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(RESEARCH ARTICLE)

Fuel management systems and its applications on green energy

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Abstract

This research shows and presents alternative fuels for the shipping industry in terms of technological maturity, availability, safety, emissions, and regulations. This analysis covers the changing needs for the energy transition and sustainability ambitions. As it will start by outlining the current state of marine fuels and the challenges ahead to decarbonize the shipping industry. Also in this research, will show that bunkering and well-to-wake emissions are approached and situated in the real-world context of global and regional regulations. Choosing an alternative fuel for maritime operations is not only based on a financial evaluation in a closed shipping eco-system, as well as considering the availability of the fuel, local government incentives and perhaps even geo-politics. This paper will add a natural progress to technology concept, reducing ship emissions, which described the IMO tools and requirements needed to reduce ship emissions. This presented paper aims to inform all stakeholders of the current context and market perspectives. The decarbonization challenge shipping emissions in future could increase by +40% to +150% by 2050 if no action is done. This will have direct effect in contributing global warming. This paper also investigates the different approaches that will be taken by 2050 in hydrogen-based fuels and biofuel instruments.

Keywords: Alternative Fuels; Energy Transition; Shipping Emissions; Sustainability

1. Introduction

Human dependency on fossil fuels for energy has led to an increase in the emission of greenhouse gases GHGs, particularly carbon dioxide CO2, sulpher oxides SOx, and nitrous oxide Nox (Elmallah et al., 2024). Fossil fuel greenhouse gas (GHG) emissions are one of the major contributors to climate change (Elmallah et al., 2023; Elmallah et al., 2024). The burning of fossil fuels like coal, oil, and diesel releases carbon dioxide (CO2), NOx and SOx, and other greenhouse gases into the atmosphere, trapping heat and causing global temperatures to rise ((Elmallah et al., 2024; Welaya et al., 2013). This article will explore the science behind fossil fuel GHG emissions, their environmental impacts, and the policies and actions being taken to reduce them. Fossil fuels are non-renewable energy sources that come from organic matter that has been buried under sedimentary rock for millions of years ((Elmallah, 2024; Elgohary & seddiek, 2013). These sources of energy include coal, petroleum, and natural gas. They are used to produce electricity, transportation fuel, and heating & cooling for buildings. CO2 is the most significant GHG emitted by fossil fuels, accounting for approximately 80% of all GHG emissions worldwide. Figure one shows the concentration of CO2 in the atmosphere in parts per million ppm and global CO2 emissions from fuel combustion in million tons Mt (Abdallah, ElShennawy, 2020).

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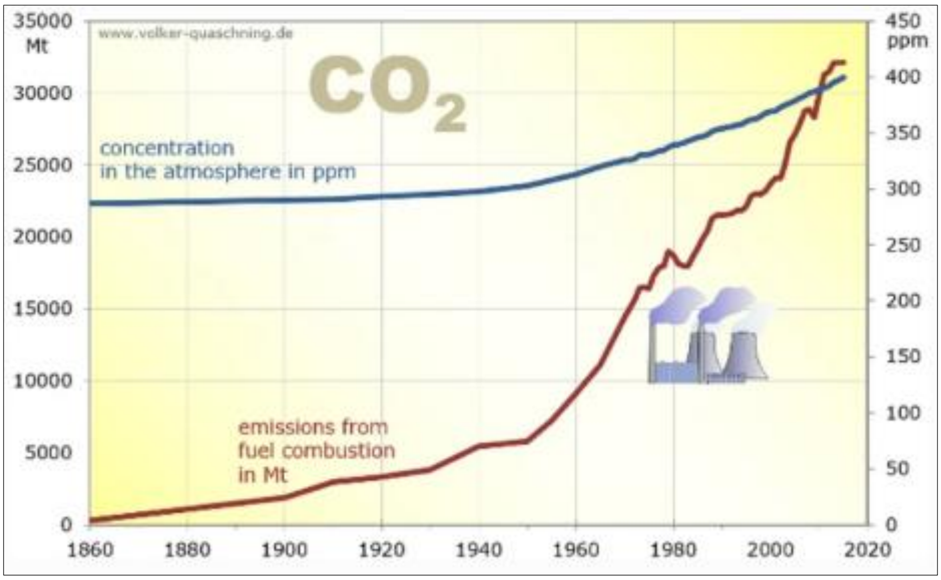

Figure 1 CO_2 emission and concentration in the atmosphere

Understanding the impact of fossil fuel GHG emissions on the environment is crucial for developing policies and strategies for mitigating climate change. By studying these emissions, scientists can identify ways to reduce them and develop alternative energy sources that are more sustainable and environmentally friendly. The shipping industry is responsible for a significant amount of global greenhouse gas (GHG) emissions, with estimates suggesting that it accounts for about 2-3% of total global GHG emissions. As the world continues to grapple with the impacts of climate change, there is increasing pressure on the shipping industry to reduce its GHG emissions. The International Maritime Organization (IMO) has been at the forefront of efforts to regulate and reduce GHG emissions in shipping, with a range of targets and goals for the industry to meet. Shipping is a major contributor to global GHG emissions. In 2018, the International Maritime Organization (IMO) estimated that the shipping industry accounted for approximately 2.2% of global CO2 emissions. Additionally, the industry is responsible for the emissions of other GHGs and air pollutants such as sulfur oxides, nitrogen oxides, and particulate matter. The growth in global trade and maritime transportation means that these emissions are likely to continue increasing unless action is taken to reduce them. The IMO has been working to regulate greenhouse gas emissions in shipping since 1997, when it adopted the MARPOL Convention. The convention sets limits on sulfur oxide and nitrogen oxide emissions, and also includes guidelines for energy efficiency measures. Since then, the IMO has continued to develop regulations aimed at reducing GHG emissions, culminating in the adoption of the Initial IMO Strategy on Reduction of GHG Emissions from Ships in 2018. The IMO aims to reduce the shipping industry's total GHG emissions by at least 50% by 2050 compared to 2008 levels. The organization has set out a series of short-term measures to achieve this, including mandatory energy efficiency requirements for new ships and a carbon intensity reduction target for existing ships. Additionally, the IMO is exploring longer-term measures, such as the use of zero-emission fuels and new operational and technological solutions. This article provides an overview of GHG emissions in shipping, the impact of shipping on climate change, the regulations and targets set by the IMO, strategies and technologies for reducing GHG emissions, as well as the challenges and opportunities in implementing these measures. This paper will also take a closer look at the role of renewable energy in addressing fossil fuel GHG emissions and climate change, as well as the challenges and opportunities in mitigating their effects.

2. The Impact of Shipping on Climate Change

The emissions of GHGs from fossil fuels are a significant contributor to global warming. As the Earth's temperature rises, it can cause extreme weather events and disrupt ecosystems. Rising global temperatures can lead to sea level rise due to melting ice sheets and glaciers. Ocean acidification, or the increased acidity of the oceans, can also occur due to higher levels of CO2 in the atmosphere. Climate change caused by fossil fuel GHG emissions can lead to more frequent and severe weather events, such as hurricanes, droughts, and floods, which can have devastating impacts on human health and the environment (Mimura, 2013).

3. Imo restrictions on CO2 emissions

International shipping generates 2.2% of the world's annual CO2 emissions, according to the International Maritime Organization's (IMO) Third GHG Study, which also predicted that by 2050, emissions from international shipping might increase by 50% to 250% (IMO, 2014). Between 2013 and 2015, total shipping CO2 emissions grew by 2.4% from 910 million tons to 932 million tons. Emissions from domestic shipping climbed by 6.8%, those from international shipping by 1.4%, and those from fisheries by 17%. The largest contribution came from international shipping, accounting for nearly 87% of all annual CO2 emissions from ships (Olmer et al., 2017). Figure two shows the CO2 emissions from 2007 to 2015.

	Third IMO GHG Study (million tonnes)						ICCT (million tonnes)		
	2007	2008	2009	2010	2011	2012	2013	2014	2015
Global CO_2 Emissions[2]	31,959	32,133	31,822	33,661	34,726	34,968	35,672	36,084	36,062
International Shipping	881	916	858	773	853	805	801	813	812
Domestic Shipping	133	139	75	83	110	87	73	78	78
Fishing	86	80	44	58	58	51	36	39	42
Total Shipping	1,100	1,135	977	914	1,021	942	910	930	932
% of global	3.5%	3.5%	3.1%	2.7%	2.9%	2.6%	2.5%	2.6%	2.6%

Figure 2 CO2 emission quantities

Three ship classes accounted for 55% of the total shipping CO2 emissions: container ships (23%), bulk carriers (19%), and oil tankers (13%), as shown in Figure 5. Out of the 223 flag nations, six flags—Panama (15%), China (11%), Liberia (9%), the Marshall Islands (7%), Singapore (6%), and Malta (5%), are responsible for the majority of CO2 emissions from ships. These flags represent 66% of the total deadweight tonnage of the world's marine fleet and have a large number of ships registered to them. Although all ships and flags have a role to fill in the combating global warming, addressing these key ship classes and flags will be necessary to reduce emissions (Olmer et al., 2017). Figure three shows emissions according to ship's class and flag.

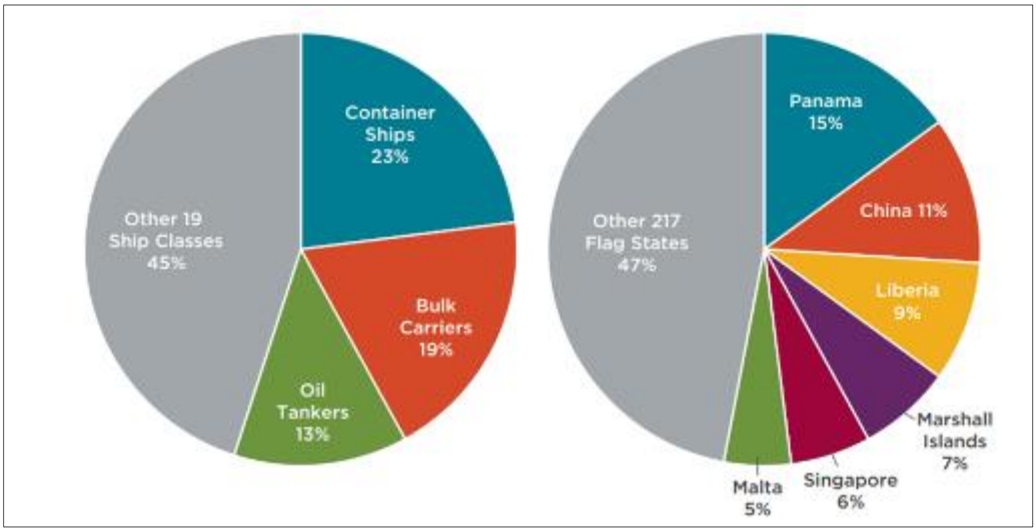

Figure 3 CO_2 Emissions according to ship's class and flag.

The IMO defined the Initial Strategy in April 2018, intending to reduce GHG emissions from shipping by at least 50% by 2050 compared to 2008 (IMO MEPC72, 2018). The strategy objectives are to:

- Reduce carbon levels by 40% levels by 2030, compared to 2008.
- cut emissions by 70% by 2050, compared to 2008.
- Reduce global shipping's carbon GHG emissions by at least 50% by 2050 compared to 2008.
- Reach zero GHG emissions by the year 2100.

4. Imo restrictions on SOx emissions

During the combustion of fuel, about 90% of the sulphur (S) in the fuel reacts with oxygen gas (O_2) and is emitted as sulphur dioxide (SO_2). A smaller portion of the sulphur in the fuel forms sulfur trioxide (SO_3). Due to the common absence of exhaust gas treatment on board ships, the amount of SOx emissions from ships depends solely on the sulphur content of the fuel (Corbett and Fischbeck, 1997). Sulfur dioxide (SO_2) is a colorless, odorless, and corrosive gas that is considered to be a major environmental issue and a cause of acid rain, the greenhouse effect, and photochemical pollution (Peng et al., 2013; Granger et al., 2011). The IMO and EU established limits on the amount of sulphur that ships were allowed to emit in order to deal with the emission issue. For some Emission Controlled Areas (ECAs), the IMO and EU mandated the establishment of a lower Sulphur limit, which was established at 0.1% in 2015. The allowable Sulphur limit was recently reduced for the Areas Outside ECAs in January 2020 from the previous maximum of 3.5 to 0.5%, resulting in an 86% decrease in the permissible Sulphur limit. Figure 3 indicates the IMO restrictions for sulphur content of fuel since 2009.

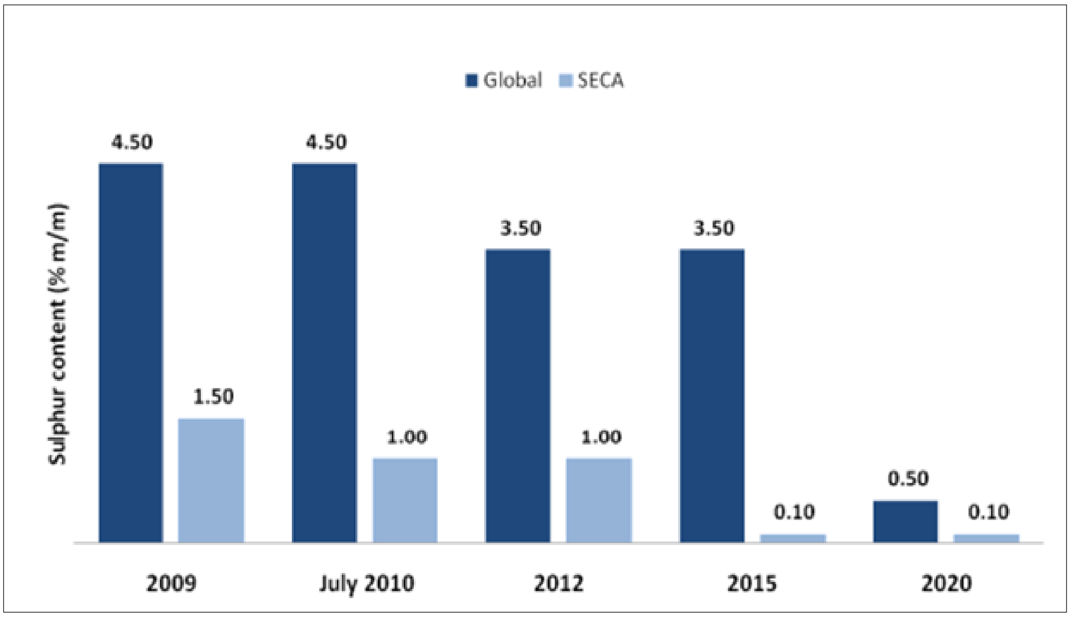

Figure 4 IMO restrictions for sulphur content of fuel since 2009

5. Imo restrictions on NOx emissions

IMO regulations for NOx emissions refer to the guidelines set out by the International Maritime Organization (IMO) to limit and control the release of nitrogen oxide (NOx) pollutants from ships. NOx emissions from shipping contribute heavily to air pollution, particularly in coastal areas and port cities, and can have severe impacts on human health, ecosystems, and climate change. The IMO has implemented various measures over the years to reduce NOx emissions from ship engines through setting emission limits, mandating improvements in engine technology and design, requiring fuel quality standards, and implementing monitoring requirements. The most recent of these measures is Tier III limits which require ships operating in Emission Control Areas (ECAs) designated by the IMO to meet stringent NOx emission limits. These regulations are an essential part of global efforts to mitigate air pollution from shipping and protect human health and the environment. Figure five shows IMO limits for NOx emissions.

Tier	Date	NOx Limit, g/kWh		
		n < 130	130 ≤ n < 2000	n ≥ 2000
Tier I	2000	17.0	$45 \cdot n^{-0.2}$	9.8
Tier II	2011	14.4	$44 \cdot n^{-0.23}$	7.7
Tier III	2016†	3.4	$9 \cdot n^{-0.2}$	1.96
† In NOx Emission Control Areas (Tier II standards apply outside ECAs).				

Figure 5 IMO limits for NOx emissions

6. Methods to decrease GHG emissions in shipping

The shipping industry is responsible for a significant portion of greenhouse gas emissions worldwide. In order to decrease these emissions, various methods can be employed. One such method is the use of alternate fuels, such as biofuels or electric power. Human behavior also plays an important role in reducing carbon footprints, which includes optimizing shipping routes and minimizing idle periods during loading and unloading. The adoption of advanced technologies like wind-assisted propulsion systems and air lubrication methods that reduce water resistance should also be encouraged. Similarly, innovative approaches like slow steaming and incorporating recyclable materials for packaging can contribute to reducing GHG emissions. International coordination between industry players may also encourage environmentally friendly regulations and increase the uptake of efficient vessels over older inefficient ships with high carbon footprints. Such measures will save costs over time, ensure more sustainable practices within the industry, and ameliorate global efforts towards combating climate change.

7. Case study

This paper highlights the advantages of using alternative renewable sources for power generation. The case study will illustrate the environmental effect of using methane as an alternative fuel and the environmental effect of applying the water addition method to methane fuel. In this paper a simulation model for a combustion chamber using commercial CFD fluid flow (fluent) is used to calculate the NOx emission for three different cases for fuel supply. Figure six shows the combustion chamber design. Table one shows the combustion chamber dimensions.

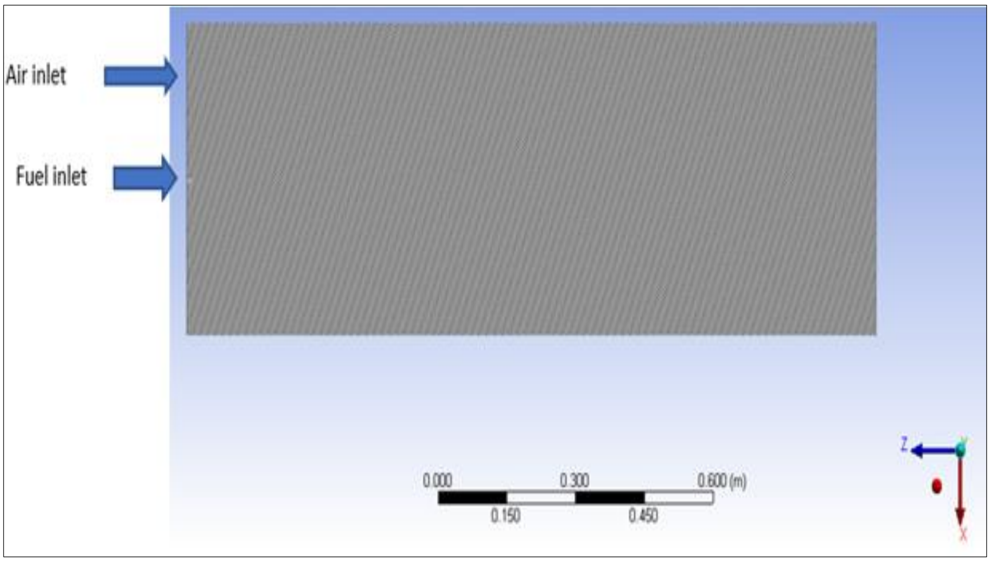

Figure 6 3D combustion chamber

Table 1 combustion chamber dimensions

Chamber dimensions	
Length (chamber)	1400 mm
Diameter (chamber)	540 mm
Dimeter (nozzle)	8 mm
Length (nozzle)	12 mm

It is crucial to use mesh metrics to evaluate the mesh's quality, which depends in part on the mesh's skewness, aspect ratio, and softness (change in cell size).figure seven shows the mesh geometry. Table two shows the mesh calculations.

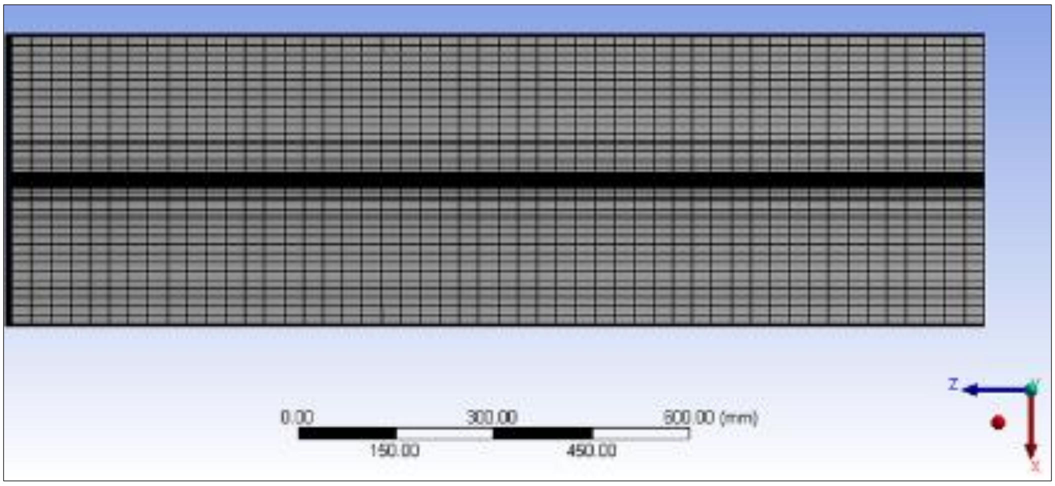

Figure 7 Mesh geometry

Table 2 mesh calculations

Mesh Metric	**skewness**
Min skewness	3.3561e-003
Max skewness	0.51228
Mesh Metric	Aspect Ratio
Min	2.3279
Max	371.63
Smoothing	High

Figure eight shows the CFD results for different percentage of water addition to methane fuel

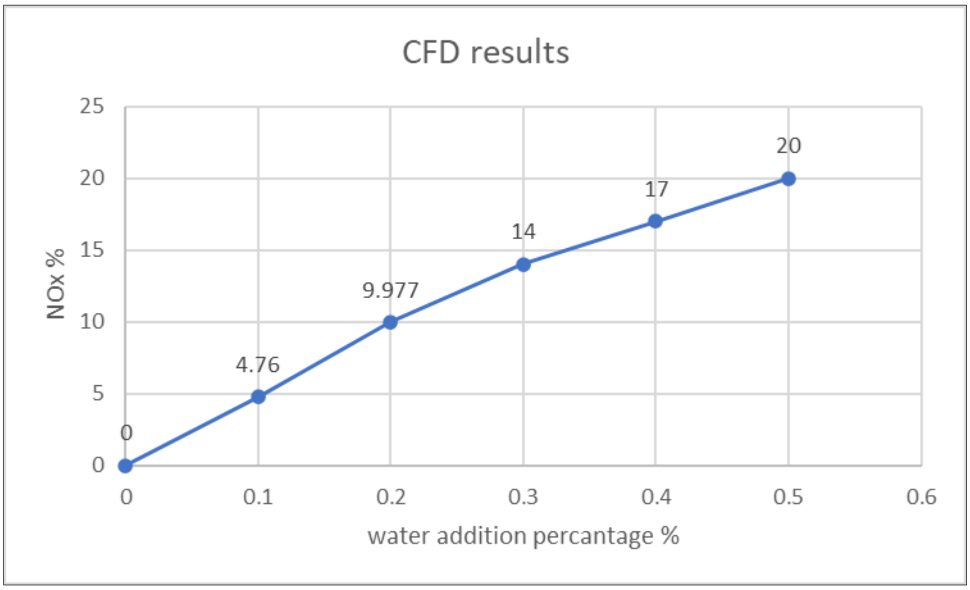

Figure 8 CFD results for different percentage of water addition to methane fuel

8. Conclusion

The burning of fossil fuels like coal, oil, and diesel releases carbon dioxide (CO2), NOx and SOx, and other greenhouse gases into the atmosphere, trapping heat and causing global temperatures to rise. The IMO aims to reduce the shipping industry's total GHG emissions by at least 50% by 2050 compared to 2008 levels. This study provided an overview of GHG emissions in shipping, the impact of shipping on climate change, the regulations and targets set by the IMO, strategies and technologies for reducing GHG emissions. The study highlighted the significant environmental effect of using methane as an alternative fuel and for using the water addition method to methane fuel. The results showed that 20% of water addition to mrthane fuel has decreased the NOx by 9.9%, 30% of water addition to methane has decreased the NOx by 14%, and 50% of water addition to methane has decreased the NOx by 20%.

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