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Maritime Decarbonization- The Pathway, Chances, Developments and Obstacles

Mehrdad Behforouzi[1,*], Reza Mirmiran[2], Mahmoud Haghdousti[3], Shahriar Mazhari[4]

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ABSTRACT

Decarbonization is crucial to meeting the world's climate goals and a more sustainable future.
As the globe works to cut greenhouse gas emissions and lessen the effects of climate change, decarbonizing the maritime sector has become an urgent problem in recent years.
Fossil fuel combustion is the leading cause of greenhouse gas emissions, which have a role in climate change and global warming. It entails moving away from energy based on fossil fuels and toward greener, lower-carbon options, including renewable energy, energy-saving devices, and sustainable mobility. The necessity of coordination and cooperation between various stakeholders is one of the significant obstacles to decarbonizing the maritime sector.
Governments, shipping firms, and other stakeholders must collaborate to develop and put into practice sustainable solutions because shipping is a global sector. In this research, the author examines the difficulties and possibilities of decarbonizing the shipping sector and the development achieved in this direction. This study investigates the decarbonization prospects available to shipping businesses, the regulatory framework, and alternatives to fossil fuels through a thorough assessment of the literature and data analysis. This article thoroughly analyses the difficulties and potential of decarbonizing the shipping sector, emphasizing fossil fuel alternatives, the regulatory environment, and the options open to shipping businesses for decarbonization. Additionally, it emphasizes the significance of stakeholder cooperation and the contribution of digital technology to the enhancement of shipping operations and the lowering of emissions.

1. Introduction.

1.1. Atmosphere and gases.

Carbon dioxide (CO2) is the primary greenhouse gas emitted through human activities.

Reported by (EPA, 2023) In 2021, CO2 accounted for 79% of all U.S. greenhouse gas emissions from human activities. CO2 is naturally present in the atmosphere as part of the Earth's carbon cycle (the natural circulation of carbon among the atmosphere, oceans, soil, plants, and animals). Human activities are altering the carbon cycle–both by adding more CO2 to the atmosphere and by influencing the ability of natural sinks, like forests and soils, to remove and store CO2 from the atmosphere. While CO2 emissions come from various natural sources, human-related emissions are responsible for the increase in the atmosphere since the industrial revolution. The main human activity that emits CO2 is the combustion of fossil fuels (coal, natural gas, and oil) for energy and transportation. Specific industrial processes and land-use changes also emit CO2.

Gases that trap heat in the atmosphere are called Green-

[1]Warsash Maritime School, Solent University, UK, E-mail Address: mehrdad.behforouzi@solent.ac.uk.
[2]Warsash Maritime School, Solent University, UK, E-mail Address: reza.mirmiran@solent.ac.uk.
[3]Warsash Maritime School, Solent University, UK, E-mail Address: mahmoud.haghdousti@solent.ac.uk.
[4]Warsash Maritime School, Solent University, UK, E-mail Address: shahriar.mazhari@solent.ac.uk.
[*]Corresponding author: Capt. Mehrdad Behforouzi, Warsash Maritime School, Solent University, East Park Terrace, Southampton SO14 0YN. Email: mehrdad.behforouzi@solent.ac.uk.

house Gases (GHG). This section provides information on emissions and removals of the leading GHG to and from the atmosphere.

- CO2: It enters the atmosphere through burning fossil fuels (coal, natural gas, and oil), solid waste, trees, and other biological materials, and also as a result of specific chemical reactions (e.g., cement production). CO2 is removed from the atmosphere (or "sequestered") when plants absorb it as part of the biological carbon cycle.
- Methane (CH4): Methane emits while producing and transporting coal, natural gas, and oil. Methane emissions also result from livestock and other agricultural practices, land use, and the decay of organic waste in municipal solid waste landfills.
- Nitrous oxide (N2O): It pours out during agricultural, land use, and industrial activities; combustion of fossil fuels and solid waste; and during treatment of wastewater.
- Fluorinated gases: Hydrofluorocarbons, perfluorocarbons, sulfur hexafluoride, and nitrogen trifluoride are synthetic, potent GHG that emit from various household, commercial, and industrial applications and processes. Fluorinated gases (especially hydrofluorocarbons) are sometimes used as substitutes for stratospheric ozone-depleting substances (e.g., chlorofluorocarbons, hydrochlorofluorocarbons, and halons). Fluorinated gases are typically emitted in smaller quantities than other GHG but are potent GHG. Global Warming Potentials (GWPs) that usually range from thousands to tens of thousands, they are sometimes referred to as high-GWP gases because they trap substantially more heat than CO2 for a given amount of mass (Epa, 2023).

Decarbonization entails ceasing fossil fuels, the primary source of GHG that raise global temperatures and threaten or destroy ecosystems that support life. Ending fossil fuel usage necessitates reengineering manufacturing techniques and, subsequently, products (Martin et al., 2023).

1.2. State shift.

The Arctic is going through a "state shift," a period of rapid change leading to a new stable state. It is becoming increasingly apparent that the Arctic, as we currently know, is being replaced by a warmer, wetter, and more unpredictable environment with each passing year of data. The following three points are the alterations that scientists expect in the future (Greenfacts, 2022):

1. The Arctic Ocean may be free of sea ice in the summer by the late 2030s.
2. The Intergovernmental Panel on Climate Change (IPCC) forecasts of the rise in the ocean's level were likely underestimated, according to subsequent findings of additional melting mechanisms affecting Arctic and Antarctic glaciers, ice caps, and ice sheets.
3. The weather changes in mid-latitudes. It can also affect the formation and strength of tropical storms.
4. Meltwater from Arctic glaciers, ice caps, and the Greenland ice sheet also impacts climate by flooding the ocean with fresh water, which affects ocean water circulation and weather patterns. Melting Arctic land ice (glaciers and ice sheets) is expected to accelerate global sea-level rise, affecting coastal communities, low-lying islands, and ecosystems.
5. In addition, the Arctic serves as both a source and a sink for GHG.

According to new estimations, Arctic soil contains roughly half of the world's soil carbon.

Changes in the amounts of GHG stored or released in the Arctic area, such as CO2 and methane, can thus have a long-term impact on world climate.

2. Literature Review.

2.1. Shipping sector.

About three per cent of all greenhouse gas emissions worldwide attribute to the shipping sector, almost equal to Japan's yearly emissions. More than one hundred thousand large ships propelled by fossil fuels on the ocean account for most of the industry's emissions, which, without decarbonization measures, might reach more than double by 2050 (Dinneen.J, 2022a).

International shipping relies on fossil fuels as an industry, particularly Heavy Fuel Oil (HFO), burning around three hundred million metric tons annually and emitting approximately one billion metric tons of CO2. It means that emissions from international shipping account for 2-3% of global emissions annually (Bingham, 2023a).

It is crucial to reduce the shipping industry emissions to reduce the effects of climate change.

Decarbonization is a crucial stage in the process of tackling the climate disaster that the world is currently experiencing. Since the industrial revolution, CO2 emissions from burning fossil fuels have considerably increased, and if unchecked, they might have disastrous effects on the world and its inhabitants.

The following are some of the consequences of climate change, per a report from the World Health Organization (WHO, 2021):

- The social and environmental determinants of health, such as clean air, safe drinking water, enough food, and adequate shelter, are impacted by climate change.
- Climate change will result in an additional two hundred fifty thousand deaths per year between 2030 and 2050, mostly from starvation, malaria, diarrhea, and heat stress.
- Between USD two to four billion/ year in direct health damage expenses are projected by 2030 (i.e., excluding costs in health- determinating industries like agriculture and water and sanitation).

Decarbonization includes lowering or eliminating these emissions by switching to cleaner, low-carbon options, including renewable energy, energy-efficient technologies, and sustainable transportation.

2.2. Regulatory bodies.

Member States of the IMO (IMO, 2023), meeting at the Marine Environment Protection Committee (MEPC 80), have adopted the 2023 IMO Strategy on Reduction of GHG Emissions from Ships, with enhanced targets to tackle harmful emissions. The revised IMO GHG Strategy includes the following:

- An enhanced common ambition to reach net-zero GHG emissions from international shipping close to 2050.
- A commitment to ensuring the uptake of alternative zero and near-zero GHG fuels by 2030.
- Indicative checkpoints for 2030 and 2040.

According to (UNEP, 2021) and to avoid these consequences, the world needs to reduce its greenhouse gas emissions and limit global warming to well below 2°C above pre-industrial levels, as outlined in the Paris Agreement. Decarbonization is essential to achieving this goal. It involves transitioning away from fossil fuel-based energy sources and adopting cleaner, low-carbon alternatives such as renewable energy, energy-efficient technologies, and sustainable transportation.

The Paris Agreement calls for limiting global warming to below two degrees over pre-industrial levels and reducing greenhouse gas emissions worldwide to prevent severe consequences.

Decarbonization is necessary to do this. It entails shifting away from energy sources based on fossil fuels and embracing greener, lower-carbon substitutes like renewable energy, energy-efficient technologies, and environmentally friendly transportation (UNFCCC, 2015).

3. Methodology.

This study thoroughly analyses the literature in scholarly journals, business reports, and official government publications. Several databases, including Google Scholar and Web of Science, were used to review the literature. Relevant keywords, such as ”decarbonization,” ”shipping,” ”alternative fuels,” ”regulations,” ”zero-emission ships,” and ”digital technologies” were used.

The data analysis identifies obstacles, chances, and developments in the decarbonization of the maritime sector. The research also provides instances of efforts and shipping firms that have made progress in lowering emissions.

The results of this study are synthesized to offer a thorough overview of the opportunities and problems associated with decarbonizing the shipping sector, as well as the role that cooperation and digital technologies play in attaining this objective.

4. Findings.

The results of study are as follow:

4.1. Initiatives underway to promote decarbonization in the shipping industry.

1. The Poseidon Principles.
   It is a collection of recommendations for banks on evaluating and disclosing the degree to which their shipping portfolios are climate-aligned. The Global Maritime Forum (GMF) and many central banks, including Citi and Société Générale, created the principles. Banks may encourage shipping businesses to invest in environmentally friendly technologies and lower their emissions by matching their lending portfolios to the objectives of the Paris Agreement. Together, they constitute a bank loan portfolio totaling more than one hundred and five billion USD for international shipping, or nearly 50% of the total ship finance portfolio. (Global Maritime Forum, 2023).
   This measure complied with IMO regulations and encouraged the maritime industry to reduce emissions. In the future, when shipping businesses from other nations seek finance sources, the Poseidon principles will be a crucial signal that financial institutions will consider.
   It will also demonstrate whether significant maritime businesses are taking climate change seriously enough. (Tai et al., 2022)
2. The Sea Cargo Charter.
   It enables signatories to evaluate their current situation more accurately and determine how well they align with IMO objectives. By gathering information, signatories understand their chartering efforts and can better plan for the future. To quantify carbon intensity and total GHG emissions and evaluate their climate alignment, signatories undertake to collaborate with ship owners and business partners to gather and process the information needed. (rightship, 2021).
3. The Getting to Zero Coalition.
   The World Economic Forum, the GMF, and other significant shipping firms have joined forces to form the Getting to Zero Coalition. By 2030, the Coalition wants to hasten the implementation of zero-emission ships. It strives to determine the most promising zero-emission technologies and provide a legal and legislative framework to facilitate their adoption to meet this objective. The Getting to Zero Coalition platform convenes around two hundred stakeholders across the shipping and fuels value chain, which is managed by the GMF and was founded in 2019 with the Friends of Ocean Action and the World Economic Forum after a 2018 Call to Action launched by thirty-four critical stakeholders dedicated to decarbonizing shipping (weforum, 2023).
4. The Green Shipping Programme (GSP).
   GSP a public-private partnership, aims to advance the Norwegian government’s maritime strategies and plans. The programme aims to develop and strengthen Norway’s goal to establish the world’s most efficient and environmentally friendly shipping. It started in January 2015 under “the Green Coastal Shipping Program”, consisting of sixteen private companies and organizations and

two government ministries. In the spring of 2019, the program changed its name to the Green Shipping Program to state its international ambitions. In the spring of 2023, the program included more than a hundred-eight private companies and organizations and twelve public observers. The GSP is financed partly by public allocations from the State budget of Norway and partly by the members themselves (greenshippingprogram, 2021).
Ship owners can effectively reduce carbon emissions in the maritime industry by using green fuels instead of conventional fossil fuels. The majority of green fuel is created from green energy, and the development of renewable energy sources like wind and solar power helps to produce more green fuel. Therefore, transforming the maritime industry into a low-carbon industry depends on green power produced by renewable energy sources. The maritime sector may benefit from the support and development of marine renewable energy power generation technologies and the subsequent production of green fuel under the environmental requirements of ship operation (Shi et al., 2023).

5. The Clean Shipping Alliance.
It is a global association of companies that are committed to reducing emissions from their ships. The alliance focuses on promoting the use of exhaust gas cleaning systems (also known as scrubbers) to reduce sulfur oxide emissions from ships. The alliance works to improve the understanding of scrubber technology and its benefits, and to promote regulatory frameworks that support the use of scrubbers.
According to (Gerlitz et al., 2022), Ammonia (NH3) has excellent potential to develop into a zero-carbon fuel that might be used as part of the future energy mix. Compared to handling and storing hydrogen, another zero-carbon fuel, easy handling, and storage circumstances can be advantageous, particularly in transportation. Additionally, due to the partially developed shoreside infrastructure, the required bunker structure requires less investment than hydrogen. However, the supply and delivery of NH3 in ports come at a high cost because of port storage facilities and more expensive transportation infrastructure. Ammonia exhibits superior handling and storage benefits, enabling lengthy maritime trips without appreciable cargo space loss at an affordable price. The infrastructure required for manufacturing, delivery, and operations of ammonia supply chains and the technology for ammonia-powered vessels is currently under development.

4.2. What are some examples of zero-emission technologies being developed for ships?

1. Hydrogen fuel cells.
A promising solution for ships with zero emissions is hydrogen fuel cells. Fuel cells use the reaction of hydrogen and oxygen to produce energy, with the sole byproduct being water.
All American Marine, Inc. (AAM) and the vessel owner SWITCH Maritime (SWITCH) operate "MV Sea Change", a Seventy-foot, seventy-five passenger, zero-emissions, hydrogen fuel cell-powered, electric-drive ferry that navigates in the California Bay Area. (allamericanmarine, 2023).
2. Battery-electric propulsion.
Battery-electric propulsion systems are already in operation for smaller ships, and larger vessels are also being designed using them.
Batteries are used in battery-electric propulsion systems to store electricity and run the ship's electric motors. Organizations like Norwegian Electric Systems and Corvus Energy are developing battery systems for ships. Norway has a long and illustrious history in shipping and the sea. The Norwegian public and business sectors have thus been eager to take the lead in a green marine transformation for both strategic and historical reasons. Furthermore, nearly all of Norway's electricity comes from renewable sources. It indicates that Norway has sought out industries that help reduce emissions more actively than other nations. Furthermore, Norway's expertise in renewable energy has made it a desirable location for producing energy-intensive goods like batteries (Saether and Moe, 2021).
3. Ammonia fuel.
Ammonia is a carbon-free fuel that can be produced from renewable sources.
A possible alternative fuel for marine diesel engines, ammonia has no carbon and no sulfur in its composition. Recently, NH3 has received much attention from scientists and companies making marine engines. Ammonia has a high auto-ignition resistance, making it challenging for ordinary diesel engines to burn it. High NOX emission, N2O emission, and Ammonia slip are the main problems following ammonia combustion but can be reduced by adopting an ideal combustion environment (Zincir, 2020).
4. Wind power.
The vessel's propulsion can use a renewable energy source like wind. Several businesses are creating wind-assist and wind propulsion systems for ships.
The Wind Assisted Ship Propulsion (WASP) project, which is supported by the Interreg North Sea Europe program and the European Regional Development Fund (ERDF), brings together universities, wind-assist technology providers, and ship owners to research, trial, and validate the operational performance of a selection of wind propulsion solutions on five vessels, enabling the market penetration of wind propulsion technology and promoting a more environmentally friendly North Sea transport system. The 143-meter, 1036 TEU feeder container ship "MV Kalamazoo", which Norse owns, will receive two 10.5-by-2.8-meter containerized Ventofoils (an upgraded Ventifoil) wind assist units from Econowind by the end of 2023, according to an announcement made in April by the Singapore-based Ocean Network Express (northsearegion, 2023).

According to (Vigna and Figari, 2023) the case study conducted under moderate wind conditions in the Mediterranean, advantages through WASP under ship design circumstances would range from 5% to 10% in terms of power savings and from 4% to 6% in terms of fuel usage. Using rotors and Controllable Pitch Propeller (CPP) together may reduce fuel consumption by up to 15% if reduced operational speeds (10–12 knots) are acceptable.

5. Biofuels.
   Biofuels are renewable fuels that can be produced from organic matter, such as algae or crop waste. Several companies, including GoodFuels and Neste, are developing biofuels for use in ships. Biofuels are clean, sustainable fuels made from plant waste or other organic materials like algae. Biofuels are being developed for use in ships by some businesses, including GoodFuels and Neste.
   A new tool from Neste, Neste Marine 0.1 Co-processed, enables maritime firms to minimize their GHG emissions by up to 80% throughout their lifecycles compared to fossil fuels. They are created using traditional refining and partially substituting renewable raw materials for fossil-based ones. The market offers three primary biofuel alternatives and low-emission co-processed bunker fuels (Neste, 2023).

   - The first is Hydrotreated Vegetable Oil (HVO), primarily from leftovers and waste materials like discarded vegetable oils and animal fats.
   - The second is Trans-esterified fuels like Fatty Acid Methyl Esters (FAME).
   - The third type is crude biofuel, which includes fuels produced from soy, rapeseed, palm, fish, and other fats.

   HVO generally emits less engine-out CO, HC, and soot under all examined conditions. Benefits over conventional petroleum-derived diesel tend to intensify at low coolant temperatures, with diesel emissions rising more sharply than HVO during cold starts and at "artificially" decreased coolant temperature conditions. Furthermore, at both high and low coolant temperatures, HVO appears to be more tolerant of variations in engine calibration parameters than diesel. HVO emission trends tend to be flatter than diesel, exhibiting sharper deterioration at the calibration ranges' lower or higher ends of calibration ranges (Mancarella and Marello, 2022).
6. Big Data Analysis (BDA). Ship operators can identify energy inefficiencies in maritime operations, such as poor route planning, excessive fuel use, or inefficient equipment utilization, using real-time digitally recorded sensor data analysis.
   According to (Jovic et al., 2019) BDA enables ship owners to determine the optimum speed for fuel consumption, efficient routing, and improving shipping efficiency.
7. Artificial Intelligence (AI) - powered energy management systems.
   AI applications can optimize energy usage by predicting energy demands, optimizing on-board systems, and providing real-time recommendations to captains and crew members. These AI systems continuously learn from data to enhance energy efficiency over time.
   Enabling digital technologies such as blockchain, AI and machine learning, the Internet of Things (IoT), and broadband, low latency satellite connectivity have progressed so rapidly that their impact on decarbonisation still needs to be fully appreciated in some parts of the maritime sector. Shipping must harness the readily available power of digital technologies to decarbonise conventional ships today, optimising the pathway to 2050 and accelerating the rate of change required to achieve the targets set by the international community (Inmarsat, 2022).
8. Carbon Capture and Storage (CCS).
   Underground storage of CO2 emissions from industrial operations and power plants is known as CCS. It can aid in lowering emissions from industries like steel and cement that are challenging to decarbonize.
   In the direct capture of CO2 from the air, the high dilution level of CO2 in the air (0.04%) increases the energy requirement and cost of the process compared to carbon capture from flue gases (with CO2 concentrations around 15% for coal power plants). Thus, investing in direct capture can have a more significant impact on emission reduction. Pre-combustion capture is typically more efficient due to the more concentrated CO2. Still, the capital costs of the base gasification process are often more expensive than traditional pulverised coal power plants. Amine scrubbing removes CO2 and converts it to fuel, a fuel feedstock to supply energy, which will, in turn, contribute to emissions. Hence using a renewable source of energy optimise this process. Carbon reutilization incentivises the industry to invest in carbon capture technology as they profit from using their emissions as feedstock (Bhate and Joseph, 2023).
9. Carbon Pricing.
   Carbon pricing includes assigning a cost to carbon emissions to encourage businesses and people to lessen their carbon impact. Carbon taxes or cap-and-trade programs can accomplish this.
   According to (Xiayimulati, 2023) Carbon pricing in the energy and fuel sector will encourage converting conventional coal energy to clean energy and hasten the development of a low-carbon and ecologically friendly society. The political context, public acceptance, the global unified normative framework, and other areas all provide difficulties for carbon pricing. Although carbon pricing has many difficulties, it is an essential strategy for combating climate change and upholding sustainable development. Through multifaceted changes and adjustments of nations, people, businesses, and institutions, carbon pricing will undoubtedly play a significant role.
   However, there must be clear environmental policies available to use Carbon pricing.
   The question is not whether carbon pricing is desirable

but whether carbon pricing policies are environmentally effective (Boyce et al., 2023).

10. Improving the ships design.
Improving the ships design can also contribute to decarbonization by reducing the bunker's consumption. A cutting-edge new propeller with variable pitch offers an economical way to cut greenhouse gas emissions from marine transportation (UKRI, 2023).

4.3. Countries, shipping companies, organizations and classification authorities that are already starting actions.

- Two huge cruise ships, "Celebrity Apex" and "Symphony of the Seas", will start their European journey utilizing sustainable biofuel to partially cover the ships' fuel requirements, according to a statement from United States-based cruise industry leader Royal Caribbean Group (Čučuk, 2023).

- According to (Gcformd, 2023), the Global Centre for Maritime Decarbonisation (GCMD) and Nippon Yusen Kabushiki Kaisha (NYK) signed a five-year Strategic Partnership agreement on 4th July 2023. This significant partnership strengthens the centre's capacity and efforts to conduct low-carbon solution pilots and trials to provide clear and specific pathways to the decarbonization of the global shipping industry. Japan is one of the world's top three shipowners, with Japanese merchant vessels accounting for approximately 11% of international tonnage. Japan leads other countries in alternative-fuel-ready vessel orders, accounting for roughly 10% of the global equivalent.

- Canada aims to achieve net zero emissions by 2050, and it is developing a national action plan, called the 2030 Emissions Reduction Plan, to align emissions reductions in the marine sector with this goal. The government created the Canadian Green Shipping Corridors Framework to support these pledges, and it also includes direct actions the government is taking to cut emissions from its vessels. (Mandra, 2023)

- According to (maritimeexecutive, 2022), The world's first fully electric and zero-emission fast ferry, classed as a high-speed craft, completed construction, and delivered to its new homeport in Stavanger, Norway. The vessel, "MV *Medstraum"*, began regular commuter service in Norway in the summer of 2022 to demonstrate future electric ferries further.

- With twelve methanol-powered container ships purchased, CMA CGM, Walmart's primary ocean shipping provider, overtook Maersk as the company with the most orders for zero-emission ships. As part of its climate policy, the business declared in June last year that it had bought six ships with dual-fuel methanol engines (Ajot, 2023).

- Some businesses are considering CCS technologies to reduce their emissions. The Lloyd's Register Maritime Decarbonisation Hub (the Hub) has released a new report that examines how Onboard Carbon Capture, Utilisation, and Storage (OCCUS) solutions might be able to serve as a significant mid-term "step" measure for shipping's transition to carbon neutrality. OCCUS technologies have the most significant promise for use with existing vessels because they offer a way to extend the useful lives of these assets without incurring the high cost of switching to zero-carbon fuels (Lr, 2023).

- The company has announced today that the technology group Wärtsilä has received its first order for carbon capture and storage-ready scrubber systems - CCS- Ready scrubbers. The Wärtsilä's received the order in November 2022; the expected delivery is in 2023. Four 8,200 TEU container vessels built at an undisclosed Asian-based yard will be fitted with Wärtsilä's CCS-Ready 35MW scrubber in an open loop configuration (Wartsila, 2023).

- Amendments to the International Convention for the Prevention of Pollution from Ships (MARPOL) Annex VI entered into force on 1 November 2022. Developed under the Initial IMO Strategy on Reduction of GHG Emissions from Ships agreed in 2018, these technical and operational amendments require ships to improve their energy efficiency in the short term and thereby reduce their greenhouse gas emissions. From 1 January 2023, all ships must calculate their attained Energy Efficiency Existing Ship Index (EEXI) to measure their energy efficiency and initiate the collection of data to report their annual operational Carbon Intensity Indicator (CII) and CII rating (IMO, 2022).

4.4. Challenges and costs involved with decarbonization.

1. Complexity.
Decarbonizing the shipping industry is a complex task that requires collaboration between governments, shipping companies, and other stakeholders. One of the biggest challenges is finding alternative fuels that are both sustainable and cost-effective. Currently, most ships run on HFO, which is a cheap but highly polluting fuel. Shipowners have been experimenting with alternative fuels such as Liquefied Natural Gas (LNG), biofuels, and hydrogen, but these fuels have their own challenges. For example, LNG produces fewer emissions than HFO, but it still emits GHG and is a fossil fuel. Biofuels are renewable and emit less GHG, but they require large amounts of land and water to produce. Hydrogen is a promising alternative, but it is expensive to produce and store. The high price of modern infrastructure and technologies is another difficulty. It can be expensive to retrofit old ships with new engines or fuel systems, and building new vessels run on alternative fuels can be considerably more costly. Compared to traditional fossil fuels, this expense may dissuade shipping businesses from investing in greener technologies.
The IMO aims to cut GHG emissions from the shipping sector by 50% by 2050. Still, the group has come under fire for not acting more quickly.

By enacting stricter pollution rules, some nations and regions are taking matters into their own hands. For instance, the European Union has suggested a target of at least a fifty- five percent reduction in shipping emissions by 2030. (Europeancommission, 2021).

2. Costs involved.
   One of our biggest challenges is the current cost differential between conventional and zero-emissions fuels. The cost of alternative fuels in the maritime sector is prohibiting the pace of decarbonisation. There is also a need for more significant investment in research, innovation, and digital adoption to help improve technologies that increase productivity throughout green corridors, ensuring they generate a positive return on investment. (Marineinsight, 2023)
   Over the following decades, the shift of the maritime ecosystem to scalable zero-emission fuels will impact international trade. While the change will result in a more distributed energy supply and associated export potential for scalable zero-emission fuel producers, it will switch to more expensive fuels, influencing trade prices. For the firm to be sustainable, this will ensure that global trade efficiently bears its environmental costs. However, this will raise freight costs globally, having a wide range of effects on different regions, commodities, and trade routes (Bingham and Mikkelsen, 2023).
   More than $1 trillion investment would be required to decarbonize the shipping industry by 2050, according to a report released on 21 September 2022 at the GMF summit in Brooklyn (Dinneen, 2022b).
3. Ammonia bunkering dangers.
   Since NH3 is poisonous, caustic, and explosive, using it as fuel raises safety concerns distinct from those associated with using standard fuels.
   The shipbuilders must use suitable materials to prevent corrosion caused by Ammonia. However, a thorough risk assessment is necessary to understand the effects of poisonous gas dispersion and fire fully. Weather circumstances, leak characteristics, exterior structure, and traffic conditions are just a few of the variables that must be reviewed and rated in order of importance when it comes to the release and distribution of Ammonia. It is also necessary to update the current safety regulations for ammonia bunkering (Duong et al., 2023).

4.5. New Opportunities for Latin America.

As stated by (Bingham, 2023b), Assuming the maritime ecosystem transitions entirely from HFO to green ammonia, this would represent over nine hundred million tons yearly, more than five times today's total global output of conventional ammonia. It reflects the emergence of a new trillion-dollar market opportunity, with countries that can produce green hydrogen, the basis for all scalable zero-emission fuels, at the lowest cost, with a massive potential to supply the fuels needed to decarbonise the international maritime value chain ultimately. Consequently, maritime decarbonisation presents a wide range of opportunities connected to supplying these fuels domestically, exporting these to areas of the world with less renewable potential and ultimately leveraging international maritime decarbonisation to accelerate the transition to renewable forms of energy regionally.

- Latin America has some of the most ideally suited areas for producing green fuels competitively and at scale, given the abundance of renewable energy resources like solar and wind.
- Many countries in the region have high climate ambitions to tap into these resources to power their national electricity grids and switch to cleaner forms of energy.
- Significantly few projects in Latin America are developing green fuels or focusing on shipping's decarbonisation. Further efforts will be needed to ensure the region maintains pace with global developments.
- With coordinated political efforts, Latin American countries could become leaders in green fuel production and export, benefiting from investment opportunities for this new market.

Conclusions

The results of this study assist the author in following up on the study's objective. The following are a few recommendations that may help to create a pathway for achieving the decarbonization goals in the maritime sector:

- Shipping corporations should conduct a feasibility study to assess the viability of various zero-emission solutions for their fleet and operations. The study should consider elements including ship size and type, travel routes and lengths, fuel consumption, and environmental effects. Consequently, they shall create a roadmap with a timeline for introducing zero-emission technology later.
- To choose the most affordable and practical technology, shipping companies should compare the costs and supply of various fuels and infrastructure choices, such as hydrogen refueling stations, battery charging infrastructure, and biofuel production facilities.
- When evaluating the legal requirements for emissions reduction and the incentives and policies supporting the deployment of zero-emission technology, shipping companies should consider the regulatory environment in which they operate, including international, national, and local regulations.
- Suppliers, clients, and investors are just a few stakeholders that shipping companies should work with to discover possibilities and difficulties for reducing emissions. Collaboration can aid in identifying shared priorities and goals and knowledge and skill sharing.

- Shipping companies can collaborate with maritime universities, including vocational colleges and specialized maritime training facilities, to provide access to top-notch training resources and knowledge.

- The training requirements for seafarers and shore staff, as well as the knowledge and abilities needed to operate new zero-emission technologies, should be determined by shipping companies.

- Shipping companies should develop a comprehensive training plan based on the identified training needs, including theoretical and practical training. The training plan should also include information on the safety procedures and best practices for operating new zero-emission technologies. Based on that, create a thorough training program that includes theoretical and practical instruction based on the identified training needs.

- Access to training tools, including manuals, simulators, and chances for on-the-job training, should be made available to their employees (at sea and ashore) by ship owners.

- To ensure that staff are qualified to operate and maintain new zero-emission technologies, ship owners should assess the success of their training programs.

- Ship owners can encourage their staff to participate in learning and professional development by offering bonuses, promotions, or recognition programs.

- Once zero-emission technologies are in place, shipping companies should monitor and evaluate their performance to ensure they meet their emissions reduction goals. The monitoring and evaluation process should include regular reporting and analysis of emissions data and feedback from stakeholders and customers.

- In addition to providing new course modules for the cadets to ensure they have the necessary expertise to operate and maintain the latest equipment, the marine institution and colleges must ensure that its professors and instructors are up to speed with zero-emission technologies.

- The shipping industry's GHG emissions must be reduced or eliminated, and IMO requires steps to be adopted more quickly, thoroughly, robustly, and strictly.

This paper's findings and recommendations rely on the authors' research. Further investigations, research, and actual trials are to be done by other researchers, investors, maritime industries, and shipping companies.

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