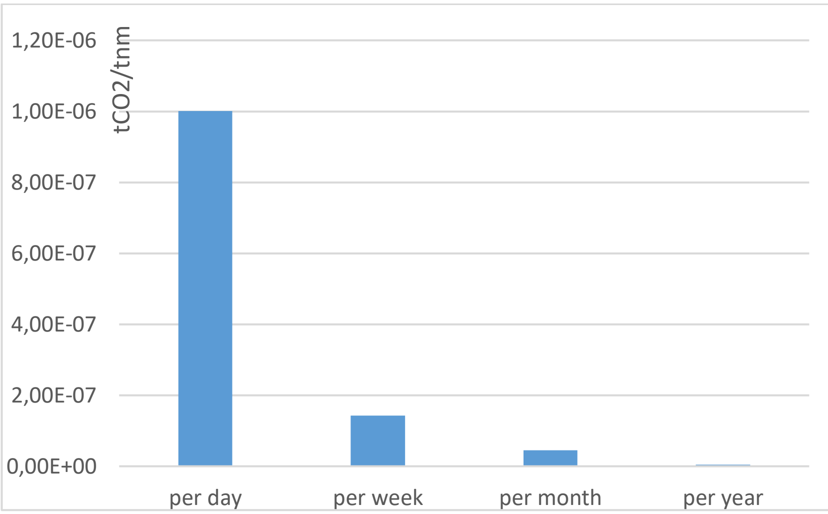

Figure 8. CO2 emission by HVO

However, the situation is not the same when it comes to the use of HVO (Hydrotreated Vegetable Oil). With this type of fuel, the generated CO2 emissions into the atmosphere are almost 80% reduced compared to those from light fuel oil and 100%, reduced compared to those from methane Figure.8.

The relationships of the generated emissions between HVO (Hydrotreated Vegetable Oil) and LFO (Light Fuel Oil) are presented in Figure 9. It becomes clear that in the ratio between HVO/Methane, the values are smaller than those in HVO/LFO. This provides information that a combination can be made when using both fuels, with the main engine running on HVO and the diesel generators using methane, or vice versa.

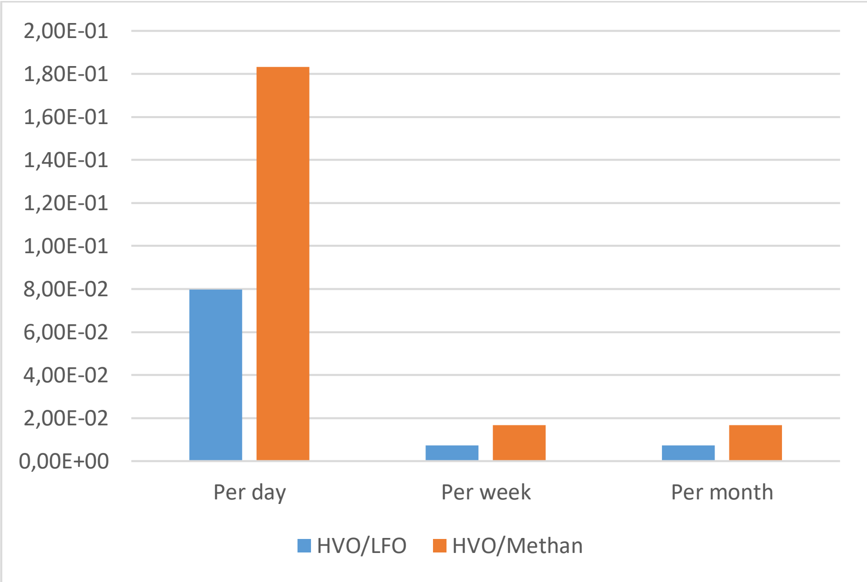

Figure 9. Relations of CO2 emissions for HVO/LFO and HVO/Methan

The production of HVO in Europe is available in nine European countries, including Belgium, Denmark, Finland, Estonia, Lithuania, Latvia, the Netherlands, Sweden, and Norway. The largest producer is the Netherlands, and the largest consumer is France. The presence of HVO in Europe provides a strong basis for its use as a fuel, especially considering that the Netherlands is the largest producer, and it is home to one of Europe's major ports, Rotterdam. When using HVO (Hydrotreated Vegetable Oil), the generated CO2 emissions are reduced to 0%, which fully complies with the emissions reduction requirements set by IMO (International Maritime Organization). However, not everything can be in the right direction, as a drawback of HVO is its excessively high market price as of today. It is approximately twice as high as that of LFO (Light Fuel Oil) and about 3.5 times higher than that of methane and methanol, figure 10.

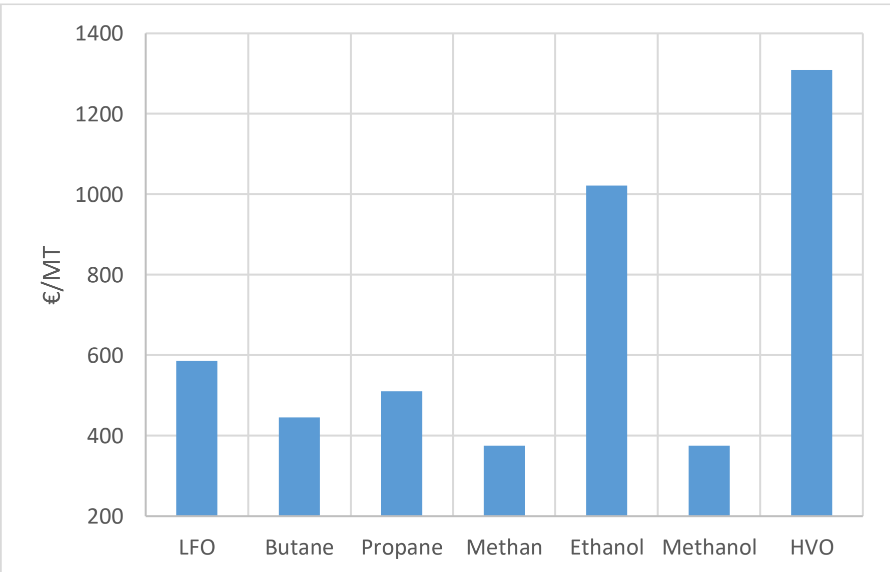

Figure 10. The price of fuels

It's precisely due to its higher price that its adoption in shipping is not as pronounced. Over time and as environmental requirements become stricter, its price is expected to normalize, providing opportunities for its use as a marine fuel. Once the environment is damaged, it's difficult to restore it compared to the money spent on its preservation.

Conclusions

The article explores the possibilities of using alternative fuels in shipping as a measure to reduce the emissions generated in the environment, specifically CO2 emissions, which have the highest percentage contribution to the atmosphere. Data on the generated CO2 emissions in the atmosphere from various modes of transportation are presented, with the finding that shipping accounts for approximately 13% of all emissions. The largest share is attributed to land transportation, approximately 80%. Referring to data on CO2 emissions generated by shipping, it becomes clear that container ships contribute the most emissions. This is largely due to their relatively high sailing speeds compared to other types of vessels, such as tankers.

A classification of alternative fuels is presented, divided into three groups with typical representatives for each group. The last group, the combined group, presents various combinations of renewable sources and fuels. Information is also provided regarding the applicability of various alternative fuels in different sailing regions. It has been determined that LNG (Liquified Natural Gas) and LPG (Liquified Petroleum Gas) have the widest range of applications.

Calculations of the EEOI (Energy Efficiency Operational Indicator) have been conducted for a multi-purpose cargo ship with 7000 DWT following the accepted sailing route between the port of Varna and the port of Rotterdam. These calculations were performed for various alternative fuels as well as for LFO (Light Fuel Oil). When using methane as the primary fuel, the generated CO2 emissions are approximately 50% lower than those with LFO. The calculations were done for harmful emissions generated per day, week, and month, depending on the ship's speed and the nautical miles sailed.

For the same ship, the same sailing speed, and the same route, when using HVO (Hydrotreated Vegetable Oil) as the primary ship fuel, the reduction in harmful emissions is approximately 90%, even compared to LFO (Light Fuel Oil), it's about 100%. This suggests that this type of fuel is environmentally clean and alternative. Its drawback, however, is its high cost, which is approximately 2 times higher than that of LFO and about 3.5 times higher than that of methane. Nonetheless, in the future, its price is expected to normalize, and it will find its place in shipping.

Future work in this direction will involve the stages of ship operation and the use of alternative fuels that still generate some degree of CO2 emissions. The gases from these emissions, which have applications in the industry (such as CO2), will need to be captured, separated, and utilized for the ship's needs.

Scientific Ethics Declaration

The author declares that the scientific ethical and legal responsibility of this article published in EPSTEM journal belongs to the author.

Acknowledgements or Notes

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