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Hydrogen as a ship propulsion fuel Environmental and economical analysis.

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By

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LIST OF EQUATIONS:

ABBREVIATION:

I.	**VLSFO**	Very low sulphur fuel oil.
II.	**SOX**	Sulphur oxide
III.	**SFOC**	Specific Fuel oil Consumption.
IV.	**SEEMP**	Ship Energy Efficiency Management Plan
V.	**RCP**	Representative Concentration Pathways
VI.	**PM10**	Particulate matter
VII.	**MRV**	Monitoring, Reporting, and Verification
VIII.	**MEPC**	Marine Environment Protection Committee
IX.	**MCR**	Maximum Continuous Rating
X.	**MCDM**	Multi-criteria decision making
XI.	**MBM**	Market-Based Measures
XII.	**LP**	Linear Programming
XIII.	**LNG**	Liquefied Natural Gas
XIV.	**LCA**	Life Cycle Assessment
XV.	**Kwhr**	Kilowatt hour
XVI.	**IPCC**	Intergovernmental Panel on Climate Change
XVII.	**IMO**	International Maritime Organization
XVIII.	**ICS**	International Chamber of Shipping
XIX.	**ICE**	Internal combustion engine
XX.	**GWP 100**	Global warming potential.
XXI.	**GHG**	Greenhouse gas
XXII.	**FC**	Fuel cell
XXIII.	**EU**	European Union
XXIV.	**ETS**	Emission trading scheme.
XXV.	**EGCS**	Exhaust Gas Cleaning Systems
XXVI.	**EEOI**	Energy Efficiency Operational Indicator
XXVII.	**ECA**	Emissions Control Area
XXVIII.	**DEA**	Data envelopment analysis.
XXIX.	**CG**	Coal Gasification
XXX.	**CCS**	Carbon Capture Storage

ABSTRACT

The Russian invasion of Ukraine, covid 19, the imbalance in energy demand and supply, and the manner we consume and generate power have all provoked vigorous arguments, as they are raising the number of greenhouse gases in the atmosphere. So, it is self-evident that if we want to save Mother Earth, we must transition away from fossil fuels to alternative fuels. Total GHG emissions from shipping are currently around 3% and are projected to increase by 50% to 250% by 2050. According to forecasts and the path the shipping industry is pursuing, decarbonization of the global energy system is required so that planet warms in 2100 does not exceed 2 degrees Celsius rise. Alternative fuel for shipping is the only practical approach to achieving the Paris MOU objective. Hydrogen is the longest-term answer among the alternatives. Due to its abundance in nature, higher volumetric efficiency, cleaner by-product (water), and widely available cryogenic technology, hydrogen is a potential option for shipping fuel.

Hydrogen production on ships, hydrogen with fuel cells, is acknowledged as a remarkable technology that can help to achieve climate crisis and power demand objectives in multiple sectors of the global energy domain. The global energy system is closely intertwined with shipping energy demand; the two are mutually linked. The thesis's main objective is to evaluate the volumetric efficiency of various alternative fuels in shipping by applying DEA modeling and evaluating which option is the most productive in terms of cost, environmental impact, and economic impact on shipping.

To get the results, the well-to-propeller emission of each alternative fuel is examined and analysed. The hypothesis is stated cost has been used as an input to the DEA model and PM10, GWP100, and Sox will be used as output variables to analyse to produce 1000 kW-hrs. of power. Based on this goal, the following research question will be investigated: What type of results does the DEA modelling offer in terms of hydrogen's potential to cope alongside other existing viable marine fuels that are used to power shipping worldwide? Under what circumstances, and with what impact on the environment and the economy?

Furthermore, we realized several potential factors in this thesis, such as the execution of cap-and-trade initiative market base measures, competitive hydrogen pricing and investment costs

on new hydrogen technology and taking into consideration well-to-propeller emissions when deciding on the next potential fuel for shipping. The work has been viewed as crucial in helping ship owners, bunker suppliers, and charters in recognizing the potential usage of hydrogen as a shipping fuel. To assist policymakers in developing effective GHG legislation for shipping. the use of hydrogen and its implications for geopolitics It is hoped that the findings of this study will support an understanding of the potential advantages of hydrogen as a future fuel for the maritime world as well as the global supply chain sector.

1. INTRODUCTION:

Can hydrogen be used to power global shipping? Future shipping emissions may rise significantly, and new regulatory frameworks to cut shipping emissions are anticipated to go into effect. Alternative fuels for shipping have gained attention recently since future technology for emissions reduction could not guarantee satisfactory outcomes Theoretically, the use of hydrogen in conjunction with onboard fuel cell devices, or the production of hydrogen onboard might reduce the carbon intensity of shipping fleets to zero.

Several factors must be considered owing to the difficulty of the target system. Even though research evaluating the possible use of hydrogen in transportation has already offered insightful information, their conclusions look conflicting and insufficient. Therefore, it indicates that the discussion is still ongoing and that a more rigorous approach is required to fueling foreign vessels using hydrogen.

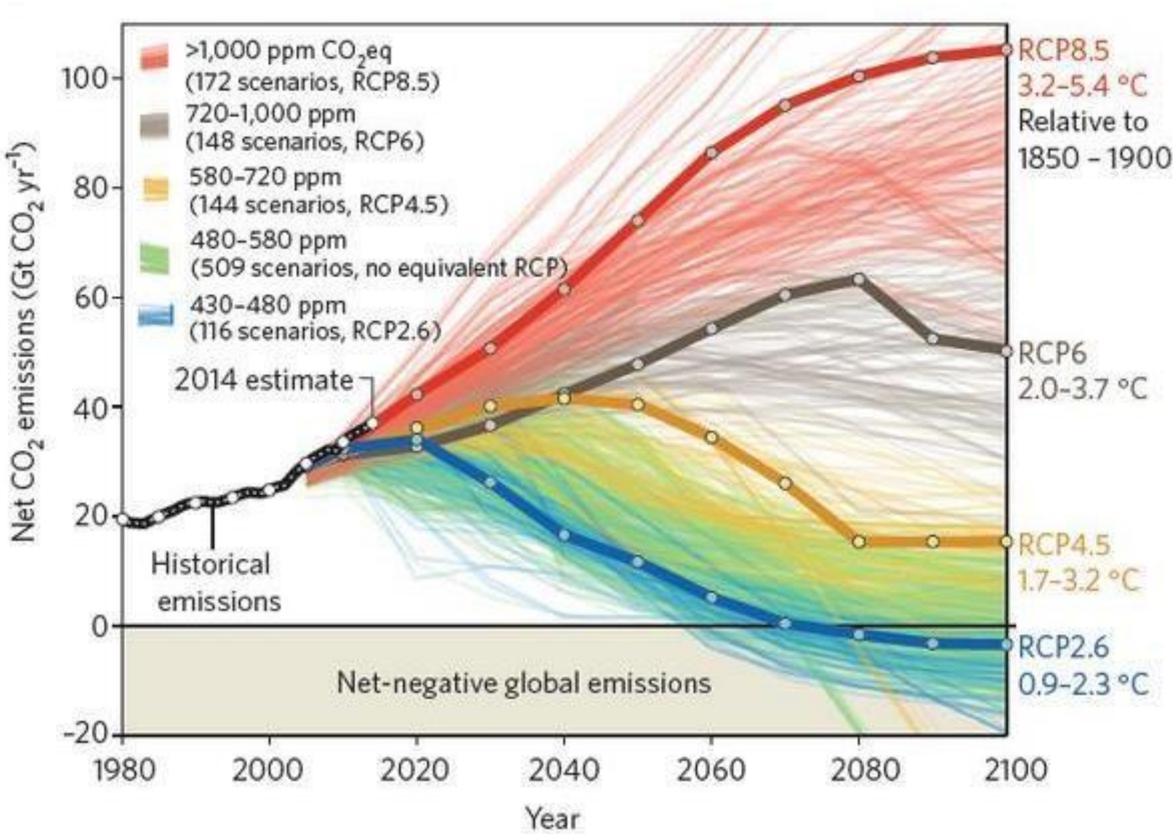
The usage of hydrogen in transportation in the future might be influenced by a variety of things.The possibility of reducing shipping emissions is one of the major advantages of using hydrogen in transportation, as will be demonstrated in chapter 5. As a result, the desire to accomplish this aim and the potential legal framework becomes crucial. Another crucial consideration is how realistic the use of alternative fuels in shipping will be, particularly if there are competing abatement technology alternatives available (ICS, 2009).

Furthermore, the use of hydrogen as a heat transfer fluid has already been thoroughly investigated (Winter and Nitsch, 2012;), and many authors have suggested moving towards a hydrogen economy in the interest of sustainable development (Ekins, 2010; Zu ,ttel et al., 2010). Therefore, another crucial element is its potential involvement in the energy system.

Based on these characteristics, The initial step is to delve deeper into each of these topics in order to comprehend the recent advancements at the time and any shortcomings. As a result, the following aspects are divided: upcoming emissions reduction, legal regime, and shipping emissions technology, alternative fuels, hydrogen use in transportation, and hydrogen's impact on global politics.

1.1 Global Ship Emissions:

It is widely acknowledged that the global energy system must be decarbonized to minimize GHG emissions. The IPCC's Fifth Assessment Report (AR5results)'s states that this plan would prevent hazardous climate change by preventing to restrict worldwide temperature rise to less than 2°C.In Paris in December 2015, 195 countries signed a historic pact. With such an agreement, All European states pledged, the target of keeping worldwide temperature increment is decade below 2°C and well below 1.5° . eventhough shipping was not mentioned in the Paris accord, the potential rise in shipping emissionsbecomes an issue in the context of global sustainable development. Figure 1.1 from Bows- Larkin et al(2015) study provides a thorough description of this issue.



Comparisons of GHG scenarios for varied climatic effects between the IMO and RCP marker scenarios. The emissions from 2012 are linked to each scenario.

Source: (EVAN LEVY, Earth.com Staff writer).

A graph from this research contrasts four typical concentration routes with the Smith et al. (2015) shipping emissions scenarios (RCPs). Each road has been calculated such thatit correlates to a distinct climatic result, according to Bows Larkin (2015), for instance, The RCP2.6 road is expected to warm by 0.9-2.3 degrees Celsius by 2100, while the RCP8.5 track is expected to warm by 3.2-5.5 degrees Celsius. The outcome was that none of the forecasted shipping possibilities came even closer to the RCP2.6 pathway, indicating that shipping would participate proportionally in avoiding 2°C of warming. To close this gap, the shipping system's sustainability has thus become crucial, which emphasizes the need to look into new environmental policies, legislations, and technological solutions, especially in the medium to long run, beyond 2030.

1.2 Regulatory framework

Emissions should drop by 25 to 30 percent by 2030 as a result of the EEDI. There are furthermeasures under consideration to reduce GHG emissions from the international marine transport industry. Several market-based measurements (MBM) approaches, for instance, are the subject of a feasibility assessment and effect analysis (MEPC.1/Circ.61/INF2,2010). Additionally, the European Commission unveiled a plan in June 2013 to reduce GHG emissions from domestic shipping. The plan calls for MRV, and CO2 emissions from merchant ships calling at EU ports are being monitored, reported, and verified. A worldwide data gathering system to assess CO2 emissions from specific ships has just received the IMO's approval in principle (ICS, 2009).

MBMs are climate regulations that uphold the "responsibility of person or organization to pay" concept and offerstakeholders monetary incentives to reduce emissions. MBMs first were suggested to the IMO in 2010 but ut on hold in 2013. They are linked to emissions trading systems (ETS), like the EU ETS, and environmental tariffs like carbon or fossil fuel taxes. Additionally, the European Commission (EC) has proposed incorporating shipping into the EU ETS in July 2021 as part of the "Fit for 55" plan and the "European Green Deal" (EC, 2021). For all Emissions of co2 from journeys within the EuropeanEconomic Area (EEA), 50% of CO2 emissions from vessels coming to the European ports, 50% of CO2 emissions from vessels coming to European ports,and 100% of CO2 emissions were reduced at berth at EU ports, emissions allowances must be purchased to comply with the legislation final form of such a strategy will be influenced by the conclusion of negotiations between the various EU regulatory authorities (Independent body, Legislature, and Commission) and maritime stakeholders.

To provide new incentives for the shipping sector to become carbon neutral, it will be crucial to watch how the regulatory environment develops. The IMO seems to be setting the standard on this issue, but local rules on ship energy efficiency design index and air pollution are also becoming stricter.

1.3 Potential shipping greenhouse gas reduction innovations:

Modern technological advancements in shipping are the topic of intense discussion. An extensive analysis of the revolutionary impacts of 18 technologies on ship design, marine engineering, and ocean capacity planning in 2030 is given in a report readily accessible by Lloyd's Register Argyros. Exhaust gas scrubbers (EGCS), commonly known as scrubbers, some of the technological solutions for reducing shipping emissions include onboard wind and solar power systems, as well as fuel cells as the primary propulsion system. Scrubber technology can only guarantee a reduced level of SOX emissions; hence ships with scrubbers on board will continue to use conventional marine fossil fuels. As a consequence, however, a carbon sequestration unit is considered one of the possibilities for retrofitting vessels, and scrubbers are not seen as potentially viable options for a subsequent reduction in Carbon emissions. Ships utilize conventional fuel and collect the carbon emitted during operation. Since wind energy has been utilized for ages, it is not a novelshipping method. Research are looking at wind technology for modern ships (2013). As it would be challenging to provide enough electricity, solar power seems to be less realistic onboard ships. Because they may be combined with a reformer and a varietyof hydrocarbons, including LNG and methanol, fuel cells for coastal vessels as the primary propulsion system may be an option for future ships (Erkko, 2011). However, when combined with hydrogen, they could provide greater environmental advantages (Argyros et. al., 2014). Auxiliary power unit (APU) prototypes that operate aboard ships currently exist, while the development of such technology for marine applications is still in its early stages (McConnell, 2010). An essential issue that will impact how future ships are designed is the examination of emerging technologies. Such advancements will also affect the use of hydrogen as a bunker fuel. Even though only the first

4 appear to become the most promising, the most successful in the industry future fuels for ocean commercial vessels LPG, methanol, Ammonia, hydrogen (including green-hydrogen), LNG (Liquid Natural Gas), and VLSFO, according to Ruud Verbeek (2011) , Argyros et al (2014).

1.4 Alternative fuels in shipping

Long-term major shipping emissions reductions may also be possible with alternative fuels. Even though just the first four appear to be the most acceptable, according to Ruud Verbeek (2011) and Argyros et al., the most Notable alternative shipping fuels are LNG, methanol, biofuels and hydrogen, LPG (Liquid Propane Gas), and ammonia (2014).

As seen by the many initiatives and programs attempting to highlight its benefits, till now the most actively promised alternative fuel in transportation is LNG, because of its easily available logistics infrastructure. According to some LNG is a fossil fuel alternative that emits less CO2 and has a lower Sulphur content than current maritime fuels. Verbeek and his associates (2011); GL (2011); Lloyds Register (2012) Advanced biofuels, including bio-methanol, are frequently mentioned as potential methanol substitutes. which isfrequently considered as a future fuel for shipping. The greatest long-term answer, however, is believed to be hydrogen with fuel cells since it has no operating emissions and can achieve better thermal efficiency on ships (Ruud Verbeek, 2011; Argyros et. al., 2014). Although thereis little data on their practicality on board ships, LPG, DME, and ammonia are promising alternatives for marine fuel. A life cycle assessment (LCA) has been used in many research to evaluate the environmental effect of alternative marine fuels, including Bengtsson (2011) and Brynolf et al. (2014). Despite the fact that many people agree on LNG, it seems that there is not a lot of agreement on which of these alternative fuels would be a practical option (DNV, 2010; GL, 2012; Wartsila, 2012; DNV GL, 2014).

Alternative fuels combined with a higher effective propulsion system may be the most realisticsolution a more If there is a significant long-term reduction in shipping emissions, technological and operational measures are insufficient to achieve a radical decrease in emissions. If alternativefuels are used in shipping, they will need several modifications and adjustments. The usage of any of these fuels raises similar issues, and because not all of them are specifically related to the shipping sector, their deployment in The future energy system will also have an impact on shipping.

1.5 Possible applications for hydrogen:

Hydrogen's function as an energy carrier Possible application for hydrogen has been thoroughly studied since it was first in the second half of the 18th century, was isolated and identified. Many academics believe that developing hydrogen depends economy is the way to creating a sustainable future. A carbon-free energy system. They claim that because of the physical and thermodynamic characteristics of hydrogen, hydrogen-based technologies might have a wide range of uses in a decarbonized global energy system, and hydrogen is expected to play a key role soon (Winter and Nitsch, 2012; Andrews and Shabani, 2012; Ekins, 2010; Barreto et al., 2003). However, the most appealing application for hydrogen would be as a transportation fuel. A means of heating, and a means of storing renewable energy (SBA, 2014). Energy storage system development is complicated by the requirement to balance the energy grid in light of the rising intermittency of renewable energy sources. According to the SBA (2014) research, hydrogen pressurized storage refrigerated systems may be the most effective option to deliver backup power when renewable sources of energy aren't supplying it and to prevent waste during peaks in renewable electricity production. According to research by Ehteshami and Chan (2014),The most promising fuel is hydrogen. to store renewable energy.

The most promising alternative, according to a comparison of choices based on a set of criteria,was found to be electrolysis-based storage of renewable energy sources such as hydrogen. Additionally, JRC (2007) said that hydrogen may be employed as a storage medium to deal with stochastic power production to attain significant renewable energy penetration in the short to medium term Concern was raised concerning hydrogen re-electrification, however, because It might not be the most cost and energy efficient storage solution. Method. The world is transitioning to a low-carbon economy. In so many countries, hydrogen technologies hold significant promise not only for combating climate change, but also for improving energy stability and developing domestic industries.

1.6 Hydrogen's impact on world politics

Studies show additional research topics that could benefit all stakeholders, lawmakers, and decision-makers better know the role of hydrogen in the prospective energy economy. The world is transforming toward a low-carbon economy. Low-emission hydrogen technologies offer promising opportunities not only to fight climate change but also to enhance energy dependency on renewable fuel and develop local hydrogen base industries in many countries. To achieve the goal of transition towards net zero emissions, committed hydrogen strategies and futuristic roadmaps are being developed by major world economies, Japan, Germany, Australia, and the EU. Still, a lot of research and industrial development are needed for different components of the hydrogen pathway, which include the production of hydrogen, logistics handling, and delivery of hydrogen from producer to end user. Dueto its extensive potential and varied uses, hydrogen also becoming a significant geopolitical concern. The predicted development of the techniques is known to press concern for the geopolitics of energy in a world with minimal carbon emissions.

1.7 The findings of the study technique

We can characterize the research in this field of hydrogen as a shipping fuel into three groups:those which specifically examine hydrogen as a fuel in shipping, those that concentrate on fuel cells in marine applications, and those that examine alternative fuel options while taking hydrogen as one of the options. All of these researchers used a variety of approaches and got a range of outcomes. According to some research, hydrogen is not the best fuel for ships due to practical, financial, and logistics concerns. Others think it will be the most expensive and distantly available alternative marine fuel in the future. In part 2, further information about that research will be given. Research that utilized a computational modeling strategy seems to be more appropriate when many different elements need to be taken into account. Even though computer modeling has offered significant and practical insights into the potential o hydrogen in shipping, its results often seem to be at odds. For instance, however, according to Taljegard et al. (2014), hydrogen a predicted to in international shipping after 2060, however, Argyros et al (2014) predicted that strong carbon taxation coupled with a reasonable hydrogen production cost ll result in a large uptake of hydrogen in international shipping starting in 2030.

1.8 The computational modeling strategy:

In addition to defining computer simulations, some writers also specify the computational models that are utilized to calculate a simulation. According to Winsberg (2013), A computer simulation is a data analytic tool that utilizes a step-by-step procedure to investigate the approximation of a mathematical model of the behavior actual world system.

An efficient computational technique, irrespective of how it is articulated, is frequently used for predicting; it is an analysis of how it will behave. Anticipated that the real world will react given a certain set of conditions. Likewise, may be stated as simulating how well the maritime system would function if hydrogen production and fuel technologies both are available at a certain price point with a specific set of technical specifications. Another aspect may be an analysis of how the world's energy total demand would function under conditions where it is required to fulfill certain emission goals by meeting a variety of energy needs utilizing a variety of technologies, including those based on hydrogen.

It is important to emphasize that there are real-world factors that might influence outcomes that are challenging to represent in a model (such as behavior elements or convenience features), necessitating more research.

1.9 Existing models' restrictions:

Models in the first category replicate the development of the shipping industry. The assumption is that shipboard technologies would be improved and chosen based on the actual situation shipowner’s desire to maximize profit and compliance with shipping regulations. The second class of models replicates changes in the global energy total demand while optimizing social welfare(consumer surplus and producer surplus) under predetermined CO2 limits. According to the interpretation, the assumption that the most economically advantageous technology would be employed would guide the choice of energy technologies in the actual world. For instance, the technical and financial viability of hydrogen-powered ships is assessed while taking into account a variety of factors including the weight, capacity, and cost of onboard hydrogen pressurized storage tanks s well as the profitability of various ship types and ship sizes in comparison to other options. To Incorporate signaling from the global financial and environmental systems, such as gasoline prices, are examples of this. The model must make several exogenous assumptions. These kinds of assumptions are significant impact on the findings The model has little impact on the supply and demand for hydrogen in transportation. It is conceivable to capture hydrogen as an alternate maritime fuel using an energy system model. The competitiveness for primary energy resources, geographical considerations, and influence of economic and climate policy drivers in some depth. The model cannot fully illustrate the relationship between hydrogen-powered ships' technological and operational requirements, and the shipping system is frequently misrepresented. This implies that a more thorough methodology and complicated depiction of hydrogen absorption in transportation are required. Chapter 3 will offer further information on the modeling representation of hydrogen.

1.10 This thesis's research questions are:

What type of results does the DEA modeling offer in terms of hydrogen's potential to cope alongside other existing viable marine fuels that are used to power shipping worldwide? Underwhat circumstances, and what potential impact on the environment and the economy?

Sub-research question:

- To perform the DEA analysis of various fuels for the shipping industry.
- Analyze and identify a fuel with the most economical and environmentally efficient, considering well-to-propeller emissions.
- how would hydrogen affect the global energy consumption market and its geopolitical implications?
- Feasibility analysis of hydrogen production on the ship, a case study of Energy observer 2.

1.11 Paper structure:

Following is the way the remaining chapters are arranged: A overview of the key research about the usage of hydrogen as a marine fuel is included in chapter 2 of this book. Finding the gaps in the literature that gives rise to the research questions is the goal of this chapter. The effectiveness of current strategies is assessed, with computer modeling techniques receiving special attention.

To determine the parameters needed for a thorough and suitable representation, the modeling schematic of hydrogen uptake in transportation is investigated in chapter 3. In this chapter,the relative ability of the model DEA and Linear Programming Model has used a tina system of analysis observations, performance measurement that enables benchmarking, continual improvement, and competitive strategy is collected for a specific number of entities known as decision-making units. (DMU). Also discussed is the research that connected two distinctmodels. Finally, the research topics and the gaps in the literature are determined.

Chapter 4 outlines the strategy used to connect two existing models after identifying a suitablemethod that may be utilized to address the research questions that have been specified (DEA and Linear Programming Model).This chapter begins by discussing computational models, which are a relatively recent technique. reviewing research that has already used connecting techniques. The accompanying assumptions are established together with each step in more depth.

The data about whether the connecting architecture enhances in this paper, the computational representations of hydrogen uptake in shipping are investigated. Chapter 5. By discussing and contrasting the outcomes of independent simulations of DEA and the outcomes of the Linear Programming Mode. There are two situations that are looked at. Under two distinct emissions reduction objectives, they examine the development of the maritime industry and the global energy system. The utilisation of hydrogen as a shipping fuel is studied using a specific scenario with different other maritime fuel sources. The outcomes of this scenario are examined in depth, including the effects on the shipping and energy sectors. This chapter also includes a robustness study, where the conclusions are examined considering several circumstances. The robustness study illustrates the connection between certain input variables and output variables, and consideration of hydrogen's potential us in transportation.

Additionally, it pinpoints key interactions between energy and transportation systems that may affect hydrogen's potential as a substitute maritime fuel.

1.12 Gaps in Research

Previous research concentrated on the direct economic and environmental aspects while performing the study of various fuels for the shipping industry. Whereas the indirect emissionof the harmful byproducts is neglected along with the cost of transportation. In this current study, DEA-based efficiency analysis of fuels is extended toward the missing factors in the literature.

1.13 Research Objectives and contribution

- To perform the DEA analysis of various fuels for the shipping industry
- Analyze and identify a fuel with the most economical and environmentally efficient considering well-to-Propeller emissions.

2. LITERATURE REVIEW

2.1 Description of the Literature Review:

The goal is to identify any potential gaps in the body of knowledge and the consequent need for more research. The concept of hydrogen in shipping is linked to the variety of technological options available to the shipping sector to increase energy efficiency and lower carbon intensity. Such technological solutions in shipping have been looked at in a variety of contexts. For instance, an examination of operational prototypes is being done to determine the effectiveness of hydrogen-powered ships. The examination of return-on-investment analysis, cross-modal analysis, and life cycle evaluation, sustainable development goals performance, and Environmental impact evaluation, just a few examples are estimates of a vessel's propulsion system and the use of computational methods to analyse maritime or energy systems. of themethods that have been utilized. Although it is acknowledged that other methodologies have previously produced several insightful findings, the research that has employed acomputational modeling approach will get special attention in this thesis.

The modeling technique has been used for a variety of projects; for instance, several researchers have investigated the use of hydrogen in shipping as well as viable fuels for shipping. Other research has concentrated on hydrogen as a fuel but has not taken the maritime industry as one of the potential players into account. This chapter will explore the consequences of modeling hydrogen representation utilization in shipping. The goal of this assessment is to identify the requirements that must be thought about for hydrogen modeling representation in shipping.

2.2 Methods and crucial takeaways:

Compared to the hydrogen literature for use in other areas of transportation, the literature on hydrogen for maritime uses is not as substantial. This literature can be divided into three categories: researchers that are research primarily focused on hydrogen as a fuel in transportation that is focused on the use of fuel cells in the marine world and hydrogen in combination with fuel cells into consideration, and researchers that are specifically focused on several potential fuels for shipping, with hydrogen being one of them.

The construction of prototypes that have been developed to illustrate the technological viability,it has been stated that on board a ship, and a small tour boat, respectively, Bevan et al. (2011) and Bulletin (2013). Both instances are running correctly. This literature is divided into three categories: researchers focusing on hydrogen as a fuel in coastal shipping, research specifically focusing on fuel cell technology in the maritime worldwide and trying to take hydrogen in combination with fuel cells into consideration, and research findings focusing specifically on potentially viable fuels in shipping, with hydrogen one of the options.

Sattler (1998) and Psoma and Sattler, another successful application of hydrogen technology is the installation of it on submarines (2002). On certain ships, other researchers have offered potential idea designs. For instance, Veldhuis et al. (2007) investigated the possibilities for hydrogen while considering coastal vessels operating on certain fixed routes.

The research performed a cross-modal comparison to identify the most effective tactic. Whenusing hydrogen as a fuel for shipping, several important considerations must be made, including where the hydrogen comes from, how it compares to competing fuels, how to load and store it on ships, and what kind of prime mover is best, and how the architecture of the ships will be affected. Koefman (2012) provided an overview of l of these considerations.

The research that mainly examined fuel cells for marine applications and took hydrogen on board ships into account fall under the second group. They include Han et al., Sattler (2000), Ludvigsen and Ovrum (2012), Vogler (2010), and Vogler (2010). (2012). This research has emphasized several important variables when addressing the uses of fuel cells in ships, particularly when combined with hydrogen. The main topics of discussion are the many typesof Hydrogen pressurized vessel storage devices that could be used on board, as well as other requirements for employing this type of fuel The third group of research includes those that concentrate on hydrogen as one of the alternative fuels for ships. These researchers may be further broken down into two categories. The former comprises two research comparing various fuels to various technical, economical, and environmental requirements to encourage future adoption in the maritime sector. While DNV GL (2014) reviewed the technical hurdles and possible advantages of each alternative fuel and offered a life cycle evaluation, Ruud

Verbeek(2011) used a variety of data to assess the output, prospects, and economics of each alternative fuel (well-to-propeller analysis).

The research in the latter group that examined the usage of alternative fuels in shipping did sousing computer models. A cost-optimization model of Taljegard et al. (2014) employed energy infrastructure (Global Energy Transitions - GET RC 6.2) to analyses, most economically efficient fuel for shipping under severe CO2 emission reduction potential. While Argyros et al. (2014) examined the function and demand for various fuels and energy efficiency solutions using the (Linear Programming Model). In response to external forces including fuel pricing, transportation demand, laws, and technology availability, In section 3.3 and chapter 4, specifics of the hydrogen representation for this model are provided.

The use of hydrogen as a fuel for transportation raises several issues that may be emphasized from various perspectives. On the one hand, the knowledge gathered from the actual installations aboard supports the notion that hydrogen and fuel cell systems may be installed on ships. On the other hand, it is challenging to conclude the ability of hydrogento power international ships from this sort of approach. Numerous research has focused on potential concept design alternatives for various kinds of ships, noting that many design issues still need to be resolved for usage on board big ships. The weight and volume consequences of the on-board hydrogen pressurized storage vessel and the operational and capital cost of both the storage system and the combined primary propulsion machinery as well as the related effectiveness of the propulsion engine appear to be the most significant considerations in the economic and technical analysis of hydrogen fuel in shipping. Ludvigsen and Ovrum (2012), Han et al. (2012), Veldhuis et al. (2007), Upadhyay (2011), as well as others.

Systematic consideration has been paid to hydrogen storage. Maximizing the fuel's volumetricand gravimetric energy density is a significant problem. Although high-pressure gas cylindersare now the most popular hydrogen storage method, the low volumetric density is seen to be amajor barrier to usage on ships. According to numerous studies, the capacity of huge storage cylinders is predicted to be 4–7 times that of conventional fuel oil DNV GL, 2014; Vogler, 2010; Taljegard et al., 2014). DNV GL, Veldhuis et al. (2007), Han et al. (2012) have all addressed the storage of liquid hydrogen in a cryogenic condition (2014). Low temperatures, significant energy losses, and the need for room for insulated pressurized storage tanks DNV GL are the key issues (2014). Additionally, a refrigeration unit is needed to keep liquid hydrogen in a cryogenic condition, which adds to the expense. Han and co. (2012). The hydrogen storage solution based on metal hydrides that has been successfully tested in submarines isanother potential hydrogen storage alternative that was examined for maritime applications.

The low weight % of hydrogen is the fundamental drawback of metal hydride hydrogen storage for cargo ships (Han et. al., 2012;). Other potential viable solutions include a method using carbon nanofibers or the production of hydrogen on board using hydrocarbons that are simple to store. Sattler (1998). In the latter scenario, the tank-to-propeller system's total efficiency must take a reformer's efficiency into consideration. Due to its low flammability limitations, specific safety considerations must be made while storing hydrogenon board ships in addition to the kind of storage system employed. To reduce the possibility and effects of hydrogen leaking, new regulations would need to be introduced, including thosefor ventilation, alarm systems, and fire protection (Ludvigsen and Ovrum, 2012).

Gas turbines and fuel cells are the two major options for a hydrogen-fueled ship's engines. There was little information on hydrogen used in gas turbines for ships, but much research hasfocused on the use of fuel cells in conjunction with hydrogen as a propulsion device, it's important to consider some of the most important difficulties with this kind of systemin marine applications. The power needed is problematic because of gasoline. It would be necessary to use cell systems with a minimum power output of 500kW In general, fuel cells should have a power output of 1 to 5 MW to be regarded an alternative for electrical power. Other problem involved is high CAPEX, weight, and size of fuel cell systems that causes a reduction in cargo carrying capacity and submerges the vessel more into water that causes higher drag and more power consumption, the lifespan they are projected to have less respond to transient loads, and the energy and pollutants they produce during their lifespan. It is acknowledged that these difficulties need more research (Vogler, 2010; DNV GL, 2014). Additionally, Shipboard fuel cell systems offer a variety of benefits, includingthe potential Fuel consumption that can be reduced to improve drove vessel efficiency, and emissions were reduced as a result. Other advantages include low noise and vibration levels, versatility, and the need for less frequent maintenance. Due to these benefits, according to DNV GL (2014), fuel cells might eventually make up the portfolio of power systems used by ships. Additionally, the recent commercialization of a few land-based fuel cellapplications may make fuel cells more accessible for usage on ships going forward. The cost and accessibility of fuel are also major determinants of the utilization of hydrogen in shipping. It is acknowledged that producing, transporting, and storing hydrogen as a fuel may be challenging and expensive. Contrarily, hydrogen is thought to be competitive when it can be created from excess solar or wind energy that the system is incapable of handling (Ruud Verbeek, 2011),however, it relies on the electrolytes' power factor. Since there is present Because hydrogen and other new alternative fuels have a restricted distribution network, there is tremendous uncertainty about their long-term availability. (Ludvigsen and Ovrum, 2012). These problems are connected to the upstream process, which should be considered in terms of emissions as well. We still don't fully understand the effects of upstream emissions from fuels that seem desirable because they could have low operating emissions. LCA is often used to study the consequences of introducing alternative fuels into port terminals, but more research is required since it is challenging to produce reliable data that describe these sorts of effects. The researchevaluated in this article comes to conflicting conclusions about the possible hydrogen uptake in shipping. On the one hand, some researchers have indicated that conventional marine fuels would continue to be preferred, since hydrogen is unsuited for ships due to practical, financial, and energy efficiency concerns. Based on pricing and proof that it reducesGHG emissions, together with the cost of the storage tank, LNG looks to be the best option (Ruud Verbeek, 2011). Farrell et al. (2003) argue that the marine industry has traditionally remained slow to adopt emerging innovations. (Taljegard et. al., 2014). Depending on the characteristics of the ship, hydrogen, synthetic fuels, and biofuels are considered the most distant future alternatives to marine fuels (Taljegard, 2014). On the other side, they have predicted a future fuel mix that includes a greater variety of fuels, including hydrogen, LNG, biofuels, and renewable energy sources (DNV, 2014). Furthermore, it is believed that a more aggressive approach to emissions reduction with reasonable hydrogen prices may contribute to considerable hydrogen adoption in the marine world. (Argyros et. al., 2014).

Few conclusions result from thinking about the market's features. For instance, DNV GL (2014) argued that since the charterer oversees covering the cost of fuel, there aren't any Incentives for operators to explore alternative fuels in specific shipping sectors While Farrell et al. (2003) acknowledge introducing hydrogen within Shipping is a more efficient approach of developing hydrogen-related technologies. Ludvigsen and Ovrum (2012) emphasize on that improved accessibility of different fuels in other logistic industries may also enhance the process of adoption of the fuel for shipping drive.

The many methodologies used to examine the usage of hydrogen in shipping are highlighted in this section. Due to the many elements that must be considered, it is challenging to draw solid findings. The potential benefits and drawbacks, as well as advantages and obstacles, are all extensively articulated; nonetheless, the findings about the ability of hydrogen to power global shipping are divergent.

2.3 Hydrogen and geopolitics:

In this section, we try to answer one among our sub-search research questions, many countries acknowledge hydrogen's potential as a viable energy source with the potential to create a new global geo-strategic map that revolutionizes global energy markets. Countries globally have established national policies and strategies to develop the hydrogen value chain, in this section, we try to review the hydrogen roadmap that has been developed in a few countries around the world such as Australia, Chile, China, Canada, Germany, South Africa, the United Kingdom, Japan, the European Union, France, the United States, and, India, countries that have taken the first step toward a future of renewable hydrogen systems will change the dynamics of the global energy market, thanks to their infrastructure capabilities, freshwater availability, and funds raised to invest in the hydrogen economy, although the major challenge is to reduce the production and logistics cost of hydrogen, it is evident when hydrogen production and availability is cheaply accessible, it is possible that hydrogen will become potential and viable fuel for shipping.

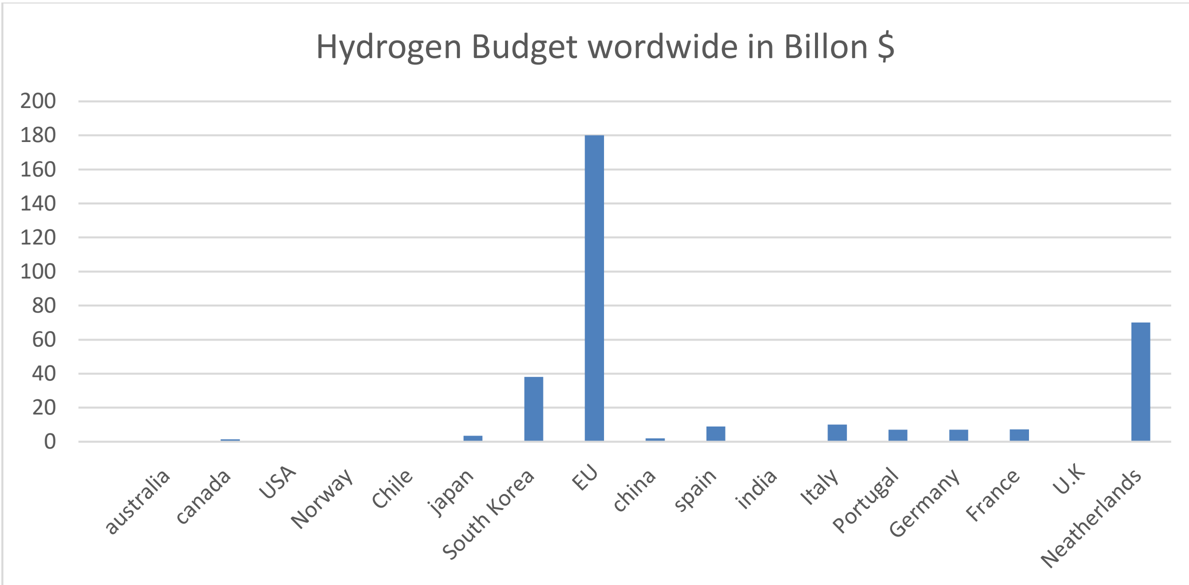


Figure: hydrogen budget worldwide in billion dollars

Australia:

Australia is investing approximately $ 275.5 million in the hydrogen industry to advance the construction of hydrogen infrastructure. The government is putting out several policy initiatives. Such as R&D project financing, while establishing relationships with other nations (Japan, Korea, Singapore, and Taiwan) to help them build their hydrogen economy. The development of the hydrogen sector can benefit the government, thousands of jobs can contribute to the economy almost $1.7 billion in GDP, allowing for the integration of Reduce reliance by incorporating renewable energy into the power system,

Canada:

The Canadian government seems to be very engaged in the development of a hydrogen economy; because of its comparative edge, Canada became the world's leading producer, consumer, and exporter of hydrogen. The availability of hydrogen-producing fuel, such as freshwater supplies, large-scale biomass supply, considerable fossil fuel resources, and high hydroelectric capacity; (ii) its entrepreneurial leadership, industrial dominance, fuel cell capability technologies, and carbon capture technology, Canada's proximity to South Korea, Japan, and other hydrogen import industries, United States, United Kingdom, Germany, and the rest of the world.

European Union:

The Russian invasion of Ukraine, the Paris MOU 2050, encourages Europe to build massive decarbonization of the transportation, manufacturing, and building sectors. Moreover, hydrogen could play an important role in the transition to renewable energies. Hydrogen would help to reduce the EU's dependency on fossil fuels, boost the value chain, and create almost one million alternative employments (Cuevas F, Zhang J, Latroche M), to expedite the hydrogen and fuel solution project development Phase 1 (2020-2024) production of million tonnes green hydhydrogens electrolyzers planned by the EU.

The H2 produced will be used in the chemical and heavy industries. Electrolyser production will increase from 6GW to 40GW in phase 2 (2025- 2030). The primary focus is on maritime applications, hydrogen refuelling stations, and local hydrogen infrastructure in phase 3 2030-2050 - H2 will be used to generate large amounts of electricity.

The EU intends to invest 100 billion Euros between 2020 and 2030 through the European Clean Hydrogen Partnership in hydrogen production projects using electrolysers, and storage and distribution projects (Eu Commission, European clean hydrogen alliance 6 September 2021). 300 billion are now being planned to ensure the production of electricity from solar and wind energy.

Within the EU, Germany, France, and the Netherlands are investing heavily in hydrogen infrastructure, with the French Multi-year Energy Plan and Energy Climate Law investing 100 million Euros in the development of service stations, and Germany planning to invest around 700 million Euros between 2020 and 2024.

Between 2020 and 2023, an energy and climate fund is established for scientific research concentrating on green hydrogen, and another $200 million for the development of hydrogen technology. The Netherlands intends to invest approximately 70 million euros in subsidies, with the goal of producing 3-4 Gw of green hydrogen production by 2030.

Table: Global hydrogen investment potential

Global H2 demand and supply market	Countries with H2 infrastructure	Budget for H2 worldwide in Billon $.
Exporters	Australia	0.2755
	Canada	1.5
	USA	0.064
	Norway	0.019

	Chile	0.05
Importers	Japan	3.4
	South Korea	38
	EU	180
Water constrained	China	2
self- sufficient producer	Spain	8.9
Infrastructure Constrained	India	0.000689
	Italy	10
	Portugal	7
importers	Germany	7
	France	7.2
	U. K	0.28
	Netherlands'	70
	Total budget for H2	335.689189

Source : authors compilations

Nations that have chosen to take a few steps forward in developing hydrogen infrastructure have a significant advantage in developing hydrogen economic growth. Countries with vast natural resources such as clean water and better renewable (wind, and solar) harvesting energy technology will perform exceptionally well in the future by developing self-sustaining energy economic systems. Countries with better hydrogen infrastructure and distribution systems, such as Japan, Germany, France, the Netherlands, Australia, and the United States, will help in the creation of the shipping industry's transition from conventional fuel to hydrogen.

2.4 Computational modelling technique used to investigate hydrogen in transportation.

There are several methods for studying hydrogen as a fuel for ships, as was covered in the preceding section. The kind of methodology used and the questions that might be answered vary between them generally. Different techniques can result in different findings. Each approach's limits may aid in defining the restrictions and the respective conclusion's level of robustness. The methodologies now in use are assessed in this part to determine which is the best way to investigate the possible usage of hydrogen in shipping. This allows for a more comprehensive comparison of social-technical transition methodologies and techno-economic modeling.

The first strategy under use is the development of hydrogen-powered ship prototypes. They are crucial for overcoming technological challenges and investigating technical viability, but they are insufficient for addressing concerns about the possible large-scale usage of hydrogen in the future. The same is true for research focusing on the design parameters of hydrogen-powered vehicle ships, including those that have concentrated on hydrogen with fuel cell technologies. They are particularly helpful in identifying technical difficulties, although they are often restricted to a technological and economical study of a single ship, sometimes taking into consideration a small number of service routes, as in Veldhuis et al (2007). The ship itself or a certain kind of ship is shown as the center of these studies' limits, which often ignore the shipping system's dynamics.

The second strategy involves doing an evaluation based on environmental, economic, and technological factors, as done in Farrell et al. (2003), Koefman (2012),and DNV GL (2014). This kind of strategy falls within the social-technical transition techniques category. They focus on discovering processes and trends in the technological transition process. They may be highly helpful in locating difficult-to-capture socio-technicalforces including market constraints, political development, and other aspects of the world economy. Despite this, the findings produced using this method depend on hypotheses that are often unsupported by high-quality empirical evidence, making them seem insufficiently robust.

The future energy demand of the shipping system has been investigated utilizing computational modeling techniques such as those used by Taljegard et al. (2014) and Argyros et al. (2014). (2015).Hydrogen is the sustainable solution that may lower the energy demand and carbon emissions of the shipping sector (2014). They have looked at potential avenues for reducing the energy and carbon emissions of the individual shipping industry or different industries together using a modeling methodology that is often employed.

Models of the energy system are one instance. The cost-effectiveness of energy systems and factors that might affect them are analyzed using this kind of model under CO2 emissions reduction limitations. Although they cannot provide scenarios for the growth of the energy system, they may be highly helpful in evaluating the impact of new policies.

Another example is sectoral models, such as those used in shipping. The scale impact of the size, technological design, and operational parameters of a ship under various shipping policy scenarios are just a few of the several elements that may be considered while analysing the routes to a future shipping system. Energy efficiency solutions may be economically and technically assessed in a sectoral model.

When several different elements must be considered, it appears to be the most useful instrument. Different approaches may provide answers to issues to a given degree of detail from different viewpoints. The adoption of hydrogen in shipping is influenced by several variables, including sectoral and worldwide approaches for reducing energy and carbon intensity, in addition to how it is implemented on board ships. Therefore, the computational modelling technique is the main emphasis of this thesis since it is thought to add fresh, useful value to hydrogen's ability to support global shipping.

2.5 Other approaches to modeling hydrogen as fuel for shipping:

The computational modeling technique will be the main emphasis of the literature study that follows, making modeling representation of hydrogen in shipping very important. Two more research areas that are relevant to the issue of modelling hydrogen representation in shipping are widely covered in this section. Research that looked at alternative fuels other than hydrogen for use in shipping go into the first category; research that looked at hydrogen as a potential future energy source for other industries fall into the second. Both of these research kinds are crucial to our investigation because they allow us to uncover effects for the statistical representation of hydrogen consumption in shipping by considering.

2.6 Models now being used to investigate alternate fuels in shipping:

Numerous research that doesn’t contain hydrogen has utilized models to look at the usage of various alternative fuels in shipping. While many models solely consider LNG as a fuel choice, certain models examine many fuel alternatives.

The scope of this thesis does not include an exhaustive evaluation; rather, it simply focuses on the requirements built into the models that were used. With the use of such specifications, it ispossible to pinpoint variables that are important for simulating hydrogen uptake in transportation.

One of the models used in DNV is one that investigates alternative fuel sources (2012). An extremely comparable simulation model to the one employed by Argyros et al. was utilised in this investigation (2014). This model mimics the efforts made by ship owners to invest in new technology in order to meet laws and growing energy efficiency standards. Its structure is fairly similar to that of the model employed by Argyros et al. (2014), however, it has fewer technicalspecifics. The model takes environmental and energy efficiency laws into account. These requirements emphasize the need of considering the impact of such restrictions on investmentdecision-making as well as on environmental effects. LSHFO, MGO, and LNG are consideredin this research as HFO substitute fuels. LNG price estimates, which may be generated in oneof two ways—linked to the price of A crucial premise is the use of crude oil or an independent gas market. The parameters of the model are determined using historical pricing. Fuel prices are exogenous to the model, similar to Argyros et al. (2014), and this complexity in LNG price forecast underscores the need of coupling fuel pricing assumptions with the uncertainty associated with the supply and logistics of fuel. The future feasibility of many emission reduction technologies, according to DNV (2012), is strongly reliant on the price of different fuels and the relative price variations among them. The Environmental Protection Agency EPA (2008a) research developed a layout to look at the marine fuels market and petroleum refining sector. In this research, regional and global forecasts of the demand for marine fuels were estimated using a model of shipping activities. Based on trade commodity estimates, ship characteristics, and journey characteristics, the model of maritime activities anticipated futurefuel consumption.

Other researchers have addressed numerous offshore and aboard technology concerns whileconcentrating only on LNG as a shipboard alternative fuel. Semolina's (2013) ,Verbeek et al. (2011) have presented an example financial study for the development of LNG in the maritime world. Thetechno-economic assessments of this research included hypotheses about the price of ship investments and the logistical needs for LNG port infrastructure. The fact that both models found numerous aggregation types is important. Particularly, Verbeek et al. (2011) consideredthree different ship types: short sea vessels , port ships, and inland ships, while Semolinos (2013)considered prospective LNG supply logistics for medium to large ports at initial and extensive phases of development. These criteria highlight the need for greater accuracy when considering the The constraints and implications of the refueling technique Another study is GL (2011), which examined at the benefits and costs of using LNG as a fuel for container ships while accounting for the extra costs associated with LNG technology on different-sized ships or under different fuel price scenarios. This suggests that the price variations across ship types and sizes must be considered. As the last example, take Lloyds Register (2012) employed a top-down strategy to forecast the future LNG fuel use while taking trading patterns into account. refueling demand, and LNG supply availability difficulties. The demand for LNG was predicted using a model that took into account laws, the availability of LNG at major ports, and the placement of new structures along certain trade routes. Through a poll of shipowners and port administrations, input data was gathered.

This approach emphasizes the need of considering the viewpoints of both fuel providers and shipowners when determining if LNG or any other alternative fuel will likely be adopted. As was said, techno-economic modelling techniques have been used to study different possible fuels for shipping. When modelling the absorption of hydrogen in transportation, theseapproaches have specific criteria that help to identify important elements that a model should take into account. The Some of these issues are environmental and energy efficiency regulations, the cost and accessibility of fuel as a function of factors on logistics and supply chain, an acceptable the solution of the depiction of the refrigeration and refilling process, and adequate categorization of ships and voyages.

2.7 Current models for investigating hydrogen in other sectors

Numerous research has examined hydrogen as a potential future energy carrier using models.This thesis does not attempt to provide a comprehensive evaluation; rather, one may be found in Joffe and Strachan (2007), and Agnolucci and McDowall (2013). Different strategies have been used to address hydrogen in energy models. In Dagdougui (2012), a classification of models and methodologies is provided. This classification comprises plans for a more successful transition to the hydrogen economy, decision support systems based on geographic information systems, and mathematical optimization methods. Furthermore, Mixed Integer Linear Programming (MILP) models with precise representations of the hydrogen network on national and domestic scales were employed in Agnolucci and McDowall's (2013) discussion of optimization strategies.

Even though hydrogen in transportation has not been taken into account in these investigations, a number of insightful conclusions about the modelling representation of hydrogen may be drawn. Here, the difficulties of modelling hydrogen in such models are in especially the emphasis. There are several difficulties that must be considered in orderto offer a meaningful study of the potential paths for hydrogen development inside the modelling technique.

The depictions of the rivalry for primary energy supplies, the depiction of the geographical aspects of the development of hydrogen infrastructure, as well as the technical precision required to accurately display the multiple hydrogen pathways These issues are essentially model specifications that are necessary to: represent the geographic dependencies of hydrogen infrastructure based on facilities of local services, distribution distance, and flow rate include the availability of resource freshwater availability, potential competition on future demand and technology characterization of various resolutions (Joffe and Strachan, 2007).

2.8 Importance of hydrogen design representation in shipping.

With a focus on techno-economic modelling methods, previous research on the use of hydrogenin shipping have been evaluated. Other pertinent models have been investigated for their high-lighting qualities and effects on how hydrogen and alternative fuels are portrayed in transportation. The target system for the thesis is the absorption of hydrogen in transportation.According to Weisberg, the connection between the target system and the model must be madebefore taking the model's capability into account (2012). It is necessary to take into consideration the underlying idea of the earlier research that were examined while analyzing such a relationship. Assuming that the underlying theory is thorough enough, we may then pinpoint the characteristics that a model has to have in order to faithfully represent our intended system Hydrogen must be present on-board ships to accurately represent the technical designof hydrogen propulsion system in a model . likewise , if hydrogen can be used with fuel cells, all technical requirements such as fuel cell efficiency, power to weight ratio analysis , safety systems needed for hydrogen vessels, influence on cargo space and freight rate, and CAPE and OPEX costs should be represented.

A hydrogen-powered vessel would operate within the maritime routes, competing with other alternative and conventional traditional ships in a variety of shipping markets defined by trading route, operating needs, ship type, and ship size. The viability of a hydrogen-powered ship may also be influenced by other factors, such as changes in the demand for transportation and the nature of the marine regulatory system. This means that a transport system model should have a certain amount of data.

Since hydrogen must be available at port refueling facilities, the model should contain a depiction of the shipping hydrogen supply network. When simulating hydrogen generation, transit, and storage, a precise level of detail should be employed. The hydrogen supply chain of the global energy system would interact with it, competing for primary energy resources and supplying other sectors' needs. This implies that a model must have a sufficiently accurate depiction of the energy system. Finally, the cost of manufacturing hydrogen would have an impact on the demand for this fuel, and vice versa. A model, such as the one used by EPA, must represent the balance of supply and demand (2008a). In general, there are two basic kinds of models that describe hydrogen in the literature: energy models that place an emphasis on the modelling sectoral models and the hydrogen supply chain that prioritize the portrayal of hydrogen end-user technologies. These models vary from one another in principle, each of them is appropriate to represent hydrogen in transportation but does so in a different way depending on their objectives, system boundaries, and geographic size. Some ofthese models address issues with the optimal arrangement that maximizes a certain objective function while concentrating on local or national hydrogen supply infrastructure. Thesupply chain is covered in more technical depth in these studies, although many variables like energy resource availability and demand are aggressive in relation to the models These models are ideal for analysing the localization evaluation of hydrogen supply chain technology, such as the hydrogen refueling procedure at a specific location. Because the shipping sector is global, an aggregate at the global level of resolution is thought to be more accurate. Furthermore, these models frequently lack the necessary technical components.

hydrogen end-user technology, such as the rarity of hydrogen-powered ships. Additionally, they lack a model of the interconnections with the rest of the energy system and an economic analysis of end-user hydrogen technologies' market presence In contrast, some models contain a full depiction of the energy system, including simulations of the end-user technologies and the hydrogen supply networks. The system boundary (for illustration, just one sector or the total energy system) and the geographic size affect these models' degree of resolution (e.g. local, regional, global).A common purpose of such models is to growth and expanding Change scenarios in the energy system under certain emission reduction constraints (Schafer, 2012). Through the examination of such scenarios, the effects of hydrogen technologies on the energy system may be evaluated. On the one hand, these kinds of models accurately depict the energy system and provide sufficient technical information about the hydrogen supply chain. They, on the other hand contain a low degree of technical information about energy service demand and end-user technologies for hydrogen taljegard et al (2014), description of this sort of model, the whole as opposed to the energy model The shipping fleet was split into three types: container ships, ocean-going ships,and coastal vessel. Bottom-up energy modeling was used.

In contrast to the prior energy model addressed, hydrogen may Models created to mimic a specific industry may also include them. These models frequently priorities hydrogen end-user technology over supply chain technologies. These models are often used to analyze market penetration with precise economic assessments and may include a considerable degree of technical depth for hydrogen end-user technologies. There are several models for using hydrogen in the road transportation system in the literature, but there aren't many examples for using hydrogen in shipping. These models often lack an adequate degree of technical granularity about the energy system and the hydrogen supply chain. In conclusion, no current model can be regarded as indicative of the hydrogen uptake in shipping based on the given parameters.

They are seldom combined to examine the balance between supply and demand. Examples ofthese models are the Linear Programming Model and DEA-CCR. It may be possible to find ways to enhance the target system's representation by taking a careful look at these models.

The below review of the literature presents the DEA analysis with different fuels and their inputand output parameters.

The proposed method in this research is data envelopment analysis. DEA has been effectively employed as a performance evaluation technique in a variety of sectors., such as manufacturing, academic institution banks, pharmaceutical firms, small business development centers, and nursing home chains. Here, this method is used to rate bonds. DEA is a non-parametric way to comparethe efficiency of decision-making units (DMUs) that use more than one input to make more than one output. The main idea behind DEA is to find the best decision-making unit (DMU) output of all the DMUs.

The author explained about the DEA approach solves the financial ratio indicator to use different inputs to give a range of services (outputs). DEA analysis includes four models: CCR, BCC, Additive, and Slacks-based Measure (SBM). Although the other three models cannot tackle invariant units or negative input or output issues, the SBM model is used in this research to assess the shipping industry's debt-paying capabilities. The SBM model has the same efficiency value either evaluated in kilometers or miles and has the following significant properties: The measure is invariant with regard to each input and output item's unit of measurement, and it decreases monotonically in each input and output slack.

When numerous inputs and multiple outputs are available, DEA is often presented as a mathematical programming tool for assessing the relative efficiency of DMUs. While the notion of inputs and outputs is generally established, DEA may be considered as a multiple-criteria assessment approach in which DMUs are alternatives, and DEA inputs and outputs are two sets of performance criteria, one set to be lowered (inputs) and the other set to be maximized (outputs). These numerous criteria are commonly described as ratios in DEA.

The environmental and economic evaluations of LNG and diesel for a UK fleet operator are given. The vehicles evaluated were a SI LNG long-distance HGV and a diesel HGV, with theinput parameters being fuel characteristics and vehicle specs. To verify the methodology approach, a Large UK Food Retailer running both diesel and SI LNG HGVs was evaluated asa case study to assess the costs and GHG emissions associated with each vehicle type. Vehicleenergy efficiency was tested throughout long-haul duty cycles and used in both economic andenvironmental studies. As a result, these evaluations give a real-world estimate of the costs and GHG emissions suffered by a typical fleet operator in the United Kingdom, providing useful insights into the trade-offs that switching to LNG may bring to fleet operators.

The author developed a mechanism for connecting ship activities with parts of a data stream from a commercially accessible monitoring system in this research. Further study is then carried out to establish the ship's fuel-efficient performance. Although the strategy adopted applies to various ship types, the success of the case study on this basis demonstrates that the methodology is resilient. The findings of the data analysis are compared to fuel consumption statistics recorded under sea-trial circumstances to confirm the approach, and they are found to be in close agreement.

3. METHODOLOGY:

Data envelopment Analysis (DEA) is a decision-making technique used to identify the greatest efficiency of each DMU (Decision-making unit). The major goal of DAE analysis is to compare DMUs (alternatives) in terms of their efficiency when common inputs and outputs are considered. The multicriteria decision-making (MCDM) method utilizes a common set of weights to express the preferences of the decision-maker. In contrast, the DEA CCR model does not give a common set of weights that could indicate a decision maker's preferences. The weights in MCDM have no evident economic value, but their implementation allows for the simulation of real features of decision-making, including such preference structure. If we can understand DEA extensively, we can use it as an option for evaluating alternatives in MCDM. Data Envelopment Analysis (DEA) is a way to measure relative efficiency when there are several inputs and outputs. DEA provides efficient analysis of distinct DMUs that do not reliant on the common weighting of inputs and outputs. A multicriteria decision-making approach assumes that a common set of weights must be applied to all possibilities.

The primary goal of this research is to determine the efficiencies of various alternative transport fuels. DEA analysis is best suited since its main objective is to compare decision-making units (alternatives) based on their volumetric efficiency in transforming inputs into outputs. In contrast, the MCDM model employs weights that vary from unit to unit. DEA could be used as a pre-process in MCDM, screening alternatives when the decision maker is unable to articulate preferences at the start of the design process or development. In this research, we focused more on the efficiency analysis of various available shipping fuel options.

DEA analysis has been widely used in the shipping industry for analysing power plant eco-efficiency, capacity impact on liner shipping industries, port, and terminal optimization, and cruise liners industries.

(P.J Korhonen, M luptacik) use DAE analysis for finding out Eco-Efficiency analysis of 24 European power plants consider input functions cost, dust, NOX, SOX, and output function is power generation.

(V.Y.H lun ,P Marlow) DAE analysis use to evaluate the capacity performance of liner shipping industries, the result shows that firms have market share of less than 5% operate efficiently. Input functions used are shipping capacity, and operating cost, and output function is profit and revenue.

(Wilmsmeier 2013) use DAE analysis for evaluating the port and terminal operations in 10 countries input functions used are terminal area, labor, and quayside crane capacity output is total movements the results indicated the financial and economic shocks and its effect on port productivity.

The primary intention of the research project is to analyses the efficacy of fuels used in the shipping industry. During this research, many kinds of fuels, including MGO, Methanol, Ammonia, LNG, LPG, H2 Liquid, and H2 Gas, have been taken into account. To decide which of the many different types of fuel is best suited for use in the shipping industry, DEA Analysis is carried out by considering the numerous environmental and economic factors that are involved. In general, DEA works to minimize "inputs" and maximizes "outputs." To put it another way,higher levels of the latter indicate greater performance or efficiency, while lower levels of the former indicate better performance or efficiency. This may then serve as a guideline for categorizing different components under each of these two categories.

3.1 DEA Methodology

The DEA is a technique of linear programming that experimentally assesses the relative efficiency of many DMU, which are entities that are quite similar to one another developed by (Charnes et al., 1978). The DMU is the one entity that is accountable for the transformation of inputs into outputs in the system. In order to conduct DEA research, it is necessary to have a matrix that is made up of the inputs, outputs, and complementary parts of the sample of DMUs. The matrix is then incorporated in the model to be solved once the DEA model has been created according to a set of characteristics such as metrics and orientation. Therefore, relative efficiency scores and operational benchmarks for each DMU are obtained as the major findings.

The original DEA model of Charnels et al. [1] considers the situation wherein each of n DMUs, $j = 1,....., n$ is to be evaluated in terms of I inputs X_{ij} , $i = 1,..., I$, and R outputs Y_{rj} , $r =$ 1, , R . The inputs and outputs that characterize the performance of the DMUs (entities under evaluation) should properly reflect the "process" under study [2]. Inputs (resources) and outputs (outcomes) should be selected in such a way that they allow for benchmarking the performance of a set of entities in each framework. Specifically, in applying the DEA methodology, one must decide whether the purpose is to minimize inputs or maximize outputs; smaller levels of the inputs and larger levels of the outputs define a better performance or efficiency.

Taking this rule for classifying the measures from the processes, it is possible to handle two approaches, as previously mentioned, namely the input-oriented or output-oriented model. In the former approach, inputs are minimized, and outputs are kept at their current level; in the later, outputs are maximized, and the inputs are kept at their current level. The conventional output-oriented model can be expressed as the solution to a fractional programming problem:

$$\min e_0 = \frac{\sum_{i=1}^{I} v_i x_{io}}{\sum_{r=1}^{R} u_r y_{ro}}$$

Equation 1: equation for fractional programming problem

Subject to:

$$\sum_{i=1}^{I} v_i x_{ij} \geq 1, \; j = 1, 2,$$

$$\sum_{r=1}^{R} u_r y_{rj}$$

Equation 2 : alternative fuel options with different DMU

$$v_i, u_r \geq 0$$

The subscript "o" in the objective function identifies that DMU (i.e. DMUo) is currently under evaluation. Along the same line, xio and yro denote the i-th inputs and r-th outputs for each DMU, respectively. Additionally, vi and ur are the weights or multipliers applied to the inputsand outputs, respectively. By obtaining the weights, it is possible to compute the ratio and getthe efficiency score for that DMU. The subscript j will take the values from 1 to n, corresponding to the DMU numbers.

In Model (1), which is under the output-oriented approach, the efficiency of a specific DMUoas a member of a given set of n DMUs is calculated subject to the condition (constraints) that each member's efficiency rating (when using the same set of weights) must not be less than unity. This condition ensures that the efficiency ratings are greater than or equal to one, with 1representing the most efficient score. (Cooper, Thore et al. 2010) This condition consists of n individual constraints in theform of ratios of weighted outputs to weighted inputs. This model will be run n times (one foreach DMU) to arrive at the efficiency scores for all the DMUs [2].

In model (2), the input and output multipliers vi and ur, are the decision variables. This modelis referred to as the DEA multiplier model. The objective function seeks to minimize the weighted sum of the inputs for DMUo under evaluation. The first constraint can be viewed as a normalization condition, while the second set of n constraints specify that the weighted inputs for each DMU j cannot be less than the weighted outputs for that DMU. Finally, the multipliers are restricted to be non-negative.

For the purposes of the DEA, observations are gathered for a limited number of organizations that are referred to as decision-making units (DMUs),

Bouysou (1999) The following procedures will subsequently be required to develop a typical DEA model:

- Identifying on the input and output variables
- Optional optimization orientation—input minimization vs. output maximization (in the current volume, output maximization is commonly assumed);
- A possible weight limit.

- The implementation of cross-sectional or longitudinal studies.

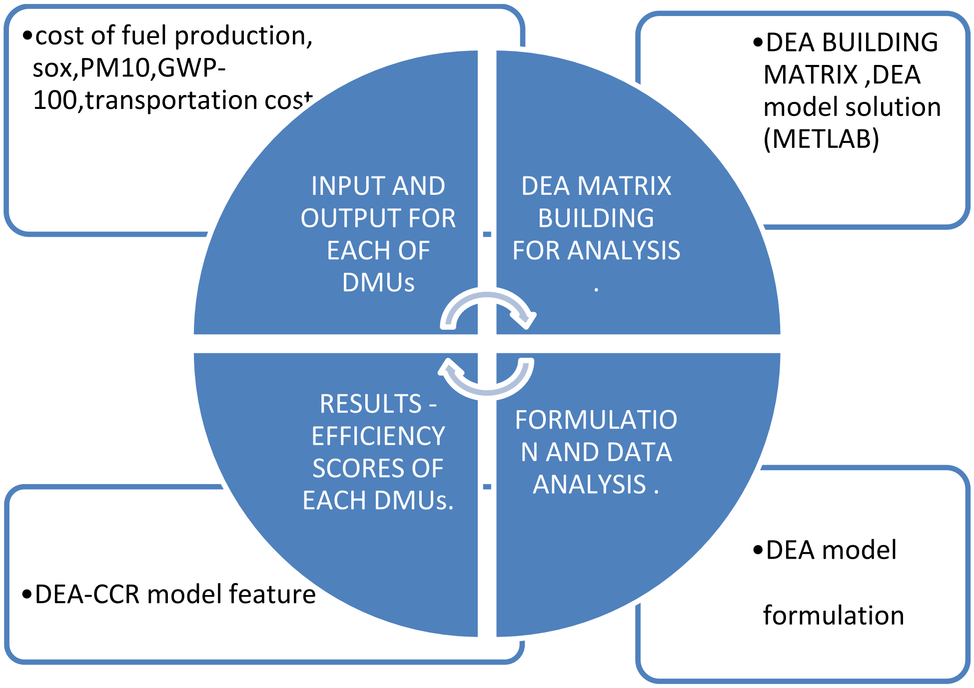


Figure 1:Detailed DEA-CCR methodology analysis description.

The efficiency ratings provided by DEA as well as the envelopment frontier are accurate since they are derived from actual observation rather than from guess.

- DEA can make use of numerous outputs and multiple inputs at the same time, with each one being scaled according to its own units.
- The DEA may be modified to account for the existence of exogenous factors, and it can take categorical variables into consideration.
- Calculations using the DEA do not consider values and do not need the definition or any priory weights or prices for either the inputs or the outputs.
- The DEA does not make any assumptions about the functional nature of the link between production and transformation.
- DEA can accept personal judgments, and managerial inputs.

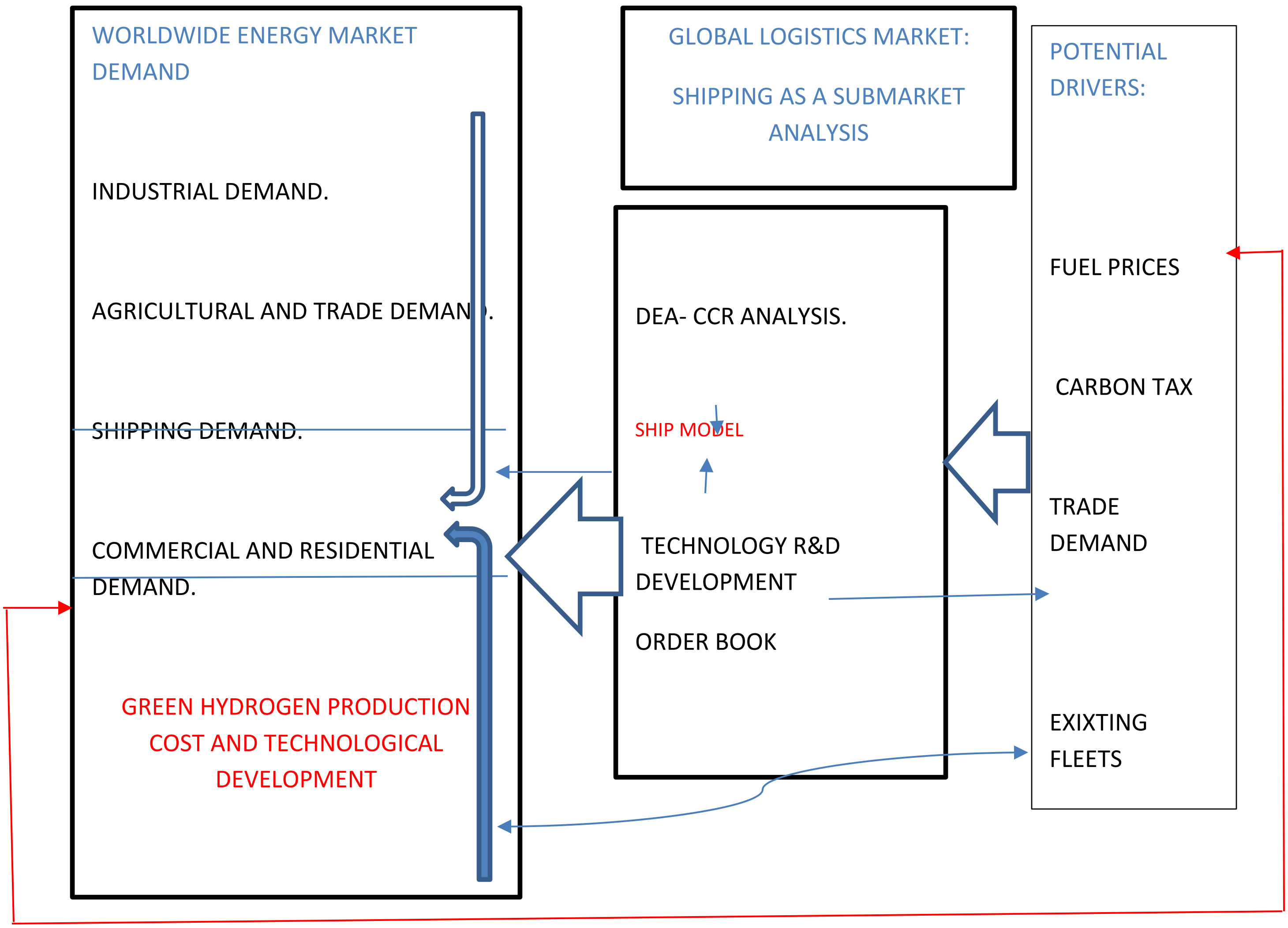


Figure 2:Overview of factors influencing green hydrogen development in world-wide energy market.

3.2 GWP100:

Greenhouse gas emissions (GHGs) are defined in this study as the release of carbon dioxide (CO2) into the atmosphere by the European Commission (European Commission, 2021). They are given in terms of equivalent CO2. GHGs' 100-year Global Warming Potential (GWP100) is sometimes stated in terms of CO2 equivalents. The GWP100 values of GHGs produced by different fuels are referred to (Lindstad et al., 2020).

Row Labels	Sum of GWP100 CO2 equivalent in g KWh
'MGO'	541
'Methanol'	533
'LPG'	500
'LNG'	492
'Ammonia'	102
'H2 Gas'	27.5
'H2 liq'	27.5
Grand Total	**2223**

3.3 SOx and PM10:

The values of sulfur oxides (SOx) and particulate matter (PM10) released by ships are determined using emissions data.

Alternative fuels	Sum of KWh	Sum of Value of PM10 generated g KWh
'MGO'	0.36	0.23
'Methanol'	0.1	0.074
'LPG'	0.1	0.074
'LNG'	0.1	0.074
'H2 Gas'	0.01	0.011
'Ammonia'	0.01	0.074
'H2 liq'	0.01	0.011
Grand Total	**0.69**	**0.548**

Table 1:PM 100 generation for unit gram Kwhr by different grades of fuel. (source: (van Lieshout et al., 2020), (MAN Energy solutions, 2020)

3.4 Emissions:

The primary reason for using alternative energy sources is to reduce carbon emissions. However, if these emissions are not measured over the duration of the fuel's entire life cycle, the post-combustion emission levels will be grossly underestimated (EU Commission, 2020). The following emissions (NOx, Sox, PM10, and CO2) are associated with the fuel its lifecycle analysis.

Well-to-tank: Emissions released during the production of fuel, fractional distillation process.

Well–to–propeller: Emission related to combustion of fuel for propulsion of ship Because natural energy resources are not equally disturbed on Earth, well-to-propeller emissions must be considered when analyzing different grades of fuel. Transporting these energy sources will eventually increase carbon emissions.

3.5 Well-to-propeller GHG analysis

The WTP system is divided into two stages: a) the Well-to-Tank (WTT) phase, which comprises fuel recovery, processing, liquefaction (LNG only), distribution, and storage, as well as vessel refueling) the Tank-to-propeller (TTP) phase, which accounts for the ultimate use of the fuel in ships engine. Because the only difference between diesel and LNG ships is the kind of tank used for fuel storage, they were believed to have the same embodied energy. Furthermore, it has been demonstrated that fuel alone accounts for more than 80% of total emissions associated with the transportation system (Nahlik et al., 2016), hence it was agreed that vehicle and infrastructure construction and decommissioning should be neglected.

Several distinct types of fuels, including MGO, Methanol, Ammonia, LNG, LPG, H2 Liquid, and H2 Gas, are taken into consideration in this study.

3.6 Ammonia

Although ammonia as a marine fuel seems promising, adoption will need to be phased out (Niels de Vries, 2019):

- First, as an ICE with MGO as a pilot fuel, and subsequently as an ICE with ammonia-hydrogen combinations.

- Third, as a solid oxide fuel driven by ammonia.

When all possibilities for producing ammonia electricity are reviewed, the Solid Oxide Fuel Cell (SOFC) is the most efficient. However, since the power density and load response capabilities are not yet at an acceptable level, it faces practical obstacles.

3.7 Liquefied Natural Gas (LNG)

LNG is one of the cleanest fossil fuels accessible today, with practically 0% Tier III emissions will need the adoption of an exhaust gas recirculation system (EGR) or a selective catalytic reduction system (SCR). The potential for LNG to reduce emissions by roughly 75% is much greater than that of existing fossil-based LNG, but the technology must evolve before it becomes an appealing choice for shipowners.

3.8 Liquefied Petroleum Gas (LPG):

LPG is a liquid combination of propane and butane. Because of its high boiling point, conventional butane is difficult to utilize in colder climates. As a result, complete To use LPG as a fuel, propane or a propane-rich mixture of propane and butane will be required.

When compared to residual fuels, CO2 emissions from LPG burning are lower. This is responsible for the low carbon-to-hydrogen ratio. However, Emissions of nox vary depending on the engine technology.

3.9 H2 Liquid

As a low-flashpoint fuel, hydrogen is governed under the International Code for the Safety of Ships Using Gases or Other Low-flashpoint Fuels (IGF Code). The present IGF code does not contain any hydrogen rules.

Due to a lack of demand, there is presently no bunkering infrastructure for hydrogen-powered ships. Pressurized containers (350 bar or 700 bar) are utilized for minor inland vessel applications powered by fuel cells. There are additional 40-foot liquid hydrogen canisters with a capacity of 3600 kg of hydrogen.

Fuel cell technology has made major advances. With its high energy density, the solid oxide fuel cell has a lot of promise in marine applications (Terün, 2020).

3.10 Methanol:

Because methanol exists as a liquid at room temperature, its storage and handling are comparable to those of traditional fuel oils. The IBC code, which was established for chemical tankers, includes expertise in handling and storage. The only modifications required are a unique Zinc coating for existing tanks and tank vapor vacuum inert gas.

Although the use of methanol shows encouraging levels of technical readiness in various domains, progress toward mainstream use would be delayed by several economic, regulatory, and sustainability challenges.

4. RESULTS & DISCUSSION

In this work different kinds of fuels such as MGO, Methanol, Ammonia, LNG, LPG, H2 Liquid, H2 Gas are considered. In order to identify the best among all the fuel types for the shipping industry, DEA Analysis is carried out by considering the economic and environmental factors involved.

Green hydrogen is thought to be created locally from several renewable sources, while the remainder of the alternative fuels will be imported from Fujairah (UAE). This will result in additional transpiration and inventory handling costs, as well as indirect CO2, SOX, NOX, and PM 10 emissions.

The influence of these hidden costs, as well as indirect emissions, are evaluated in this research to perform an extensive DEA Analysis.

4.1 Well-to-propeller analysis:

The below table shows the number of days required for a cargo ship to reach from source to bunker location with a speed of 13knots along with voyage consumption.

DESTINATION	DAYS REQUIRED	SPEED	TOTAL CONSUMPTION
ROTTERDAM	19	13	475
LOS ANGELES	38	13	950
HONGKONG	15	13	375
SINGAPORE	12	13	300

Table 2 : Days of sailing from Fujairah to different destinations with total consumption.

For DEA analysis, we assume the VLSO as bunker fuel for alternative fuel transportation, and these oil tankers will return in ballast voyage from destination ports to Fujairah, leading to increased sox, NOx, and carbon emissions.

Row Labels	Sum of days Required	Sum of total consumption
Los angles	38	950
Rotterdam	19	475
Hongkong	15	375
Singapore	12	300
Grand Total	**84**	**2100**

Table 3: loaded and ballast voyage number of days of sailing and total consumption.

Factors	Fujairah to Rotterdam	Fujairah to Los angles	Fujairah to Hongkong
Destinations	Rotterdam	Los Angeles	Hongkong
Daily Consumption	552055.55	1140111.11	435833.33
production cost	517341.5	1034683	408427.5
GWP100 CO2	313567555	627135111	247553333

Table 4: Production cost of VLSFO and generated quantity of GWP100 carbon dioxide.

The above table depicts the overall emissions of greenhouse gases with production and handling associated costs with these alternative fuels; a considerable distance between source to destination will results in much more emissions as well as higher shipping and manufacturing costs. By performing a detailed DEA analysis, we could see that green hydrogen has an advantage in this scenario because it reduces the unwanted emissions generated by alternative fuel transportation, which lowers the well to propeller emissions.

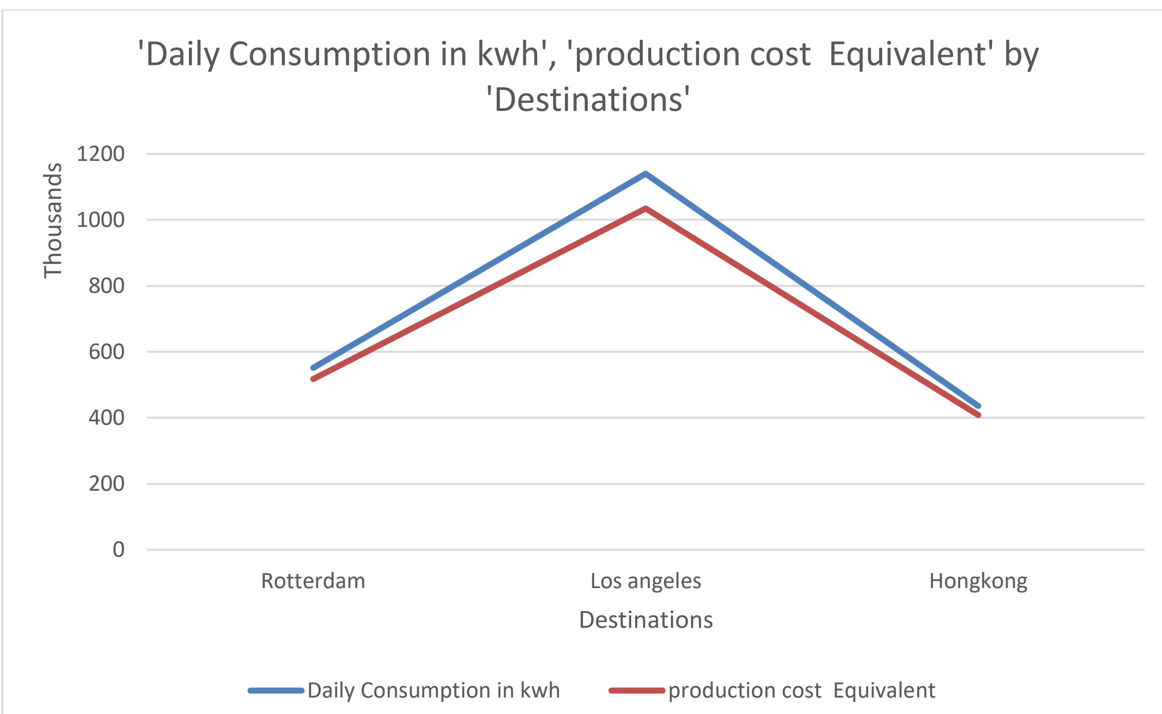


Table 5 : daily consumption and production cost Equivalent for VLSFO.

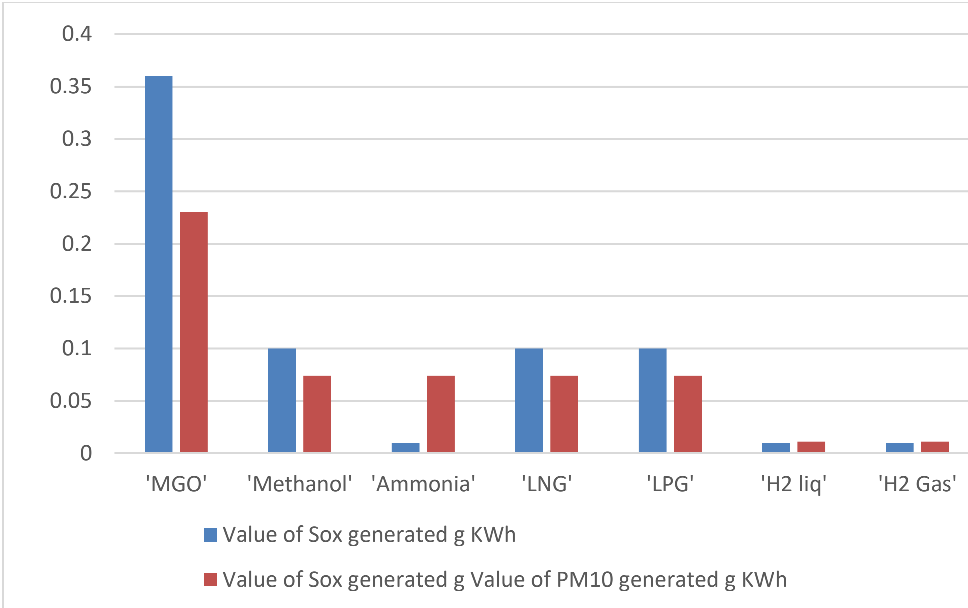


Table 6: Sox and PM 10 generation for different grade of marine fuels.

The values of Sox generated, and PM10 generated per kwh is visualized in the above figure with type of fuel in x-axis and values of Sox and PM10 generated values in y-axis. It is observablethat H2 gas and H2 liquid emits a minimum value of SOX and PM10 than the other fuels. MGO have high values of Sox generated g KWh and, the Sox value created g KWh, and the PM10 value generated g KWh.The values of Sox generated g kWh and value of PM10 generated g kWh for every fuel type is tabulated below.

Fuel type	Value of Sox generated gram KWh	Value of PM10 generated Gram KWh
'MGO'	0.36	0.23
'Methanol'	0.1	0.074
'Ammonia'	0.01	0.074
'LNG'	0.1	0.074
'LPG'	0.1	0.074
'H2 liq'	0.01	0.011
'H2 Gas'	0.01	0.011

Table 7: value of Sox and PM 10 generated in gKwhr . source :lieshout et al , 2020

From the above figure H2 Gas and H2 Liquid emits low GWP100 CO2 Equivalent than otherfuels. ammonia also produce a reasonable amount of GWP100 CO2. MGO and methanol have high GWP100 CO2 equivalent in g kWh. The values for every fuel type is tabulated below.

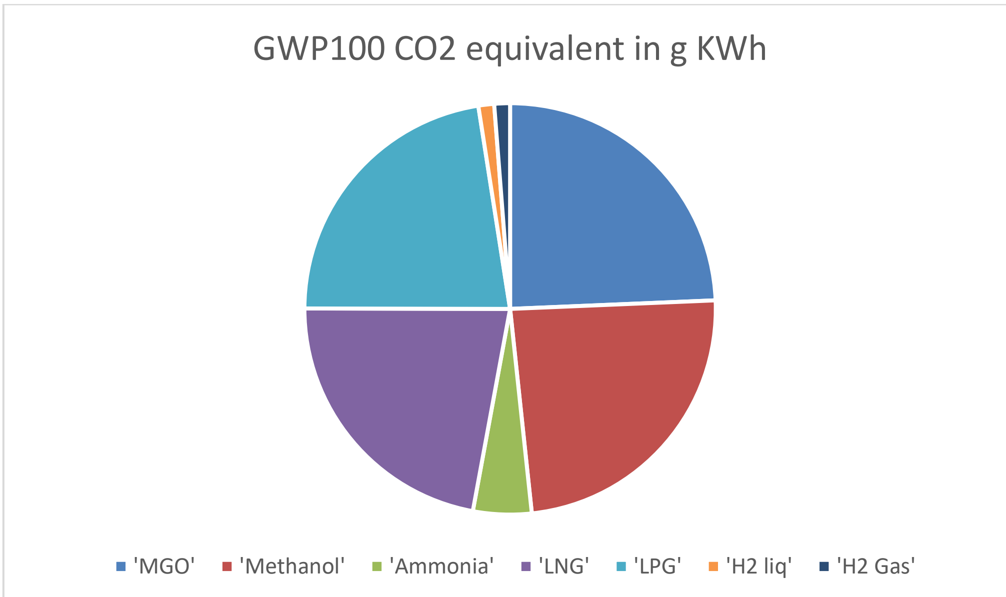
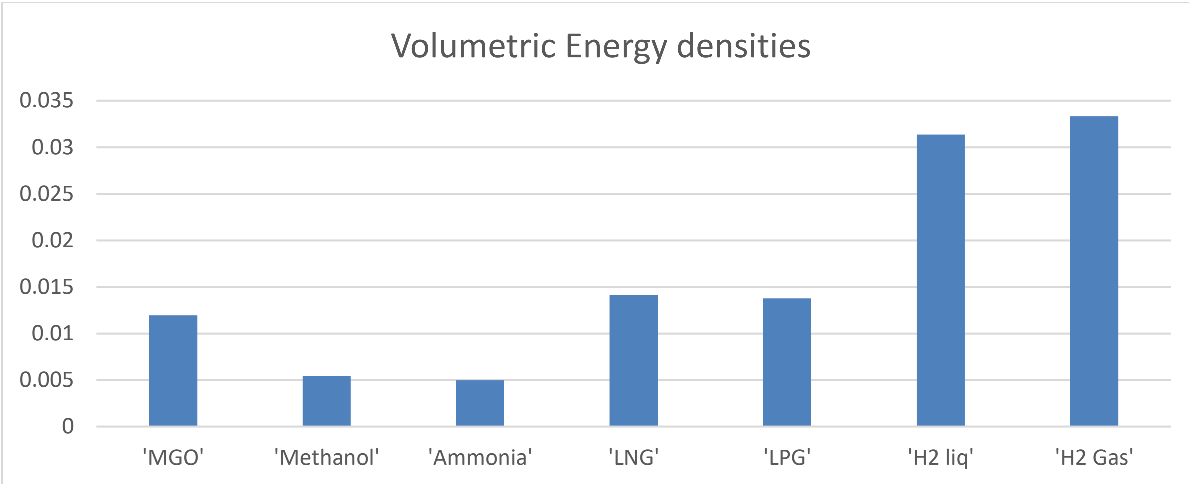


Figure 3:GWP100 Co2 Equivalent in gKWhr.

Fuel type	GWP100 CO2 equivalent in g KWh
'MGO'	541
'Methanol'	533
'Ammonia'	102
'LNG'	492
'LPG'	500
'H2 liq'	27.5
'H2 Gas'	27.5

Table 8: GWP 100 CO2 equivalent in gram KWhr.

4.2 Volumetric density comparative analysis for alternative fuels:



source: (Lindstad et al., 2020) and (ABS, 2021c)

The Volumetric energy densities of all the fuels are shown in the above figure with the x-axis being the fuel type and the y-axis being the densities of volumetric energies. It is observable that H2 Gas, and H2 Liquid hold the maximum volumetric energy density than the other fuels. Ammonia and Methanol have low volumetric energy densities. The values for every fuel type are tabulated below.

Fuel type	Volumetric Energy densities
'MGO'	0.011944
'Methanol'	0.005422
'Ammonia'	0.004967
'LNG'	0.014146
'LPG'	0.013778
'H2 liq'	0.031365
'H2 Gas'	0.033333

Figure 4: volumetric energy densities function

source : authors compilations

From the above figure volume required for ammonia to generate 1000 kWh is higher than theother fuels such as MGO, Methanol, LNG, LPG, H2 liquid, and H2 gas. It is observed that methanol has high volume required to generate 1000 kWh. For every fuel type the volume required to generate 1000 kWh is tabulated below.

Fuel type	Volume required to generate 1000 kWh
'MGO'	83720.86326
'Methanol'	184418.6047
'Ammonia'	201333.3333
'LNG'	70689.65517
'LPG'	72580.5871
'H2 liq'	31882.47449
'H2 Gas'	29999.976

Table 9:volume required to generate 1000 kwhr

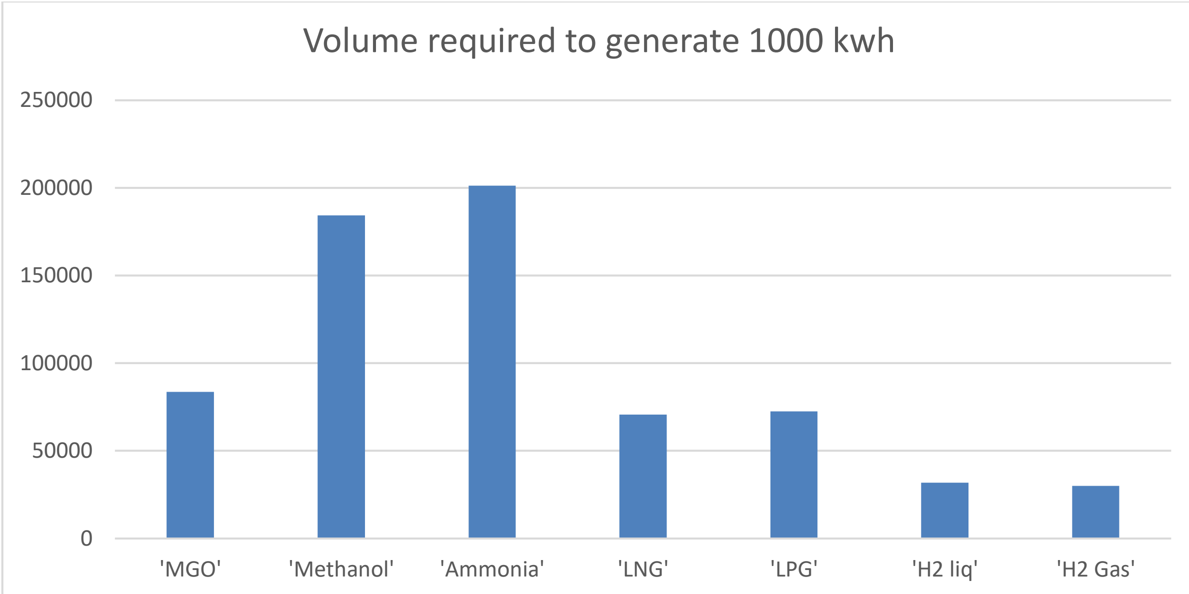


Figure 5: volume required to generate 1000 Kwhr.

The per gram cost of all the fuels except H2 Gas is given in the above figure as it is because the cost of H2 Gas is 0.38 Euro per liter and its density is 0.0899 gms per liter which makes its per gram cost equals to 4.2269 euros per gram, highly expensive than other alternative fuel options. That's why hydrogen gas is removed from the efficiency analysis of fuels.

Fuel type	Per gram cost
'MGO'	0.000455
'Methanol'	0.000459
'Ammonia'	0.00325
'LNG'	0.000793
'LPG'	0.000918
'H2 liq'	0.005505

Source: authors compilation.

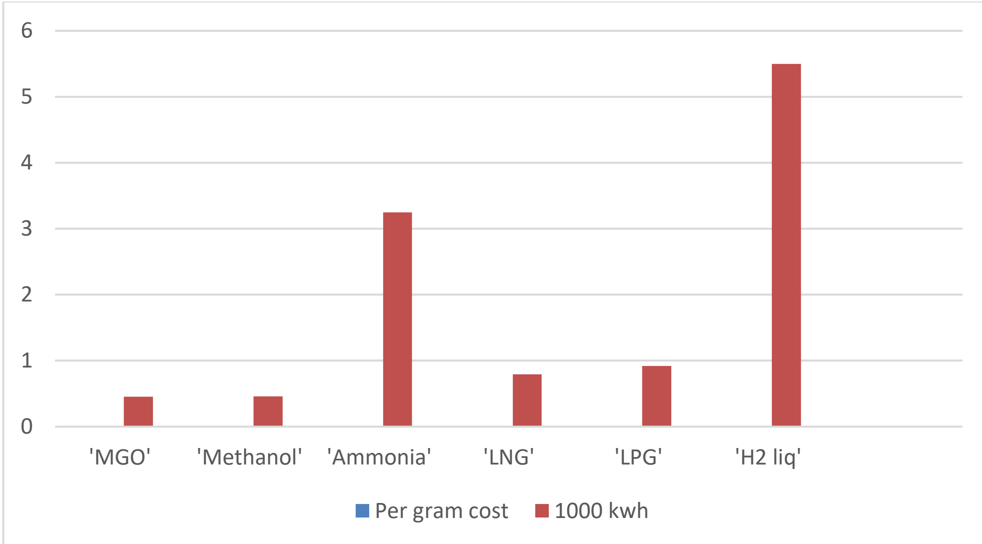


Figure 6:cost of different grades of fuel for production of 1000 Kwhr.

The cost per 1000 kWh is displayed in the above figure with x-axis being the fuel type and y-axis being the value in Euros. Figure 7 indicated that the price of producing ammonia and liquid hydrogen to produce 1000 kwhr of power is relatively high compared to alternative fuels. Hydrogen production development and logistics are in the initial stages, and it will require more investment and research to lower the production cost of liquid hydrogen. The cost per 1000 kWh is tabulated below for a particular fuel type.

Source: authors compilation

Fuel type	Per 1000 kwh
'MGO'	38.09299
'Methanol'	84.65116
'Ammonia'	654.3333
'LNG'	56.03448
'LPG'	66.64636
'H2 liq'	175.4999
'H2 Gas'	130144.5

4.3 DAE efficiency analysis for different alternative marine fuel:

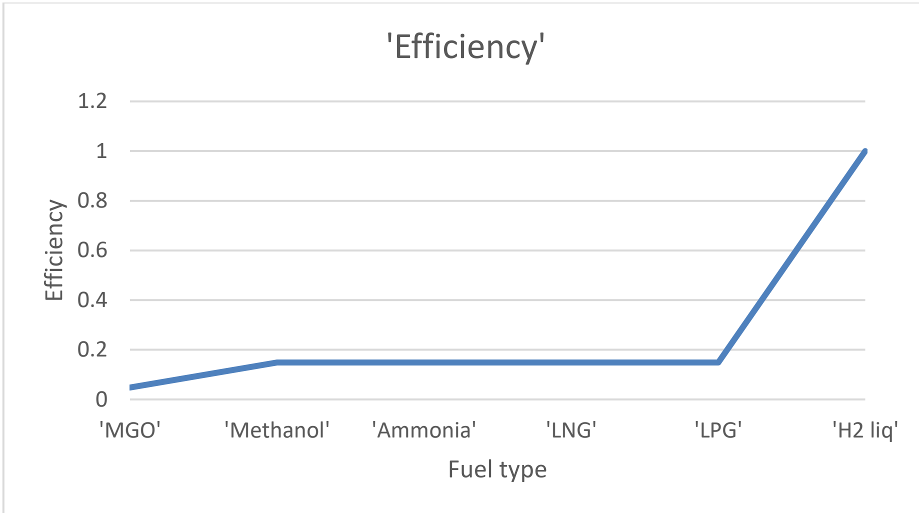


Figure 7:volumetric energy efficiency analysis.

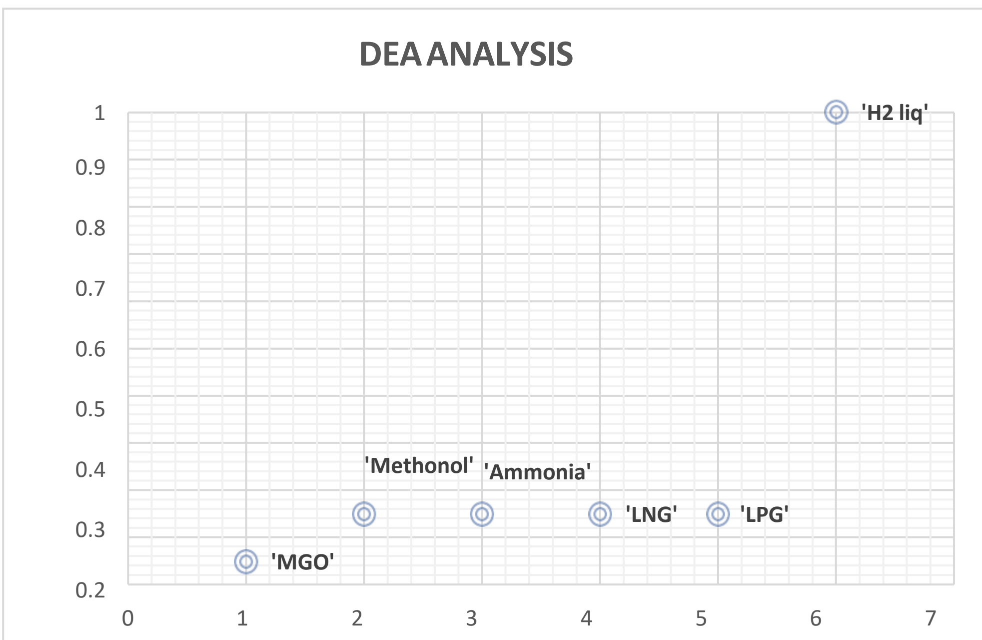


Figure 8:DEA analysis for alternative marine fuel

Total 'Efficiency' by 'Fuel type'

Row Labels	Sum of Efficiency
'MGO'	0.047826
'LNG'	0.148649
'LPG'	0.148649
'Methanol'	0.148649
'Ammonia'	0.148649
'H2 liq'	1
Grand Total	**1.642422**

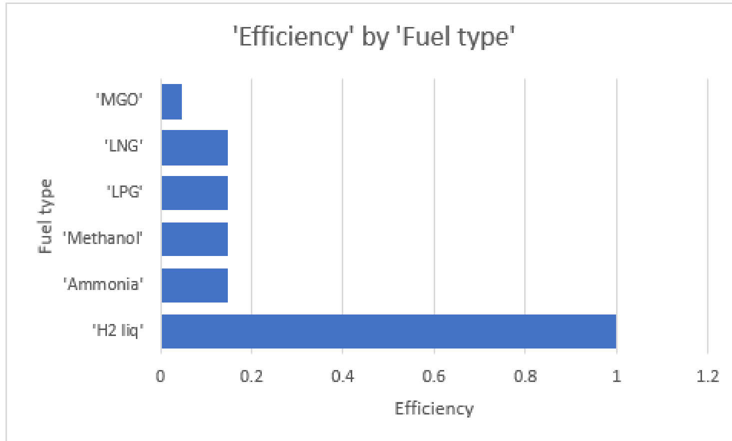


Figure 9:efficiency by fuel type.

4.4 Hydrogen production on vessels by Electrolysis of purified seawater, energy needed for electrolysis.

In this section, we attempt to conduct a technical viability analysis of a hydrogen production system on a vessel, however we do not account for mechanical and frictional energy losses. Conventional ocean-going cargo vessels have freshwater generators on board that really can produce 25 to 30 tons of natural water per day with a purity of around 1 ppm. The produced water requires further purification and salt removal by reverse osmosis. The system proposed in the study is the Energy Observer 2 ship system, where produced fresh water is passed through electrolysis and produces hydrogen and oxygen.
H2 is used in the boiler for moderate combustion and produce saturated steam, which is used to power four auxiliary steam-driven generators (1500 KW each) and one main steam-driven turbine engine for propulsion (10,000 kw).

Fresh water has a specific quantity of salt and minerals that must be removed using a reverse osmosis membrane filter to reduce the conductivity of the water to 3 uS / cm. Fresh water has a specific quantity of salt and minerals that must be removed using a reverse osmosis membrane filter to reduce the conductivity of the water to 3 uS / cm.

Water Electrolyser,

Inside the electrolyser cell, hydrogen is produced on the cathode and oxygen is produced on the anode during in the electrochemical processes.

Anodic reaction: $H2O \rightarrow 2H+ + 2e- + 1/2\ O2$ ---1

Cathodic reaction: $2H+ + 2e- \rightarrow H2$ ---2

Generic reaction: $H2O \rightarrow H2 + 1/2\ O2$ (Energy needed: 237 KJ)--------------------------3

Daily production of Hydrogen on vessel:

237kj of energy is required to produce 2 g of hydrogen. Energy observer 2 does have a total auxiliary power capacity of roughly 6000 kw. The energy available for electrolysis is 21600000 kilojoule/hour. The energy required to make grams (g of hydrogen is approximately 91,140 Kilo joule, and the total amount of hydrogen produced per day is approximately 183 kg.

If necessary, produced hydrogen is extracted, compressed, and stored in a hydrogen pressure vessel; alternatively, directly produced hydrogen can be burned inside the boiler using a controllable ignition process to produce superheat steam, which is used to drive auxiliary power and main steam engines.

5. CONCLUSION:

The main aim of this work is to evaluate the efficiency of fuels in the shipping industry with economic and environmental aspects. Several distinct types of fuels, such as MGO, Methanol,Ammonia, LNG, LPG, H2 Liquid, and H2 Gas, are taken into consideration in this study. DEA Analysis is carried out by taking into consideration the many economic and environmental considerations involved in order to determine which of the several kinds of fuel is optimal foruse in the shipping sector. In this study, we calculated the efficiency for each and every fuel byusing input and output parameters. In general, DEA works to minimize "inputs" and maximizes"outputs." To put it another way, higher levels of the latter indicate greater performance or efficiency, while lower levels of the former indicate better performance or efficiency. In this study, Daily consumption, production cost, number of days required, per gram cost, per 1000 kwh is evaluated to know the efficiency. finally, we concluded that H2 liquid produces maximum efficiency compared to the other fuels.

The discovery of hydrogen as a feasible alternative for a significant drop in emissions demonstrates that LNG, ammonia, Methanol, and MGO is not a long-term decarbonization solution; rather, adoption of a In order to reach the aims of decarbonization, a carbon free fuel such as hydrogen is required. However, because other potential marine fuels like biofuels and other synthetic fuels are not included The only low-carbon fuel is hydrogen. Considered in the marine fuel portfolio. Only when carbon taxes are high or production costs are low will hydrogen become a commercially viable future shipping fuel., therefore any low-carbon fuel might be adopted by the industry as long as it offers a competitive advantage over fuels with high carbon content in terms of price and carbon price. In other words, the high cost the cost of any low-carbon fuel as relation to fossil fuels might theoretically be offset by carbon pricing.

It seems increasingly difficult to predict the cost and availability of low-carbon fuels in the future, as well as their upstream emissions This is a disadvantage of the a fore mentioned interpretation because the supply of these fuels must be incorporated in the DEA analysis in analyses the total consequences of using energy sources for their production and distribution.

To establish a global hydrogen infrastructure for shipping, investments would likely need to be made soon, according to the predicted consumption of hydrogen from 2030. The supply infrastructure may be significantly impacted by this circumstance. Investing in LNG infrastructure could not be entirely justified since LNG ships might lose their competitiveness after a very short time (after 2030). Investments made now are crucial for shipping since both the infrastructure and the ships themselves have lengthy average lives (approximately 20 years).

In practise, it is probable that the configuration of an infrastructure will alter according to distinct local conditions, especially when port-level considerations are taken into account. The depiction of hydrogen commerce within areas is another factor that might restrict the conclusions that were previously provided. Since it is believed that hydrogen Production While the energy sources used to make hydrogen can be sold globally, trade in hydrogen is not permitted. However, this may not be the case as hydrogen may be generated where it is more practical and exchanged into areas where it will be in demand. The infrastructure on board ships also has an impact on the choice of alternative fuel. This thesis also notes that the need for space for a liquid hydrogen storage system has financial repercussions. These cost consequences may be significant depends on the size of the ship For tiny ships, for instance, the need for space may have a big effect on the ship's economics. Such things to think about apply to any alternative fuel, not only liquid hydrogen. The properties of the fuels and related storage systems crucial since they may result in various technological design solutions that might alter the cost implications. it is more probable that not all routes will switch to hydrogen. That's the final assessment for hydrogen infrastructure. The infrastructure development could begin with just a few key routes where hydrogen is most affordable and has the fewest upstream emissions.

The basic premise was that, during 2030 and 2040, the shipping industry could buy CO2 offsets without competition from other industries, and that other businesses could invest in renewables to make CO2 offsets more inexpensive. This concept served as the foundation for the decarbonization of the maritime sector at the time, as a significant number of CO2 offsets were acquired. This condition may necessitate the shipping industry making allies with other industries or localities in order to provide access to such a large amount of money during this period.

If hydrogen is selected, the shipping industry will need to cooperate with other stakeholders, particularly port authorities, to ensure that hydrogen infrastructure at ports is supported. In order to enable a competitive pricing, the hydrogen supply business may also be interested in agreeing to contracts with transportation companies. For instance, the price of hydrogen can be matched to that of conventional marine fuel in the initial stages before a global infrastructure is built, meaning that the price is not necessarily based on the supply and demand balance, but rather on the anticipation that such a fuel will be adopted by shipping. Finally, beyond 2030, shipping may compete with other modes of transportation for hydrogen utilisation. particularly with buses and trucks. This suggests that future maritime access to hydrogen may benefit from integration and cooperation with these modalities. Due to hydrogen's poor volumetric energy density, this has two ramifications for costs and physical space needs. The robustness study conducted for this thesis has already shown that a modification in these assumptions may have a considerable impact on the absorption of hydrogen. Therefore, hydrogen storage is seen as a crucial component. If hydrogen is ultimately selected, the shipping sector may be interested in working with hydrogen storage companies to make sure that this technology is made accessible for maritime applications. This thesis emphasizes important conclusions to policy makers and EU legislators, which has sparked discussion about potential future policies that might enable the decarbonization of the industry and its future contribution of global CO2 emissions, Contrarily, the adoption of a goal that permits a proportionate rise in the price of carbon made hydrogen a realistic alternative for a significant emissions reduction, that maintained the future share of shipping emissions at or near the current level. This suggests that, from a policy standpoint, setting a goal should be a top priority to on the notion that all other sectors will achieve more than equal burden sharing avoid relying on the notion that all other sectors will achieve more than equal burden sharing.

The primary objective of this research project is to assess the efficacy of fuels used in the shipping sector from both an economic and an ecological perspective. In the course of conducting this research, a number of unique kinds of fuels, including MGO, Methanol, Ammonia, LNG, LPG, H2 Liquid, and H2 Gas, were taken into account. For the purpose of determining which of the many different types of fuel is most suitable for use in the shipping industry, DEA Analysis is carried out by taking into account the many different economic and environmental factors that are involved. Throughout the course of our investigation, we determined the efficiency of each and every fuel by using a variety of input and output factors. In general, the DEA strives to reduce "inputs" while simultaneously increasing "outputs." To put it another way, higher levels of the second indicator imply better performance or efficiency, but lower levels of the first indicator suggest better performance or efficiency. In order to determine the efficiency, this research analyses the following variables: daily consumption, production cost, number of days necessary, cost per gram, and cost per 1000 kilowatt hours. In the end, we came to the conclusion that liquid hydrogen generates the highest efficiency compared to the other fuels.

In a market setting where freight transportation has evolved into the most unstable and expensive part of many enterprises' supply chain and logistics operations, the container system is gradually attaining maturity. In addition to dealing with trade imbalances, increasing energy costs, complicated security challenges, and transportation system delays, managers also have to cope with labor and equipment shortages.

5.1 Recommendations for further research:

The constraints and concerns expressed by this thesis require further discussion, generating a series of research suggestions. Four factors could be used to cluster these.

1)Additional input and output variables in present DEA, linear programming model

The Data envelopment analysis Optimization Method could be extended to include a variety of potential elements that could strengthen the modeling depiction of the interactions of alternative fuels and to make this assessment more realistic and accurate, additional input/ output factors might well be added to the interpretation DEA model systems.

2) other modes of transportation can be added to this analysis:

As previously stated, power system simulations are much less useful whenever the main objective is to examine technology diffusion. As a result, alternative means of transportation may not decarbonize as expected, which might have several consequences, including the likelihood that Carbon dioxide In the short run, offsets may not be as easily available as advertised.

3)Technological development in propulsion system:

Although there are several other hydrogen storage techniques that can be used in marine applications, only the liquid hydrogen fuel system is considered in this thesis. The fuel cell installation and equipment is another technology that is projected to be available for delivery. although there is currently no a fuel cell system with enough energy to function as a propulsion engine for huge ships. Even if we are able to build it, the space required aboard to install these fuel cells will be a worry because these the cargo carrying capacity of the vessel will be reduced due to the use of fuel cells. The use of such technologies, as well as their prospective capital expenses, in the maritime environment, pose a serious threat. Since hydrogen is a highly flammable gas, storing it on board can also pose a possible fire hazard. Those possible causes can be examined further. Technology development in ship design to produce hydrogen on onboard and consume it for the propulsion system. Opex and capex for associated equipment can be analyzed and assessed.

6. REFERENCES:

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7. Appendix: (MATLAB code)

```
clc; clear
all;
   SOx_PM10_GWP100=table();
   SOx_PM10_GWP100.Fueltype={'VLSFO','MGO','Methonol','Ammonia','LNG','LPG',...
      'H2 liq','H2 Gas'}';
   SOx_PM10_GWP100.Value_of_SOx_generated_g_KWh=[2;0.36;0.1;0.01;0.1;0.1;0.01;0.01];
   SOx_PM10_GWP100.Value_of_PM10_generated_g_KWh=[0.74;0.23;0.074;0.074;0.074;0.074;0.0
   11;0.011];
   SOx_PM10_GWP100.GWP100_CO2_equivalent_in_g_KWh=[568,541,533,102,492,500,27.5,27.5]';
   figure;
   bar([SOx_PM10_GWP100.Value_of_SOx_generated_g_KWh(2:end),SOx_PM10_GWP100.Value_o
   f_PM10_generated_g_KWh(2:end),...
      ]);
   xticklabels(SOx_PM10_GWP100.Fueltype(2:end))
   ylabel('g/KWh');
   grid on;
   legend('Value of SOx generated',...
      'Value of PM10 generated');
   %%
   figure;
   bar(SOx_PM10_GWP100.GWP100_CO2_equivalent_in_g_KWh(2:end),'g');
   xticklabels(SOx_PM10_GWP100.Fueltype(2:end));
   grid on;
   legend('GWP100 CO2 equivalent');
   ylabel('g/KWh');
   %%
   %Volumetric_energy_densities
   Volumetric_energy_densities=table();
   Volumetric_energy_densities.Fueltype={'VLSFO','MGO','Methonol','Ammonia','LNG','LPG',...
      'H2 liq','H2 Gas'}';
   Volumetric_energy_densities.VED(1)=(11.8*1e6)/(1e6);
   Volumetric_energy_densities.VED(2)=(43*0.277778)/1000;
   Volumetric_energy_densities.VED(3)=(4.3)/(0.793*1000);
   Volumetric_energy_densities.VED(4)=(3)/(0.604*1000);
   Volumetric_energy_densities.VED(5)=(5.8)/(0.41*1000);
   Volumetric_energy_densities.VED(6)=(49.6*0.277778)/1000;
   Volumetric_energy_densities.VED(7)=(8*0.277778)/70.85;
   Volumetric_energy_densities.VED(8)=(120*0.277778)/1000;
   %%
   figure;
   plot(1./Volumetric_energy_densities.VED(2:end),'h','LineWidth',2);
   text(1:7,(1./Volumetric_energy_densities.VED(2:end)+(ones(7,1)*10)),Volumetric_energy_densiti
   es.Fueltype(2:end));
   grid on;
   title('Volumetric Energy densities')
   ylabel('g/kwh');
   %%
   Volume_required_for_1000kwh_energy=table();
   Volume_required_for_1000kwh_energy.Fuel_type={'VLSFO','MGO','Methonol','Ammonia','LNG','L
   PG',...
```

```
   'H2 liq','H2 Gas'}';
Volume_required_for_1000kwh_energy.Value=1000.*(1./Volumetric_energy_densities.VED);
figure;
plot(Volume_required_for_1000kwh_energy.Value(2:end-1),'rh--','LineWidth',2);
grid on;
xticklabels(SOx_PM10_GWP100.Fueltype(2:end-1));
ylabel('Grams');
title('Volume required to generate 1000 kwh');
%%
cost_table=table();
cost_table.Fuel_type={'VLSFO','MGO','Methonol','Ammonia','LNG','LPG',...
   'H2 liq','H2 Gas'}';

cost_table.per_gram_cost(2)=35/1000;
cost_table.per_gram_cost(3)=28/(0.793*1000);
cost_table.per_gram_cost(4)=250/1000;
cost_table.per_gram_cost(5)=25/(0.41*1000);
cost_table.per_gram_cost(6)=1003/(14.2*1000);
cost_table.per_gram_cost(7)=30/(70.85);
cost_table.per_gram_cost(8)=30/(0.0899);
cost_table.per_gram_cost=cost_table.per_gram_cost.*0.013;
for i=2:8
cost_table.per_1000_kwh(i)=cost_table.per_gram_cost(i)*Volume_required_for_1000kwh_energ
y.Value(i);
end
figure;
bar(cost_table.per_gram_cost(2:end-1),'k');
grid on;
ylabel('EURO');
title('Per gram cost');
xticklabels(SOx_PM10_GWP100.Fueltype(2:end-1));
grid on;
%%
figure;
bar(cost_table.per_1000_kwh(2:end-1),'c')
xticklabels(SOx_PM10_GWP100.Fueltype(2:end-1));
ylabel('EURO');
title('Cost to generate 1000 kwh energy');
grid on;
%%
Fianl_table_transportation=table();
Fianl_table_transportation=readtable('Transportation_production.xlsx');
%%Location---rotterdam
FF=table();
FF.fuel_type=cost_table.Fuel_type(2:end-1);
FF.Prodcuction_cost_VLSFO_trans(1)=Fianl_table_transportation.ProductionCost(2);
FF.Prodcuction_cost_VLSFO_trans(2)=Fianl_table_transportation.ProductionCost(2);
FF.Prodcuction_cost_VLSFO_trans(3)=Fianl_table_transportation.ProductionCost(2);
FF.Prodcuction_cost_VLSFO_trans(4)=Fianl_table_transportation.ProductionCost(2);
FF.Prodcuction_cost_VLSFO_trans(5)=Fianl_table_transportation.ProductionCost(2);
FF.Prodcuction_cost_VLSFO_trans(6)=0;
```

```
FF.SOX(1:5)=Fianl_table_transportation.ValueOfSoxGenerated(2);
FF.PM10(1:5)=Fianl_table_transportation.ValueOfPM10Generated(2);
FF.CO2(1:5)=Fianl_table_transportation.GWP100_CO2_equivalent_in_g_KWh(2);

%%

%Final_table for DEA
analysis
Final_table=table();

Final_table.Fuel_type=cost_table.Fuel_type(2:end-1);
Final_table.per_1000_kwh=cost_table.per_1000_kwh(2:end-1);
Final_table.Value_of_SOx_generated_g_KWh=SOx_PM10_GWP100.Value_of_SOx_generated_
g_ KWh(2:end-1)+FF.SOX;

Final_table.Value_of_PM10_generated_g_KWh=SOx_PM10_GWP100.Value_of_PM10_generated

_g_KWh(2:end-1);
Final_table.GWP100_CO2_equivalent_in_g_KWh=SOx_PM10_GWP100.GWP100_CO2_equivalent

_in_g_KWh(2:end-1)+FF.CO2;
Final_table.Value_of_SOx_generated_g_KWh=1./Final_table.Value_of_SOx_generated_g_KWh
;
Final_table.Value_of_PM10_generated_g_KWh=1./Final_table.Value_of_PM10_generated_g_K
W h;
Final_table.GWP100_CO2_equivalent_in_g_KWh=1./Final_table.GWP100_CO2_equivalent_in_
g_ KWh;

%%
disp('======================================================================
==

===========')

disp('Final table for DEA analysis');
disp('======================================================================
==

===========')

disp(Final_table);
disp('======================================================================
==

===========')

%%
```

```
disp('Decision making units
are');
disp(Final_table.Fuel_type)

disp('=====================================================================

===========');

%%

disp('The input variables are');
disp('cost to generate 1000
kwh');disp('The output
variables are');

disp('inverse of value of SOx generated
(g/KWh)'); disp('inverse of value of PM10
generated(g/KWh)'); disp('inverse of GWP100
CO2 equivalent in(g/KWh)')

disp('=====================================================================

===========');

%%


Final_table.per_1000_kwh=Final_table.per_1000_kwh./(sqrt(sum(Final_table.per_1000_kwh.^2))

);

Final_table.Value_of_SOx_generated_g_KWh=Final_table.Value_of_SOx_generated_g_KWh./(sqr
t(sum(Final_table.Value_of_SOx_generated_g_KWh.^2)));
Final_table.Value_of_PM10_generated_g_KWh=Final_table.Value_of_PM10_generated_g_KWh./
(sqrt(sum(Final_table.Value_of_PM10_generated_g_KWh.^2)));
```

```
Final_table.GWP100_CO2_equivalent_in_g_KWh=Final_table.GWP100_CO2_equivalent_in_g_KW
h./(sqrt(sum(Final_table.GWP100_CO2_equivalent_in_g_KWh.^2)));
%%
%%
f=[0 0 0 Final_table.per_1000_kwh(1)];
A=[Final_table.Value_of_SOx_generated_g_KWh,Final_table.Value_of_PM10_generated_g_KWh..
.
  Final_table.GWP100_CO2_equivalent_in_g_KWh,...
  ones(length(Final_table.Value_of_SOx_generated_g_KWh),1).*-Final_table.per_1000_kwh(1)];
Aeq=[Final_table.Value_of_SOx_generated_g_KWh(1),...
   Final_table.Value_of_PM10_generated_g_KWh(1),...
   Final_table.GWP100_CO2_equivalent_in_g_KWh(1),0];
b=[0;0;0;0;0;0];
lb=[0 0 0 0];
beq=1;
ub=[];
[X,g1]=linprog(f,A,b,Aeq,beq,lb,ub);
h1=1/g1;
%%
f=[0 0 0 Final_table.per_1000_kwh(2)];
A=[Final_table.Value_of_SOx_generated_g_KWh,Final_table.Value_of_PM10_generated_g_KWh..
.
  Final_table.GWP100_CO2_equivalent_in_g_KWh,...
  ones(length(Final_table.Value_of_SOx_generated_g_KWh),1).*-Final_table.per_1000_kwh(2)];
Aeq=[Final_table.Value_of_SOx_generated_g_KWh(2),...
   Final_table.Value_of_PM10_generated_g_KWh(2),...
   Final_table.GWP100_CO2_equivalent_in_g_KWh(2),0];
b=[0;0;0;0;0;0];
lb=[0 0 0 0];
beq=1;
ub=[];
[X,g2]=linprog(f,A,b,Aeq,beq,lb,ub);
h2=1/g2;

%%
f=[0 0 0 Final_table.per_1000_kwh(3)];
A=[Final_table.Value_of_SOx_generated_g_KWh,Final_table.Value_of_PM10_generated_g_KWh..
.
  Final_table.GWP100_CO2_equivalent_in_g_KWh,...
  ones(length(Final_table.Value_of_SOx_generated_g_KWh),1).*-Final_table.per_1000_kwh(3)];
Aeq=[Final_table.Value_of_SOx_generated_g_KWh(3),...
   Final_table.Value_of_PM10_generated_g_KWh(3),...
   Final_table.GWP100_CO2_equivalent_in_g_KWh(3),0];
b=[0;0;0;0;0;0];
lb=[0 0 0 0];
beq=1;
ub=[];
[X,g3]=linprog(f,A,b,Aeq,beq,lb,ub);
h3=1/g3;
%%
%%
```

```
f=[0 0 0 Final_table.per_1000_kwh(4)];
A=[Final_table.Value_of_SOx_generated_g_KWh,Final_table.Value_of_PM10_generated_g_KWh..
.
  Final_table.GWP100_CO2_equivalent_in_g_KWh,...
  ones(length(Final_table.Value_of_SOx_generated_g_KWh),1).*-Final_table.per_1000_kwh(4)];
Aeq=[Final_table.Value_of_SOx_generated_g_KWh(4),...
   Final_table.Value_of_PM10_generated_g_KWh(4),...
   Final_table.GWP100_CO2_equivalent_in_g_KWh(4),0];
b=[0;0;0;0;0;0];
lb=[0 0 0 0];
beq=1;
ub=[];
[X,g4]=linprog(f,A,b,Aeq,beq,lb,ub);
h4=1/g4;
%%
f=[0 0 0 Final_table.per_1000_kwh(5)];
A=[Final_table.Value_of_SOx_generated_g_KWh,Final_table.Value_of_PM10_generated_g_KWh..
.
  Final_table.GWP100_CO2_equivalent_in_g_KWh,...
  ones(length(Final_table.Value_of_SOx_generated_g_KWh),1).*-Final_table.per_1000_kwh(5)];
Aeq=[Final_table.Value_of_SOx_generated_g_KWh(5),...
   Final_table.Value_of_PM10_generated_g_KWh(5),...
   Final_table.GWP100_CO2_equivalent_in_g_KWh(5),0];
b=[0;0;0;0;0;0];
lb=[0 0 0 0];
beq=1;
ub=[];
[X,g5]=linprog(f,A,b,Aeq,beq,lb,ub);
h5=1/g5;
%%
f=[0 0 0 Final_table.per_1000_kwh(6)];
A=[Final_table.Value_of_SOx_generated_g_KWh,Final_table.Value_of_PM10_generated_g_KWh..
.
  Final_table.GWP100_CO2_equivalent_in_g_KWh,...
  ones(length(Final_table.Value_of_SOx_generated_g_KWh),1).*-Final_table.per_1000_kwh(6)];
Aeq=[Final_table.Value_of_SOx_generated_g_KWh(6),...
   Final_table.Value_of_PM10_generated_g_KWh(6),...
   Final_table.GWP100_CO2_equivalent_in_g_KWh(6),0];
b=[0;0;0;0;0;0];
lb=[0 0 0 0];
beq=1;
ub=[];
[X,g6]=linprog(f,A,b,Aeq,beq,lb,ub);
h6=1/g6;
%%
bar([h1,h2,h3,h4,h5,h6]);
xticklabels(SOx_PM10_GWP100.Fueltype(2:end-1));
grid on;
ylabel('efficiency');
title('DEA analysis ');
```